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The effects of attentional focus on jump performance and knee joint kinematics in patients after ACL reconstruction

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ABSTRACT

Objectives: The purpose of this study was to determine the effect of an internal and external attentional focus on single leg hop jump distance and knee kinematics in patients after ACL reconstruction (ACLR).
Design: Experimental.
Setting: Outpatient physical therapy facility.
Participants: Sixteen patients after ACLR.
Main Outcome Measures: Patients received either an instruction with an internal focus or an external focus before performing a single leg hop jump. The jump distance, knee valgus angle at initial contact, peak knee valgus angle, knee flexion angle at initial contact, peak knee flexion angle, total ROM and time to peak angles for the injured and non-injured legs were recorded. A repeated measures MANOVA was used to determine significance between the experimental conditions with the primary outcome measures as dependent variables.
Results: The external focus group had significant larger knee flexion angles at initial contact, peak knee flexion, total ROM and time to peak knee flexion for the injured legs.
Conclusions: This study demonstrates the applicability of using an external focus during rehabilitation of patients after ACLR to enhance safer movement patterns compared to an internal focus of attention and subsequently may help to reduce second ACL injury risk.

1. Introduction

An injury of the anterior cruciate ligament (ACL) is a devastating injury, (Majewski, Susanne, & Klaus, 2006) and athletes who wish to resume high-level activities are often counseled to undergo ACL reconstruction (ACLR) (Marx, Jones, Angel, Wickiewicz, & Warren, 2003). The rate of return to sport (RTS) by 12 months is relatively low, (Feller & Webster, 2013) with up to two-thirds of patients being unable to return to their pre-injury level of sport (Ardern, Taylor, Feller, Whitehead, & Webster, 2013). Long term follow-up indicates that after a mean of 41 months following ACLR, 82% of patients returned to some form of sports participation: however, only 44% returned to competitive sport (Ardern, Webster, Taylor, & Feller, 2011a). During late phase rehabilitation, the potential gap between the patient's perceived versus actual sports readiness must be addressed, as subjective patient scores often do not correlate well with good knee function (Ardern et al., 2011a). Recently, it was shown that return to a high activity level after a unilateral ACLR was the most important risk factor for sustaining a contralateral ACL injury (Sward, Kostogiannis, & Roos, 2010). Other risk factors such as altered biomechanics and neuromuscular function, that affect both the ACLR leg and the contralateral leg, further increase the risk for a second ACL injury (Paterno et al., 2010). Thus, consideration of one's biomechanics and neuromuscular function is considered an important factor for reducing the risk of secondary ACL injury upon returning to high level activity.

Hop tests are commonly used to quantify knee function after ACLR to determine safe RTS (Bizzini, Hancock, & Impellizzeri, 2012; Waters, 2012). Single leg hop tests can help to discern between those patients after ACLR who will return to previous activity level

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from those who do not (Ardern, Webster, Taylor, & Feller, 2011b). Single leg hop tests are performance-based measures used to assess the combination of muscle strength, neuromuscular control, confidence in the limb, and the ability to tolerate loads related to sports-specific activities (Reid, Birmingham, Stratford, Alcock, & Giffin, 2007). In addition, side to side deficits can be detected with single leg hop tests (Myer, Martin, et al., 2012). Recent evidence indicates that the most common biomechanical factor for increased risk of a second injury is asymmetrical loading during sports related tasks (Hewett, Di Stasi, & Myer, 2013; Paterno et al., 2010).

Unfortunately, ACLR rehabilitation programs may not be optimally effective in addressing deficits related to the initial injury and the subsequent surgical intervention (Simoneau & Wilk, 2012) in terms of prevention of second injury (Hewett et al., 2013).

Rehabilitation programs typically focus on range of motion (ROM), balance, strengthening and neuromuscular exercises (Wilk, Macrina, Cain, Dugas, & Andrews, 2012). Criteria to determine an athlete's readiness to RTS after ACLR include temporal guidelines as well as criteria using balance, strength and hop tests (Wilk et al., 2012).

Feedback provided during rehabilitation sessions is typically directed to body movements such as “keep your knee over the toe” during a squat exercise (Durham, Van Vliet, Badger, & Sackley, 2009). In the motor learning domain, this type of attentional focus is termed “internal focus” (Wulf, Hoss, & Prinz, 1998). Conversely, an external focus of attention is induced when a patient's attention is directed towards the outcome or effects of the movement (e.g., “imagine kicking a ball”, to facilitate extension of the knee during gait). Recent studies have demonstrated that instructions that induce an external focus of attention rather than an internal focus of attention produce significant benefits illustrated by greater knee flexion angles, (Myer, Ford, McLean, & Hewett, 2006) lower peak ground reaction force (Myklebust et al., 2003) jump performance in terms of jump distance and movement efficiency in healthy subjects (Makaruk & Sacewicz, 2010; Porter, Anton, & Wu, 2012; Porter, Ostrowski, Nolan, & Wu, 2010; Wu, Porter, & Brown, 2012; Wulf & Dufek, 2009). These findings are promising, as improved landing technique even with increased jump performance, yield an optimum between low ACL injury risk without reduction in performance.

An essential part of current ACL injury prevention programs is to instruct athletes to use safe landing techniques. For example, instructions during landing from jumping are directed towards the execution of the movements itself alike “keep the knee over the toe”; “land with a flexed knee”; “raise the knee to the level of the hip” or “land with your feet shoulder-width apart” and have been shown to effectively target biomechanical risk factors associated with increased risk of ACL injury in female athletes (Myer, Ford, Brent, & Hewett, 2012).

While there may be intuitive reasons that clinicians tend to give internal focus instructions, this approach may not facilitate the full potential in patients after ACLR while re-learning skills. Reports indicate that clinicians provide feedback that induces an internal focus 95% of the time (Durham et al., 2009). Employing newly developed advanced feedback techniques may help to further improve outcome after rehabilitation (Benjaminse & Otten, 2010; Gokeler et al., 2013). Although the literature is sparse on the effect of attentional foci in orthopedic rehabilitation, several studies have been published (Laufer, Rotem-Lehrer, Ronen, Khayutin, & Rozenberg, 2007; Rotem-Lehrer & Laufer, 2007). Patients who suffered an acute ankle sprain experienced clear benefits by adopting an external focus as reported by Laufer and co-workers (Laufer et al., 2007). The results of their study indicated that 3 sessions of balance training with an external focus on a dynamic stabilometer improved the balance capabilities of patients who sustained an ankle sprain. There was an improvement made immediately following training while retention was maintained. The evidence found in rehabilitation of ankle injuries is one of the first to demonstrate the feasibility and relevance of applying specific principles of motor learning to orthopedic rehabilitation.

To the best of the author's knowledge, there is no data available on the effect of attentional focus after ACLR. Myer et al. recommended the use of single leg hop tests as these are performed unilaterally, which means that no compensatory strategies can be used (Myer, Martin, et al., 2012). The purpose of this study was twofold. We wanted to evaluate the effect of internal and external focus instructions on single leg hop jump distance. In addition we wanted to determine the effect of attentional focus on knee joint kinematics in patients after ACLR. We hypothesized that the external focus of attention group will achieve greater jump distance and land with a safer landing technique compared to the internal focus of attention group.

2. Methods

2.1. Subjects

Sixteen patients (7 females, 9 males) after ACLR participated in the current study. Inclusion criteria for the patients were as follows: 1) age older than 16 years, 2) more than 4 months after ACLR, 3) returned to their active ADL lifestyle. Patients were excluded if 1) they experienced pain during the experiment, 2) presence of swelling of the injured knee or 3) feeling of instability in the injured knee. The patients participated in various sports (soccer n = 9, team handball n = 5, basketball n = 1, volleyball n = 1).

2.2. Procedures

The University's Institutional Review Board approved all forms and experimental methods. The patients received a letter that included information about the objective of the research, the kind of research being performed, the time associated with it, and possible risks. Patients were required to wear their own athletic clothing and shoes during the experiment. The patients were identified from a list obtained from the hospital were all patients underwent surgery. From this list, patients were recruited from the outpatient physical therapy facility in the period from March–June 2013 where the study took place. Descriptive data for the patients after ACLR are presented in Table 1. The random allocation sequence for patients was kept concealed until intervention groups were assigned. The allocation sequence, enrollment and assignment of patients were in the hands of one of the testers. Patients who were willing to participate were entered in a MATLAB 6.1 (The MathWorks Inc., Natick, MA) randomization script that allocated patients to the experimental conditions to either the external attentional focus group (EF) or the internal focus (IF) group (each n = 8). The other tester was blinded to patient group assignment.

Before measurement, an informed consent and a questionnaire including questions about general health characteristics were completed and signed by the patient. Data collection took place in an outpatient physical therapy facility. This study used a between-group experimental design to explore the effect of 2 verbal instructions that either promoted an external focus of attention or an internal focus of attention on performance of the single leg hop for distance test. With respect to the dependent variables, the study used one outcome measure in terms of distance jumped and the following performance measures; 2) knee kinematics in the sagittal and frontal plane, 3) time to peak knee angles. For the current study the single leg hop test for distance was used which has been shown

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Table 1
Descriptive data for the patients after ACL reconstruction.

	N	Gender females/males	Age (years)	Weight (kg)	Length (cm)	Time since surgery (weeks)	Injuries of the dominant knee
Internal focus	8	4/4	23.75 ± 4.46	73.75 ± 10.32	180.1 ± 7.53	22.63 ± 16.89	5/8
External focus	8	3/5	22.63 ± 6.02	76.50 ± 12.02	181.25 ± 7.70	28.0 ± 16.73	4/8

The dominant knee was defined as the leg with which the patient prefers to kick a ball.
Data are expressed as mean values, ± SD.

to be a reliable and valid test for patients after ACLR (Reid et al., 2007). Distance jumped was used as the outcome measure because it is the most available measure used by clinicians (Wilk et al., 2012). Knee kinematics and time to peak knee angles were chosen as dependent performance variables as these were shown to be related to increased ACL load (Hewett et al., 2013; Paterno et al., 2010; Yu & Garrett, 2007). Knee kinematics were recorded with 2 commercial video cameras (Sony; DCR-hc62) placed in the sagittal and frontal plane. The frontal plane camera was placed at a distance of 4 m from the start line whereas the sagittal plane camera was placed 0.9 m from the start line at a distance of 4 m to the side. Both cameras were set at a height of 1 m from the floor to the lens. Padua and co-workers reported a very similar set up and demonstrated that is a valid and reliable method for identifying potentially high-risk movement patterns during a jump-landing task (Padua, Marshall, Boling, Thigpen, Garrett, & Beutler, 2009).

Prior to data collection, participants completed a 5-minute warm-up on a stationary exercise bike. Before jumping commenced, patients were given a general instruction about the jumping task “Stand on one leg, jump as far possible and land on the same leg.” All patients practiced 3 times with each leg. Subsequently, patients were given specific verbal instructions, adapted from Porter (2013), Porter, Ostrowski, et al. (2010) which induced either an internal or an external focus of attention. The patients allocated to the IF group received the instruction “Jump as far as you can. While you are jumping, I want you to think about extending your knees as rapidly as possible” and for the EF group “Jump as far as you can. While you are jumping, I want you to think about pushing yourself off as hard as possible from the floor.” Patients always started with the uninjured leg and finished the 5 trials before proceeding to the injured leg. A jump was recorded as a successful trial when the patient could stabilize for at least 2 s after landing. Thirty seconds recovery time between each of the 5 jumps were included to prevent fatigue effects. The distance for each was measured from the start line to the back of the heel and was recorded to the nearest half centimeter for each attempt.

2.3. Data analysis

Prior to testing, each patient was fitted with 8 retroreflective markers of 14 mm in diameter (MotionCap, USA). The markers were bilaterally placed on greater trochanter, lateral epicondyle femur, lateral malleolus and base of the 5th metatarsal. Each trial was loaded into a custom made program in MATLAB 6.1 (The MathWorks Inc., Natick, MA) for further analysis. The script calculated joint positions from reference points of the bony landmarks as identified with the markers and reference points manually added by clicking on the superior aspect of the medial thigh, center of patella midline of the ankle joint in each video frame.

In the sagittal plane, the knee flexion angle at initial contact (IC) was defined as the knee flexion angle at the instant the foot contacted the floor. Peak knee flexion was defined when maximum knee flexion occurred during landing. Flexion ROM was calculated from the difference in knee flexion between initial contact and peak knee flexion. In the frontal plane, knee valgus angle at initial contact was defined at the instant the foot contacted the ground. Peak valgus angle was defined at the point where maximal valgus occurred during landing. The valgus ROM was measured by the difference in angles between initial contact and peak valgus. Time to peak flexion and valgus was determined from the time elapsed between initial contact and the peak values for respectively flexion and valgus. The sample rate of both cameras was 25 Hz and a lens correction was built into MATLAB (The MathWorks Inc., Natick, MA) to correct for typical geometrical lens errors that occur. All subjects performed 5 trials per leg and the mean results were entered for analysis.

3. Statistical analysis

Data were analyzed using SPSS (IBM SPSS Statistics for Windows, Version 20. Armonk, NY: IBM Corp). The primary outcome measure was 1) jump distance and the primary performance measures were 2) knee valgus angle at IC, 3) peak knee valgus angle, 4) knee flexion at IC, 5) peak knee flexion angle, 6) total ROM and 7) time to peak angles. As all data was normally distributed as determined with post-hoc Skewness & Kurtosis, a repeated measures MANOVA was used to determine differences between the experimental conditions with the primary outcome/performance measures as dependent variables. The criterion for significance was set a priori with an alpha level of $P \leq 0.05$. Cohen's effect size (ES) statistics were calculated to determine the magnitude of observed significant differences with $d = 0.2–0.5$, $d = 0.5–0.8$ and $d \geq 0.8$ representing a small, moderate and large effect, respectively. Peak knee flexion angle data from comparable athletes during landing after ACLR pre and post training were used to determine the clinically significant minimal expected changes for the current study groups (Tsai & Powers, 2013). Based on these data a power analysis revealed that to achieve a 80% power in the current study, with an alpha level of 0.05, a minimum of 8 subjects per group (IF and EF) were required.

4. Results

The mean jump distance, knee valgus angle at IC, peak knee valgus angle, time to peak knee valgus angle and valgus ROM showed no significant differences between the IF and EF group ($P > 0.05$) (Table 2). Knee flexion at IC showed no significant group differences for the non-injured legs ($P = 0.82$). However, for the injured leg there was a significant ($P = 0.04$) smaller knee flexion in the IF group (27.25° ± 11.09°) compared to the EF group (37.38° ± 6.44°) with a large ES (1.12). A typical landing style of a patient in the IF and EF group is presented in Fig. 1 to demonstrate the difference in peak knee flexion. Peak knee flexion was significantly lower in the IF group for the non-injured legs compared to the EF group (IF 51.63° ± 12.93°; EF 69.26° ± 12.21°; $P = 0.01$; ES 1.40) and also for the injured legs (IF 51.75° ± 16.67°; EF 69.54° ± 11.44°; $P = 0.01$; ES 1.24). Time to peak knee flexion angle demonstrated distinct differences for both non-injured and injured legs. Specifically, the IF group's time to peak knee flexion for the non-injured leg (0.16 s ± 0.03 s) compared to the EF group (0.21 s ± 0.04 s) was

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Table 2
Results of internal and external focus of attention on jump distance and knee joint kinematics.

	Non-injured				Injured			
	IF	EF	*P*-value	ES	IF	EF	*P*-value	ES
Mean jump distance (m)	1.35 ± 0.33	1.46 ± 0.22	0.43	0.39	1.33 ± 0.35	1.39 ± 0.16	0.66	0.22
Knee valgus angle at IC (°)	8.34 ± 3.98	6.09 ± 3.33	0.24	0.61	8.64 ± 4.69	8.11 ± 6.44	0.85	0.09
Peak knee valgus angle (°)	16.60 ± 7.75	14.98 ± 6.58	0.66	0.23	16.06 ± 7.19	14.05 ± 8.76	0.62	0.25
Time to peak valgus angle (sec)	0.18 ± 0.13	0.32 ± 0.16	0.07	0.96	0.14 ± 0.08	0.19 ± 0.11	0.32	0.52
Valgus RoM (°)	8.26 ± 5.02	8.89 ± 8.06	0.85	0.09	7.42 ± 5.96	5.94 ± 5.40	0.61	0.26
Knee flexion angle at IC (°)	24.81 ± 10.80	32.56 ± 7.85	0.12	0.82	27.25 ± 11.09	37.38 ± 6.44	0.04*	1.12
Peak knee flexion angle (°)	51.63 ± 12.93	69.26 ± 12.21	0.01*	1.4	51.75 ± 16.67	69.54 ± 11.44	0.01*	1.24
Time to peak flexion angle (sec)	0.16 ± 0.03	0.21 ± 0.04	0.01*	1.41	0.16 ± 0.05	0.21 ± 0.03	0.02*	1.21
Flexion RoM (°)	26.82 ± 3.51	36.71 ± 11.13	0.03*	1.2	24.50 ± 6.92	32.16 ± 7.36	0.05*	1.07

EF = external focus; IF = internal focus; IC = initial contact; knee valgus IC = knee valgus angle at initial contact; knee valgus max = peak knee valgus angle; Valgus RoM = difference in valgus angle between IC and peak angle; knee flexion IC = knee flexion at initial contact; Flexion RoM = difference in flexion angle between IC and peak angle; * = significant difference ($P \leq 0.05$). Data are expressed as mean values, ± SD.

significantly shorter ($P = 0.01$; ES 1.41). Time to peak knee flexion for the injured legs was significantly (P = 0.02; ES 1.21) shorter for the IF group (0.16 s ± 0.05 s) compared to the EF group (0.21 s ± 0.03 s).

5. Discussion

The purpose of the present study was two-fold. First we sought to investigate if athletes after ACLR performing a single leg hop for distance showed differences in jump distance when they were provided instructions that induced an internal or external focus of attention. The results of this study showed that, although the EF group jumped 6–11 cm further compared to the IF group, these differences were not statistically significant. The results of the present study lend partial support in favor of the hypothesis that providing instructions that direct a patient's attention externally facilitates jump performance compared to instructions that focus attention internally.

A potential reason for not reaching a statistically significant difference in the current study could be related to the instructions provided. Wu et al. recently demonstrated a significant improvement in standing long jump performance when subjects adopted an external focus of attention (Wu et al., 2012). The instruction provided to their EF group was "Jump as far as you can. While you are jumping, I want you to think about jumping as close to the green target as possible." The green target (or cone) for the EF group was placed 4.57 m from the start line and was not presented to the IF group. Such an extra stimulus resulted in a significant increased jump distance in their EF group compared with the IF group. The explanation was that the subjects in the EF group were able to produce an optimal movement plan that efficiently combined both vertical and horizontal force components, resulting in a greater jump distance.

In addition, a simple change in the wording of instructions or feedback can have dramatic effects on motor performance and learning (Wulf, 2012). For instance, jumping, often already present in the repertoire of motor skills in athletes, can be improved by adopting an external focus. In a series of studies, participants performed a jump-and-reach task with the Vertec (Sports Imports, Hilliard, OH) device and were instructed to either focus on the rungs of the Vertec that were to be touched (external focus), or on the finger, with which the rungs were to be touched (internal focus), or to focus on jumping as high as possible (control condition) (Zachry, Wulf, Mercer, & Bezodis, 2005). Participants' jump-and-reach height was greatest with an external focus, compared with the other two conditions. One of the intriguing aspects of our study is that both the IF and EF group only received instructions related to jumping performance, yet remarkable differences were found in landing kinematics.

The second purpose of this study was to measure the influence of internal and external focus on knee kinematics. In the current study an external focus induced attention yielded larger peak knee flexion angles at IC for the involved leg as well as greater peak knee flexion angles for both legs. The results show that the IF group showed significantly less knee flexion ROM compared to the EF group for both legs. Based on the results, this indicates that the IF group utilized a stiffer landing strategy compared to the EF group which may pose a higher risk to sustain an ACL injury.

These findings are in agreement with recent research by Makurak et al. examining the effect of internal focus and external focus instructions in healthy athletes. (Makaruk, Porter, Czaplicki, Sadowski, & Sacewicz, 2012). Their EF group increased the range of knee flexion during a counter movement jump, whereas both the

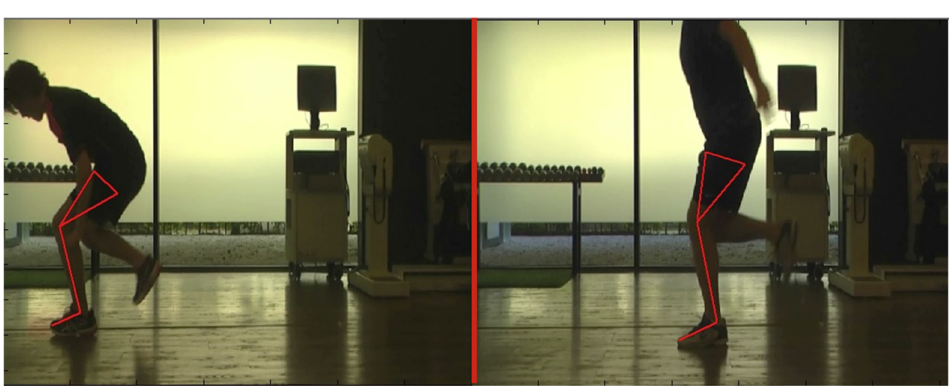

Fig. 1. Representative example of two patients performing the single leg hop test. Note the magnitude of peak knee flexion of the patient on the left who received an external focus instruction versus the patient on the right who received an internal focus instruction and clearly had smaller peak knee flexion.

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IF and a control groups decreased the knee flexion ROM. In addition, the EF group increased contact time, whereas both the IF and control groups decreased contact time during drop jump landing (Makaruk et al., 2012). There were no statistical significant differences for valgus between the IF and EF group. Female soccer players after ACLR exhibited increased knee valgus angles compared to healthy athletes (ACLR: 3.8° vs healthy: 1.8°) during a sidestep cutting task (Stearns & Pollard, 2013). These values are clearly lower than values we found probably due to differences in task, movement analysis and time after ACLR.

Excessive frontal plane movements of the knee have been implicated to increase ACL injury risk in female athletes (Hewett et al., 2005). Various methods of calculating 2D knee valgus have been reported in the literature and have been referred to as knee-separation distance, frontal-plane projection angle and medial knee displacement (Bell, Oates, Clark, & Padua, 2013). All of these measurements assess frontal-plane knee motion and use combinations of standard video cameras, basic editing software and motion analysis. It needs to be recognized that valgus as observed with 2D techniques should nonetheless be interpreted with caution. What is visible as valgus is in fact a combination of a set of movements from femoral and tibial motions, which can be influenced by the joints proximal and distal to the knee, including the trunk, hip, and ankle (Bell et al., 2013).

Most ACL tears do not occur from player-to-player contact. The most common causes of non-contact ACL injury include: change of direction or cutting maneuvers combined with sudden stopping, landing awkwardly from a jump, or pivoting with the knee nearly fully extended when the foot is planted on the ground. (Olsen, Myklebust, Engebretsen, & Bahr, 2004) Dissipation of large loads at initial contact through muscular activity is therefore critical for prevention of ACL injury.

Females, when compared with males, exhibit decreased force attenuation abilities during landing (Hewett, Myer, Ford, Paterno, & Quatman, 2012). Work by Koga et al. (2010) demonstrated that in 10 actual ACL injury situations in handball and basketball players, the mean knee flexion angle at IC was 23°, which is remarkably similar to the amount of knee flexion at IC for IF group (uninjured leg 24.81° ± 10.80°; injured leg 27.25° ± 11.09°) in the current study. These authors suggested, in line with established ACL injury prevention programs, training should focus on acquiring a cutting and landing technique with large knee flexion angles.

Interestingly, the EF group in the current study had significantly more knee flexion at IC (uninjured leg 32.56° ± 7.85°; injured leg 37.38° ± 6.44°), this suggests that external focus instructions should also be implemented in rehabilitation after ACLR. There is only sparse information available on the effect of attentional focus in patients after ACLR. Tsai and Powers determined the effect of a single training session on landing kinematics and kinetics in 10 female patients after ACLR (Tsai & Powers, 2013). Specifically, patients were provided combinations of both IF instructions ("land with increased flexion of the hip and knee") and EF instructions ("land as softly as possible"). Their study showed that employing a combination of different feedback techniques resulted in improved knee kinematics and kinetics.

The flexion ROM during landing may primarily affect the loading rate, as landing with greater hip and knee flexion angles decreases ACL load (Blackburn & Padua, 2008). The results of our study may suggest that the increased knee flexion ROM during landing in the EF group reduces the loading rate. Previous studies have shown the benefits of using an external over an internal or a neutral attentional focus to enhance safe knee landing techniques (Makaruk et al., 2012; Wu et al., 2012). The results of the study by Wu and co-workers demonstrated that the subjects in the external focus of attention condition elicited significantly greater standing long jump distance than the subjects in the internal focus group (Wu et al., 2012). Interestingly there were no significant differences observed between conditions in peak ground reaction force indicating greater neuromuscular efficiency in the external focus group. Makaruk et al. found that after a 9 week training program, the subjects in the external focus group exhibited greater improvement in standing long jump distance, had increased peak knee flexion and increased contact time when compared to the internal focus and control group (Makaruk et al., 2012).

The performance differences (knee kinematics) of the current study between external and internal focus of attention are best explained by the constrained action hypothesis (Wulf, McNevin, & Shea, 2001). The hypothesis states that consciously focusing on the movements of a motor action disrupts automatic motor control processes that regulate coordinated movements. When our patients actively focus and consciously control their movements (the IF group), they interrupt automatic non-conscious motor behavior processes that normally control movements in an efficient manner (Wulf et al., 2001). In contrast, directing attention externally to the movement effects allows the motor control system to naturally regulate and organize motor actions (the EF group). As a result, movements are fast and reflexive (Wulf, Tollner, & Shea, 2007).

5.1. Implications for clinicians

In addition to previous research in healthy athletes, the findings of this study provide sports physical therapists a potential useful tool by employing external focus instructions in rehabilitation that may help to target altered movement patterns after ACLR.

A recent study showed that 95% of physical therapists provide feedback instructions that induce an internal focus (Durham et al., 2009). Presumably, the patients in the current study, used this type of attentional focus as they had received these type of internal focus instruction throughout the entire rehabilitation. Subsequently, adopting this type of attentional focus for a prolonged period of time may hamper motor learning. For example, commonly used instructions during rehabilitation after ACLR are directed towards the execution of the movements itself such as "keep the knee over the toe"; "land with a flexed knee"; "raise the knee to the level of the hip" or "land with your feet shoulder-width apart" (Risberg & Holm, 2009; Wilk et al., 2012). While there may be intuitive reasons that clinicians tend to give internal focus instructions, this approach may not facilitate the full potential in patients after ACLR while re-learning skills (Gokeler et al., 2013).

5.2. Study limitations

There are limitations to the findings of this study that highlight the need for continued experimentation to validate the results reported here. For example, future studies should utilize a between-participant design and implement a retention and/or transfer test following practice. Doing this would indicate if the verbal instructions used in this study result in enhanced motor skill learning, or if the findings reported here are a temporary phenomena observed only after instructions are given.

In the present study we used a between groups design comparing the 2 focus of attention instructions. Inter-individual variations in performance could be addressed in future studies through a within-subjects design, with participants using external and internal focusing instructions in a counter-balanced order. Another shortcoming is the lack of a control group. As suggested in a study by Porter et al., adding a control group that adopt their "normal" focus of attention may help to better understand how motor performance was affected by altering the conscious focus of attention (Porter, Anton, Wikoff, & Ostrowski, 2013). It cannot be

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said with full certainty that the differences, which were found in this study actually were due the different foci of attention as we did not employ questionnaires to determine responses of patients whether they adhered to the instructions provided (Porter, Nolan, Ostrowski, & Wulf, 2010). In addition it may be important for future studies to ask participants to indicate which instruction type they would most prefer.

The current study had a relatively small sample size of 8 patients per group. While differences were observed in lower extremity biomechanics in athletes who had undergone ACLR and returned to sports participation, it is unknown if these movement patterns were present before the injury or surgery. Furthermore, various methods of calculating 2D knee valgus have been reported in the literature and have been referred to as knee-separation distance, frontal-plane projection angle and medial knee displacement. All of these measurements assess frontal-plane knee motion and use combinations of standard video cameras, basic editing software and motion analysis. It needs to be recognized that valgus angles as observed with 2D techniques should nonetheless be interpreted with caution. However, although most studies to date have used 3D methods to assess lower limb kinematics, the use of 2D video analysis has become more common because of its greater practicality and has shown good to excellent reliability (ICC .72 to .91) between sessions with a 1 week interval (Munro, Herrington, & Carolan, 2012).

6. Conclusion

This study makes a unique contribution to the field of sports physical therapy by demonstrating the influence that verbal instructions alone can have on jump performance and knee joint kinematics in patients after ACLR. In addition, this study demonstrates the applicability of using an external focus in the RTS phase to enhance safer movement patterns compared to an internal focus of attention and subsequently may help to reduce second ACL injury risk. This was evidenced by the patients in the EF group who showed greater peak knee flexion and increased ROM in both legs compared to the IF group. Furthermore, an external focus resulted in increased time to peak knee angles which allows for improved shock attenuation. The findings add to a growing body of research showing the benefits of instructing performers to use an external focus during motor skill execution. Future research should focus on the effectiveness of implementing an external focus of attention in ACLR rehabilitation programs.

Conflict of interest

None declared.

Ethical approval

Ethics approval was obtained from the institutional review board of the University of Groningen.

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