ORIGINAL ARTICLE

Effect of verbal instructions on muscle activity and risk of injury to the anterior cruciate ligament during landing

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Background: Minimising the likelihood of injury to the anterior cruciate ligament (ACL) during abrupt deceleration requires proper synchrony of the quadriceps and hamstring muscles. However, it is not known whether simple verbal instructions can alter landing muscle activity to protect the knee.
Objective: To assess the efficacy of verbal instructions to alter landing muscle activity.
Methods: Twenty four athletes landed abruptly in single limb stance. Sagittal plane motion was recorded with an optoelectric device, and ground reaction force and surface electromyographic data were recorded for the rectus femoris, vastus lateralis, biceps femoris, and semimembranosus muscles. Subjects performed 10 landings per condition: normal landing (N); repeat normal landing (R); landing after instruction to increase knee flexion (K); and landing after instruction to recruit hamstring muscles earlier (M). Muscle bursts immediately before landing were analysed relative to initial foot-ground contact (IC).
Results: The K condition resulted in significantly ($p \leq 0.05$) greater knee flexion at IC compared with the other conditions. The M condition did not result in earlier hamstring muscle activity, but instead caused significantly ($p \leq 0.05$) earlier rectus femoris onset relative to IC, with a similar trend for the vastus lateralis. As these muscles are ACL antagonists, earlier onset times would be detrimental to the ACL.
Conclusions: Subjects successfully increased knee flexion during landing following the K condition instruction. However, further research is warranted to establish the efficacy of more extensive lower limb muscle retraining programmes to ensure landings that decrease susceptibility to ACL injury.

The anterior cruciate ligament (ACL) is a complex three dimensional multifascicular structure, which controls forward gliding of the tibia relative to the femur.[1] Although it provides primary restraint to anterior tibial translation, the hamstring muscles act as synergists to this ligament, recruited on demand when the ACL is excessively loaded.[2] Kain *et al*[3] suggested that a muscle recruitment strategy whereby the hamstring muscles contract before the quadriceps muscles, thereby initiating a posterior tibial drawer and negating the quadriceps initiated anterior tibial drawer, would offer optimal protection to the ACL during dynamic activities.

The importance of optimal hamstring-quadriceps muscle synchrony to protect the ACL was reinforced by Steele and Brown,[4] who examined the compensatory mechanisms developed by 11 functional, chronic, isolated ACL deficient patients, during a task known to excessively stress the ACL, namely dynamic landing. They reported that, compared with matched controls, the muscular coordination of these chronic ACL deficient athletes was significantly altered during landing. That is, they delayed activation of their hamstring muscles so that peak hamstring activity better coincided with the high tibiofemoral shear forces generated during the deceleration task. As landing occurred with the knee near full extension, the more synchronous activation of the hamstring muscles with the peak tibiofemoral shear forces was thought to assist in stabilising the knee by increasing tibiofemoral joint compression and, to a lesser extent, posterior tibial drawer when the knee would be most vulnerable to anterior subluxation. Steele and Brown[4] speculated that these compensatory strategies used by the functional ACL deficient patients to protect their knees against giving way episodes were acquired through a learned motor programme. If this speculation is correct, the question arises as to whether healthy athletes can be trained to learn alternative muscle recruitment strategies to protect their knees from non-contact ACL rupture episodes?

Despite a plethora of research on ACL injury prevention, we found none on whether healthy athletes can be trained to alter their muscle activation patterns during abrupt dynamic tasks such as landing. Prapavessis and McNair[5] showed that athletes could be trained to alter their range of knee joint motion during landing simply by asking them to do so. However, whether simple verbal instructions can be used to alter the muscle activation patterns of athletes during a more complex abrupt deceleration task is not known. Therefore, the purpose of this study was to investigate whether athletes could alter their hamstring muscle activation patterns during a dynamic landing task by following simple verbal instructions. It was hypothesised that a simple verbal instruction would be insufficient information to allow athletes to effectively change their hamstring muscle recruitment patterns during landing.

METHODS

Subjects

Based on a power analysis (power = 80%), 24 healthy, female, A grade netball players (mean (SD) age 21.8 (4.7) years) with no history of knee injury, trauma, or disease were chosen to participate as experimental subjects in the study. Ethical clearance was gained for the study, and informed consent was obtained from all subjects before testing. All testing was conducted in the Biomechanics Research Laboratory at the University of Wollongong, New South Wales, Australia, in accordance with the NH&MRC Statement on Human Experimentation.[6]

Dynamic landing task

For data collection, subjects were required to run forward for about three paces, to leap from their non-dominant leg, and to land on their dominant (test) limb in single limb stance, with

Abbreviations: ACL, anterior cruciate ligament; IC, initial foot-ground contact; RF, rectus femoris; VL, vastus lateralis; EMG, electromyographic

Table 1 Descriptive data for the ground reaction forces generated during landing

Variable	Condition Normal	Repeat	Knee instruction	Muscle instruction
Peak F_V (N)	2303 (519)	2277 (493)	2092 (626)*	2441 (634)†
Peak F_{AP} (N)	1147 (227)	1157 (255)	1029 (264)*	1118 (301)
Peak F_{ML} (N)	157 (51)	161 (56)	149 (64)	164 (83)
Peak F_R (N)	2522 (555)	2506 (537)	2277 (654)*	2631 (680)
Peak F_V (BW)	3.41 (0.77)	3.37 (0.73)	3.10 (0.93)*	3.61 (0.94)†
Peak F_{AP} (BW)	1.70 (0.34)	1.71 (0.38)	1.52 (0.39)*	1.65 (0.45)
Peak F_{ML} (BW)	0.23 (0.08)	0.24 (0.08)	0.22 (0.09)	0.24 (0.12)
Peak F_R (BW)	3.73 (0.82)	3.71 (0.79)	3.37 (0.97)*	3.89 (1.01)

Values are mean (SD).
*Significantly different from remaining three conditions ($p<0.05$).
†Significantly different from remaining three conditions ($p<0.05$).
F_V, Vertical ground reaction force; F_{AP}, anteroposterior ground reaction force; F_{ML}, mediolateral ground reaction force; F_R, resultant ground reaction force.

their foot centrally located on a force platform while catching a chest height pass. This task was performed for 10 trials under four test conditions: normal landing (N); repeated normal landing (R); landing after a knee angle instruction (K); landing after a muscle activity instruction (M). The K instruction was as follows: "This time when you run to land I want you to land with your knee bending". The M instruction stated: "This time when you run to land I want you to turn the muscles at the back of your thigh on earlier and more before landing". The order of the K and M conditions was reversed in 12 of the 24 subjects to balance the experimental design. The purpose of the repeated normal landing condition was to establish the normal variability in the data between two sets of landing trials independent of variations in verbal instructions.

The same experienced thrower, positioned about 3 m in front of the force platform, was used for all trials. Before data collection, subjects completed a warm up consisting of five minutes of cycling (50–100 W workload) and stretching of their major lower and upper body muscle groups. The purpose of the warm up was to minimise the risk of injury when performing the dynamic landings. Subjects also completed familiarisation trials before data collection to measure their approximate run up distance, and to become familiar with the landing task. The deceleration task was chosen for the study, as abrupt landing has been suggested to be a typical non-contact ACL injury mechanism.[7] A successful trial constituted the subject landing, with the foot of the test limb in the middle of the force platform, while catching a ball.

Ground reaction forces

The ground reaction forces generated during landing were recorded (1000 Hz) using a 600 mm × 400 mm Kistler Multichannel force platform (model 9281B; Kistler Instrumente AG, Winterthur, Switzerland) connected to a Kistler Multichannel Charge Amplifier (type 9865A), for 10 successful trials per test condition. The variables of interest were force-time curves in three orthogonal directions (anteroposterior = F_{AP}; mediolateral = F_{ML}; vertical = F_V) and the peak resultant ground reaction force (peak F_R).

Kinematic data

Subjects' sagittal plane motion was recorded (200 Hz) during deceleration using an OptoTrak 3020 System (Northern Digital, Waterloo, Ontario, Canada), which monitored infrared light emitting diodes (LED) placed on the test limb lateral malleoli of the fibula, the knee joint line, and the greater trochanter of the femur. The three dimensional coordinates of the light emitting diode markers were used as input to determine the sagittal plane knee joint angle at the times of initial foot-ground contact (IC) and the time of the peak F_R.

Electromyography

3M Infant Monitoring adhesive silver/silver chloride disposable surface electrodes were placed over the muscle bellies in a bipolar configuration (interdetection surface spacing of 10 mm) parallel to the line of action of the muscle fibres of the rectus femoris (RF), vastus lateralis (VL), semimembranosus, and biceps femoris muscles. Each electrode site was prepared by shaving, abrading, and swabbing the site with diluted ethanol so that the impedance of the skin was less than 6 kΩ (CardioMetrics Artifact Eliminator, model CE01, Australia). Electrode placement sites were confirmed by palpating the muscles while the subjects performed isometric contractions. A reference electrode was placed on the lateral femoral epicondyle. After confirmation of the clarity of the electromyographic (EMG) signals, the wires from the electrodes were taped to the skin surface of each subject's lower limb to minimise movement artefact. Myoelectric signals were relayed from the electrodes to a Telemyo 8/16 battery powered transmitter (Noraxon, Scottsdale, Arizona, USA; mass = 0.96 kg), which was strapped firmly to the subject's lower back and supported by Tubifast bandaging. The EMG signals were then relayed from the transmitter to the Telemyo 8/16 receiver through an antenna connected to the transmitter. The analogue output for the muscles from the receiver (± 5 V for full scale) were sampled at 1000 Hz (bandwidth 0–340 Hz) by the OptoTrak software via an OptoTrak Data Acquisition Unit (Northern Digital). This software was also responsible for the synchronisation of the kinematic, kinetic, and EMG data.

Muscle activity analysed during the deceleration task included the burst immediately before IC for each of the four muscles. The EMG data were demeaned using signal processing software. The raw signal was then filtered using a fourth order zero phase shift Butterworth high pass filter[8] (f_c = 15 Hz) to eliminate any movement artefact. To assess the temporal characteristics of the muscle bursts, the filtered EMG data were full wave rectified and low pass filtered (f_c = 20 Hz) to obtain linear envelopes, and subsequently screened with a threshold detector (7% of maximum burst amplitude). The calculated values were visually inspected to confirm that the results truly represented the temporal characteristics of each muscle.

The following temporal variables were then calculated for each of the four muscles from the processed EMG data: duration of the muscle burst (milliseconds); timing of the onset of muscle activity relative to IC (onset to IC; milliseconds); timing of the peak of muscle activity relative to IC (peak to IC; milliseconds). These variables were calculated to provide an indication of the effect of the verbal instructions on the sequence and timing of the contractions of the hamstring and quadriceps muscles during the deceleration task.

Table 2 Kinematic variables displayed during landing

Variable	Condition			
	Normal	Repeat	Knee instruction	Muscle instruction
Knee angle at IC time (°)	8.7 (3.9)	8.5 (4.0)	11.3 (4.0)*	11.3 (3.9)*
Knee angle at peak F_R time (°)	14.5 (4.2)	14.3 (4.1)	18.2 (5.3)*	16.4 (4.1)*†

Values are mean (SD).
*Significantly different from normal and repeat conditions (p<0.05).
†Significantly different from knee instruction (p<0.05).
IC, Initial contact time of the test foot with the force platform during landing; F_R, resultant ground reaction force.

Statistical analysis

Means (SD) for the dependent variables were calculated for each of the four test conditions. After normality (Kolmogorov-Smirnov test with Lilliefors' correction) and equal variance (Levene Median test) of the data had been confirmed, the dependent variables were analysed using a repeated measures analysis of variance with one within factor (test condition). Where a main effect was found, post hoc analysis of the data used a Student-Newman-Keuls test. The α level was set at 0.05.

RESULTS

Ground reaction forces

A significant main effect of test condition on the ground reaction data was found (F_{AP}: $F_{(3,69)} = 6.969$; F_V: $F_{(3,69)} = 13.004$; F_R: $F_{(3,69)} = 12.4$; $p<0.001$). Post hoc analysis indicated that the subjects displayed similar ground reaction forces for the N and R landing conditions (table 1). However, when subjects were given the knee angle verbal instruction before landing (K), they displayed significantly diminished landing forces compared with the other three conditions. Conversely, when subjects were given the muscle instruction before landing (M), they displayed significantly larger vertical landing forces compared with the remaining test conditions (table 1).

Kinematic data

A significant main effect of test condition was again found for the kinematic data characterising knee motion during landing (at IC: $F_{(3,69)} = 15.545$; at peak F_R: $F_{(3,69)} = 21.479$; $p<0.001$). That is, although the subjects displayed no significant differences in the knee angles between the N and R landing conditions, the K and M instruction conditions resulted in significantly greater knee flexion at IC and at the time of the peak F_R (table 2).

Muscle activation patterns

The test condition also had a significant main effect on the muscle activation data. Post hoc analysis of the data showed that the subjects displayed no significant differences in any of the muscle activity variables between the N and R test conditions (table 3). However, the K condition resulted in significantly longer quadriceps muscle burst durations than for the remaining three conditions. Conversely, the M condition resulted in significantly longer RF onset to IC times than for the other conditions (fig 1), and, although not significant, a similar trend was noted for the VL muscle. In addition, the M condition resulted in a significantly shorter RF peak to IC time ($q = 4.782$) compared with the K condition.

DISCUSSION

Ground reaction forces

The average peak ground reaction forces generated by the subjects during the landings were smaller than reported by Cowling and Steele[9] for subjects performing a similar landing task. This may have been due to between study differences in the skill level of the subjects and their sporting participation, as our study used A grade netball players, whereas Cowling and Steele[9] used recreational athletes from a variety of sporting activities who were less experienced at performing the landing task.

Table 3 Muscle activation patterns displayed during landing

Variable	Muscle	Condition			
		Normal	Repeat	Knee instruction	Muscle instruction
Muscle burst duration (ms)	RF	447 (67)	435 (45)	527 (59)‡	461 (98)
	VL	366 (65)	372 (56)	459 (54)‡	383 (88)
	SM	312 (85)	302 (80)	327 (101)	330 (111)
	BF	447 (126)	430 (128)	457 (114)	475 (134)
Muscle burst onset time to IC (ms)*	RF	−83 (33)	−77 (27)	−72 (34)	−110 (53)§
	VL	−86 (37)	−82 (28)	−81 (39)	−97 (51)
	SM	−183 (39)	−185 (35)	−189 (42)	−194 (70)
	BF	−216 (54)	−209 (34)	−203 (42)	−220 (66)
Muscle burst peak time to IC (ms)†	RF	82 (29)	81 (26)	93 (41)	72 (26)¶
	VL	66 (44)	74 (23)	81 (23)	68 (25)
	SM	−54 (24)	−59 (19)	−60 (23)	−68 (47)
	BF	−46 (59)	−51 (43)	−38 (50)	−51 (66)

Values are mean (SD).
*A negative value indicates that muscle burst onset occurred before IC time.
†Negative value indicates that peak muscle activity occurred before IC time.
‡Significantly different from other three conditions (p<0.05).
§Significantly different from other three conditions (p<0.05).
¶Significantly different from knee instruction condition (p=0.013).
IC, Initial contact time of the test foot with the force platform during landing; RF, rectus femoris; VL, vastus lateralis; BF, biceps femoris; SM, semimembranosus.

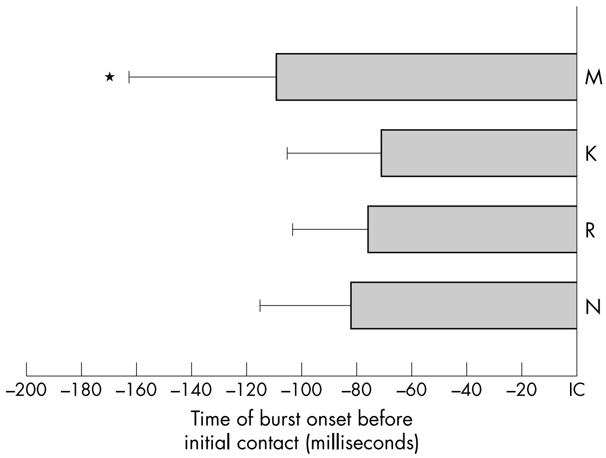

Figure 1 Rectus femoris muscle burst onset time relative to initial contact (IC). M, Muscle instruction; K, knee instruction; R, repeat landing; N, normal landing. *Significant difference from remaining three conditions.

The K instruction condition consistently resulted in lower landing forces than the other three conditions. This finding suggested that the K instruction was effective in modifying the subjects' landing techniques such that the forces imposed on the body during landing were significantly diminished. Notably, the peak anteroposterior (braking) forces were significantly smaller in the K condition compared with the other three conditions. As the primary role of the ACL is to restrain anterior tibial translation, a decrease in these anteriorly directed braking forces would result in a smaller load for the ACL to withstand. This is positive in terms of the K condition ensuring a less stressful landing for the ACL. Prapavessis and McNair[5] similarly noted smaller landing forces during drop jump landings when a verbal instruction was used before landing, asking players to bend their knees more. As the landing used in our study was more dynamic and complex than drop jumping, these results not only confirm those of Prapavessis and McNair,[5] but also substantiate the effectiveness of simple verbal instructions in changing knee flexion during landing to minimise forces during dynamic landing.

When subjects were given the M instruction before landing, they displayed significantly larger vertical landing forces compared with the remaining test conditions. As similar approach velocities were encouraged for the four conditions, the attempts of the subjects to respond to the M instruction were probably responsible for this result. However, we acknowledge that approach velocities were not quantified, although the movement task was standardised by using the same thrower for every trial and the same number of approach steps to receive the ball, in an attempt to ensure that similar approach velocities were adopted for each subject's landing. There was also a trend for the M instruction to result in a higher peak F_R. Although larger vertical forces experienced during landing do not specifically strain the ACL, these increased forces are likely to subject other knee joint structures to higher forces during landing. Consequently, the M condition, in contrast with the K condition, was suggested to increase rather than decrease the likelihood of injury to the lower limbs during landing.

Kinematic data

Steele[10] suggested that players performing dynamic landing tasks, akin to this study, should land with the knee flexed at about 17° at IC time and 40° at peak F_R time to minimise musculoskeletal injury. However, knee flexion angles displayed by subjects in our study were substantially below these values (table 2) and smaller than those reported previously in studies that used dynamic landings.[9 11 12] Hirokawa *et al*[13] suggested that more extended knee positioning at landing diminished the ability of the hamstring muscles to provide a posterior drawer force to assist the ACL in combating the high shear forces generated during dynamic landing—that is, the hamstring muscles are particularly ineffective in providing a posterior tibial drawer force when the knee is near full extension (0–15° flexion), as the muscle force line of action has a small perpendicular (posterior drawer force) component versus the vertical (joint compression) component.

As subjects displayed no significant differences in the knee angles between the N and R landing conditions, these two landing conditions were considered highly reproducible. In contrast, the K and M instruction conditions resulted in significantly greater knee flexion at both IC and the time of the peak F_R, and the K condition resulted in significantly greater knee flexion at peak F_R than for the M condition. As greater knee flexion was the explicit aim of the K condition, this instruction proved the most effective in achieving this goal, as expected. However, the M instruction condition, which specifically pertained to muscle activity, also resulted in greater knee flexion during landing. This increased knee flexion, for the K and M conditions, could be suggested to be beneficial in providing a more advantageous line of action for the hamstring muscles to provide a posterior tibial drawer force to assist the ACL. However, despite reaching significance, the increase in knee flexion achieved by the M and K conditions was only limited (16.4° and 18.2° respectively at peak F_R time) such that joint compression caused by hamstring muscle contraction was a far greater component in assisting knee stability than the posterior tibial drawer component.[13]

Muscle activation patterns

In agreement with previous studies in which a similar landing movement was performed,[4 9] subjects in our study displayed the muscle activation sequence recommended by Kain *et al*,[3] whereby the hamstring muscles were activated before the quadriceps muscles and before IC. Furthermore, peak hamstring muscle activity occurred before IC for all test conditions, whereas peak quadriceps muscle activity occurred after IC.

The lack of significant differences identified in any of the muscle activity variables between the N and R landing conditions confirmed the consistency of the subjects' landing techniques, which could be expected with this sample of skilled players. In contrast, the K condition resulted in significantly longer burst durations of the quadriceps muscle than for the other three conditions. Quadriceps muscle activity during landing is thought to effect a knee extension moment to prevent the stance limb from "collapsing" under body weight.[4] The longer quadriceps activity during the K condition is therefore attributed to the need for the eccentric quadriceps contractions to "control" the greater knee flexion during this landing condition.

Contrary to expectations, asking players to turn their hamstring muscles on earlier in the M condition actually resulted in significantly longer RF onset to IC times than for the other conditions (fig 1), with VL displaying a similar, albeit non-significant, trend. As increased shear forces are associated with activation of these muscles, earlier RF and VL onset time before IC would limit the time available for the hamstring muscles to generate a posterior tibial drawer before the onset of the counteracting quadriceps muscle force.[3] Furthermore, the M condition resulted in a significantly shorter RF peak to IC time compared with the K condition. As RF is a powerful ACL antagonist, closer synchronisation of this muscle's peak activity with the onset of the high braking forces experienced at landing would be less protective to the ACL than a larger time window between these two events.[11] Therefore, not only were the subjects unable to selectively recruit the hamstring muscles as requested, in an attempt to do so they altered their quadriceps muscle synchronisation in a manner that is

Take home message

Simply asking players to flex their knees while they land can decrease the risk against ACL injury and therefore promote safer landings.

suggested to be less protective than in the other landing conditions. These results for the M condition suggest that simply asking players to alter the manner in which they recruit their hamstring muscles, without any accompanying training on how to achieve this, was not beneficial in altering the muscle activity displayed during dynamic landing.

Conclusion

It was concluded that subjects can accurately respond to a simple verbal instruction, such as to increase knee flexion during landing. However, they are unable to respond appropriately to a more complex instruction requiring them to selectively change the way they activate specific muscle groups. In fact, although instructed to alter hamstring muscle activity in the M condition, subjects generated earlier onset times of the antagonistic quadriceps muscles before landing, thereby imposing a greater risk of injury to the ACL during landing. It is postulated that, to alter the activity of specific muscle groups during dynamic landing to better protect the ACL from non-contact injury, subjects may require more specialised muscle activation training. Further research is therefore warranted to investigate whether lower limb muscles can be retrained to alter landing technique, so that safer landing practices can be adopted.

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COMMENTARY

This study highlights the efforts in the search for a way to reduce the incidence of ACL injuries, especially in women. A muscle pattern has been identified that may protect the ACL, but can this strategy be trained? The study clearly shows that changes in joint angle can be achieved through simple verbal instruction, but the ability to alter muscle activation patterns is not possible through such instruction. This leads to more questions that need to be answered:

- If knee angle changes can be made easily, what are the optimum ranges at landing and after landing?
- Is it possible to habituate knee angle changes during the stress of a competitive game?
- Is it possible to alter muscle activation in a time frame and manner that can be used by all sportspeople?

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