# The effect of proprioception training on knee kinematics after anterior cruciate ligament reconstruction

**Lisi Jiang**
Department of Emergence, Shenzhen Hospital, Southern Medical University
**Yongjian Wang**
Department of Emergence, Shenzhen Hospital, Southern Medical University
**Wenhan Huang** (wenhanx@126.com)
Guangdong General Hospital

**Research article**

**Keywords:** Anterior cruciate ligament reconstruction, Proprioceptive training, Rehabilitation, Kinematics

**Posted Date:** January 2nd, 2020

**DOI:** https://doi.org/10.21203/rs.2.19922/v1

# Abstract

Background Proprioception is essential for the normal movement of joint knees. The degree of functional recovery after ACL reconstruction is related with the degree of postoperative recovery of proprioception. The current study aimed to investigate the effect of proprioception training on functional level of activity and knee kinematics after anterior cruciate ligament reconstruction.

Methods Forty patients who underwent ACL reconstruction between January 2017 and June 2019 were included. The patients were divided into proprioception group (n=20) and control group (n=20). All the patients followed common postoperative rehabilitation program. The proprioception group were given proprioception enhancement program besides common postoperative rehabilitation program. All the patients were assessed preoperatively, 6 months and 1 year after operation. The lymsolm scores, hop distances, and knee kinematics during unanticipated jump–cut maneuver were compared at different follow-up time points.

Results There were no significant differences preoperative and postoperative Lysholm scores between two groups. After surgery, the proprioception group showed significantly higher hop distance (133.9 ± 26.2 cm) when compared with the control group (81.2 ± 17.2 cm, P=0.026) in 6-months and one-year follow-up (153.1 ± 19.3 vs 105.8 ± 20.7cm, P=0.034). For knee joint kinematics, the proprioception training group showed reduced knee abduction (valgus) angles and external rotations, and increased knee flexion when compared with the common training group.

Conclusions We conclude that proprioceptive rehabilitation training enhance the kinematic performance and single leg hop distance in ACL-reconstructed populations during jump-stop, unanticipated cut maneuver. The findings will be scientific evidences to help clinicians and physiotherapists to evaluate the patients’ readiness for exercises and sports, especially in the cases of loading and extreme rotation conditions.

Trial registration This study was retrospectively registered on Clnicaltrails.gov on 24 December.


# Background

The anterior cruciate ligament (ACL) is the most frequently injured knee ligament in sports injuries. ACL ruptured patients often show knee instability which may lead to degenerative changes and damage to other joint structures. It is often found that athletes are difficult to return to full function after ACL injury[1]. Recently, reconstructive techniques have been refined to achieve better stabilization of the knee joint and, consequently, better functional recovery[2]. Despite these efforts, functional recovery of the knee after ACL surgery is still unsatisfactory in many cases. It has been suggested that the lack of full recovery of knee function after ACL reconstruction is due to sensory and motor behavior deficits.

The aim of rehabilitation after ACL reconstruction is to restore the patient’s joint stability and so enable them to return as safely as possible to unrestricted, pre-injury levels of activity. In recent years, rehabilitation programs following ACL reconstruction have become more aggressive than common rehabilitation program, and proprioception training, neuromuscular training programs and functional activities are all used in clinical practice[3, 4]. The purpose of these modified rehabilitation program is to enhance knee joint stability more comprehensively and facilitate the decision-making process in returning to sport earlier.

Many previous studies used passive angle reproduction, joint position sense (JPS) to evaluate the recovery of proprioception[1, 5]. However, these outcomes are associated with static sensation ability, which can not predict the dynamic sensation in movement. Moreover, the dynamic sensation is correlated with rotational stability in daily life activity and sports performance and injury prevention and re-injury prevention after ACL reconstruction. The kinematics during the jump-stop, unanticipated cut maneuver has not been investigated before in ACL-reconstructed populations. Therefore, it's very important to evaluate the efficacy of proprioception training in dynamic motions.

Although sensory and motor changes have been described in individuals with ACL lesions, such changes have not been well described in individuals who have undergone ACL reconstruction[2]. After ACL reconstruction, these sensory and motor changes are more variable and, therefore, more difficult to describe [6]. Even though the proprioception can not be measured directly, it affects the knee joint kinematics during high demanding motion tasks such as loading and extreme rotation conditions. Therefore, this study aimed to compare the functional level of activity and knee joint kinematics of ACL-reconstructed knees between using proprioception rehabilitation program and common training program.

# Methods

Patients recruitment

Between 2018–2019, 40 patients underwent ACL reconstruction with a hamstring graft technique were recruited for this study. The study obtained ethical approval from an institutional review board. All the included subjects signed the consent form. The study consisted of 22 male subjects and 18 female subjects, with a mean age of 25 years. All subjects were involved in sports activities (amateurs). The period of time from injury to reconstruction was 3.0 ± 2.4 months. The common rehabilitation program was carried out for all the included patients. Patients who met the following criteria were participated in the study: (1) only one surgery for tear of the ACL that did not include a concomitant tear of the posterior cruciate ligament; (2) no evidence of collateral ligament repair at the time of surgery; (3) no history of surgery or traumatic injury to the contralateral knee; (4) no history of surgery or traumatic injury of the ankle joint; and (5) no history of surgery or traumatic injury to either hip joint. The subjects were clinically evaluated before participating in testing. None of the patients and controls had instability or additional lesions during the study period. All subjects underwent a common rehabilitation program.

Rehabilitation program

For the common rehabilitation program, all patients underwent a standardized rehabilitation protocol [7]. The details of the protocol can be found in Appendix 1. Apart from the common rehabilitation program, the proprioception group accepted proprioception training as well 8 hours after the common program. All the program was conducted by one experienced physiotherapist.

The proprioceptive rehabilitation protocol was consisted of proprioceptive and balance training. The details of the protocol can be found in Appendix 2. The proprioceptive rehabilitation protocol was based on a previous study[8]. Balance training was performed by using an inflated stability wobble cushion, with open and closed eyes in a two-leg stance and then single-leg stance using the involved limb (Fig. 1).

This standard protocol was applied to each patient under the supervision of the physiotherapist. The subjects were asked to come back to the physiotherapist for training guidance once per week from week 1 to week 6; once every two weeks from week 7 to week 12; self-monitoring training after week 12.

Assessment

Lysholm scores were used to assess the patients’ ability to manage in daily activity. The kinematic assessment protocol is described as following:

Before testing, patients were required to complete a 5-min warm-up on a stationary exercise bike. For the kinematic assessment, a portal optical tracking system (Opti_Knee®, Shanghai Innomotion Company) was used to collect kinematics of patients’ involved knees during jump-stop, unanticipated cut maneuver (JSUC). This validated system was used in previous studies [9, 10]. Firstly, spatial orientation was identified for bone landmarks with the assistance of handheld marker (Fig. 2), including the greater trochanter of the femur, lateral and medial femoral condyle, lateral and medial tibial plateau, lateral fibular head, tibial tubercle, and medial and lateral malleolus. Two infrared inductors were fixed on the distal femur and proximal tibia of respondents. Based on the bone landmarks in the system, three-dimensional coordinate systems of femur and tibia were built. The rotation was defined as the tibia’s rotation along with the origin of the coordinate system in the femur. Similarly, displacement was defined as the tibia’s movement relative to the origin of the coordinate system in the femur.

The subjects were shown on JSUC and allowed to practice the maneuver first without observing the visual unanticipated direction cue. This maneuver was selected in order to examine a common sport lover and potentially high ACL injury risk movement that occurs in sports. Incorporation of unanticipated elements into testing protocols may better mimic the demands placed on the lower extremity during sports. Each subject was positioned in an athletic ready position to react to a randomized unanticipated direction cue. The ready position was established before cutting trials. The subject was asked to perform single leg hop before landing; when landing, the subject was instructed simultaneously to perform a sidestep cut at 45 degree and run past a marker 2.5 m away (Fig. 2). The subject was asked to perform a crossover cut immediately when he or she landed on the floor as the knee demonstrated valgus and external tibia rotation with this movement (Fig. 3). It’s well established that this position is a risk factor of ACL injury mechanism. A custom computer program to show signal (left and right) on a digital monitor was used to cue the subject when the subjects were going to land within 0.3 seconds. The subject was instructed to reposition his or her knees to the same flexed position before the start of each JSUC trial. The subjects were asked to try to perform all JSUC trials in consistent postures to minimize the variations of movement.

Totally the subjects were asked to perform six trials with equal ones for each knee. The order of trials was randomly performed to examine the subjects' performance react to an unanticipated direction movement. After testing, we only exacted the data when subjects performed JSUC. Kinematic data were collected in 15 seconds at a frequency of 60 frames per second. Rotational motions, including abduction and external rotation angles at toe off when cutting, and peak flexion angles during single leg hop test were analyzed. Upon data collection, these parameters were calculated and compared between two groups preoperatively, 6 months after operation, and 12 months after the operation.

Data processing and analysis

Demographic data of included subjects, including age, BMI, and the duration between injury and reconstruction were compared between two groups using independent-t test. Gender, dominant sides, and injured sides were compared using chi-squared test. Lysholmes scores and hop distances measured preoperatively, 6 months, and 12 months after the operation were compared using independent-t test. For kinematics, peak values of knee flexion angles during single leg hop, abduction-adduction angles and tibia external rotations at cutting were compared using paired-t test at different follow-up time points, respectively. The significance level was set at 0.05. Statistical analyses were conducted in SPSS (IBM, Chicago, Ill., USA).

# Results

Demographic data of the included subjects are shown in Table 1. No significant differences were found in gender, age, BMI, dominant sides, the duration between injury and reconstruction between the common group and the proprioception group. The Lysholm scores are shown in Fig. 4. There were no significant differences between the two groups in preoperative Lysholm scores. After surgery, although the proprioception group showed a higher score in Lymsolm score in both 6 months (85.7 ± 5.3vs 83.7 ± 4.5, P = 0.938) and one year (94.6 ± 4.3 vs 92.1 ± 4.4, P = 0.726) when compared with the control group, however, the differences were not statistically significant.

Table 1
Demographic information of the included subjects

| | Common (n = 20) | Proprioceptive (n = 20) | P value |
|---|---|---|---|
| Gender | | | |
| Female | 8 | 10 | 0.751 |
| Male | 12 | 10 | |
| Age (yrs.) | 25.7 ± 5.5 | 24.3 ± 4.8 | 0.401 |
| BMI (Kg/$m^2$) | 21.8 ± 4.2 | 20.3 ± 4.6 | 0.168 |
| Dominant side: | | | |
| Right | 17 | 16 | 1 |
| Left | 3 | 4 | |
| Injured side: | | | |
| Right | 16 | 15 | 1 |
| Left | 4 | 5 | |
| Period between injury and reconstruction (mos.) | 3.2 ± 2.6 | 2.8 ± 2.2 | 0.140 |

For hop distances (Fig. 5), there were no significant differences between the two groups preoperatively (P = 0.913). After surgery, the proprioception group showed significantly higher hop distance (133.9 ± 26.2 cm) when compared with the control group (81.2 ± 17.2 cm, P = 0.026) in 6-months and one-year follow-up (153.1 ± 19.3 vs 105.8 ± 20.7 cm, P = 0.034).

For kinematics, representative curve of the maneuver-cutting step kinematics were shown as Fig. 6. Specifically, the proprioceptive group showed increased knee flexion angle (60.9 ± 9.2°) when compared with the figure from common group (65.9 ± 9.1°) at 6 months after operation (P = 0.045) (Fig. 7a). At one year after the operation, the knee flexion angle was increased as compared to the figure at 6 months after operation. The proprioceptive group showed greater knee flexion angle (75.4 ± 5.8°) when compared with the figure from the common group (68.2 ± 7.3°) (P = 0.041).

The proprioception group showed decreased knee external rotation angles, compared with control group in 6-month follow-up (20.0 ± 4.1° vs 29.6 ± 2.9°, P = 0.024) and in one-year follow-up (13.1 ± 3.7° vs 26.3 ± 4.6°, P = 0.003) after the operation (Fig. 7b).

The proprioception group showed decreased knee abduction (valgus) angles when compared with control group in 6-month follow-up (7.7 ± 1.7° vs 12.8 ± 2.2°, P = 0.028) and in one-year follow-up (5.4 ± 1.6° vs 10.6 ± 1.6°, P = 0.021) after the operation (Fig. 7c).

# Discussion

The purpose of the current study was to compare dynamic knee function and proprioception sensation between using the common rehabilitation program and proprioception training program. The current findings support our hypothesis, that proprioception training program enhance the dynamic knee function and sensation. The current study is so far the first study to evaluate the impact of proprioception training on the dynamic knee performance. These findings could be the evidences to support that proprioception training could be beneficial to recover knee rotational stability in unanticipated cutting, which is a good indication for injury prevention program aimed to reduce ACL re-injury after ACL reconstruction.

The Lysholm scores indicated both the proprioception training program and common training program could facilitate to manage patients' daily activity after ACL reconstruction. However, there is no significant difference between the two kinds of training program. The Lysholm scale does measure the domains of symptoms and complaints and does measure functioning in daily activities slightly, but does not measure the domain of functioning in sports and recreational activities such as motion tasks in the current study[11]. Therefore, it is not comprehensive to evaluate the knee function using scales like Lysholm score.

Many studies have found evidence of significant proprioceptive deficits in ACL-injured knees[12, 13]. In most of these studies, knee joint proprioception was evaluated as joint position sense by isokinetic measurement [14]. However, joint position sensation is a semi-static measurement, which can not represent comprehensive assessment of proprioception. What's more, in high-demanding tasks such as jumping and side cutting, the ability to control dynamic movement is crucial and extremely important for the prevention of ACL re-injury for ACL-reconstructed populations. For single-leg hop distance, it is used as the movement that is comparable with the high functional demands needed in sport for analysis[15]. It is already used as a functional test for lower extremity and has turned out to be a reliable measure[16]. The findings in the present study indicate that proprioceptive training has significant improvement to help ACL-reconstructed patients restore readiness for sports.

More importantly, the kinematics in the proprioceptive group demonstrated significant enhancements in sports performances. The instantaneous cutting with unanticipated directions reproduced the scenario that the sportsman does in the court (such as football or basketball player). Theoretically, enhanced proprioceptive performance will allow the sportsman to have a better capacity to control the core muscles, which facilitates the knee to avoid representing the ACL-injured position. Specifically, the proprioceptive group showed increased knee flexion angle when compared with the figure from the common group at 6 months after the operation. Similarly, at one year after the operation, the knee flexion angle was larger as compared to the figure at 6 months after the operation. Nagai et al. reported that enhanced knee proprioception and greater knee strength were correlated with a greater knee-flexion angle at initial contact during a single-legged stop-jump task[17]. The mechanism is that with a larger knee flexion angle during landing, proprioception may be enhanced due to increased afferent mechanoreceptor feedback associated with loading of the ACL [18, 19].

The proprioception group showed reduced knee external rotations when compared with the control group. One of the main functions of the ACL is to maintain knee rotational stability. ACL-reconstructed knees demonstrate greater internal-external rotation than the healthy side especially during loading and extreme rotation conditions[20]. In the present study, ACL-reconstructed knees show external knee rotation during JSUC. Reduced knee external rotations in proprioceptive group indicate proprioception is beneficial for the restoration of knee rotational stability. We speculate that the enhancement of rotational stability is associated with the increased mechanoreceptor by proprioceptive training on the knee joint.

The proprioception group showed reduced knee abduction (valgus) angles when compared with control group. It is well established that one of the most common mechanisms of noncontact anterior cruciate ligament injury is dynamic knee valgus[21]. Knee joint valgus is often implicated as a hazardous position for the ACL, due to the increased sharing loading between the ligament and the bone at this position. In the present study, the proprioceptive group showed enhanced capacity to make the knee joint expose a significant valgus position. This improvement is crucial to prevent ACL re-injury for ACL-reconstructed populations.

Proprioception loss after ACL reconstruction can be indirectly demonstrated by the altered movement patterns of the ACL-reconstructed knee. Altered gait patterns in conjunction with proprioceptive deficits add significantly to the mechanical instability of ACL-reconstructed knees and can predispose patients to secondary injuries. Clinically, one of the obstacles, when clinicians help ACL-reconstructed populations rehabilitate after surgery, is how to determine the perfect timing of return to sports. The present study suggest that the effect of rehabilitation on proprioception could not be objectively presented; however, rehabilitation was found to be extremely important for the restoration of knee joint kinematics, especially in the case of loading and extreme rotation conditions.

It must be noted that certain limitations do exist in this study. Firstly, we did not measure the contralateral ACL-intact knee as a control group. Secondly, kinematics was not analyzed with simultaneous myosthenic and electromyographic analysis, which may affect the comprehensive understanding of kinematic results. Third, the follow-up was relatively short. In further study, the mid-term and long-term follow-up should be investigated. Finally, measures of strength and neuromuscular function were not assessed here.

In summary, this study shows that proprioceptive rehabilitation training enhanced the kinematic performance and single leg hop for distance in ACL-reconstructed populations during jump-stop, unanticipated cut maneuver. The findings will be scientific evidences to help clinicians and physiotherapists to evaluate the patients’ readiness for exercise and sports, especially in the cases of loading and extreme rotation conditions.

# List Of Abbreviations

ACL Anterior Cruciate Ligament

JPS Joint Position Sensation

JSUC Jump-Stop, Unanticipated Cut

# Declaration

### Ethics approval and consent to participate

This study was approved by the Institutional review board of our institute, and all the subjected recruited in the current study have signed the consent form to participate.

### Consent for publication

All authors have signed a consent form for publication.

### Availability of data and material

All raw data and materials are available in the [datadryad.org] repository, [https://datadryad.org/stash/dashboard]

### Competing interests

There is no competing interest in the current study.

### Funding

We did not receive any funding support for this study.

### Authors' contributions

LISI JIANG, YONGJIAN WANG, and WENHAN HUANG carried out the research design, and acquisition, analysis and interpretation of data. LISI JIANG and YONGJIAN WANG participated performed the statistical analysis. WENHAN HUANG and YONGJIAN WANG helped to draft the manuscript. All authors read and approved the final manuscript.

### Acknowledgements

We acknowledge all the patients recruited in this study.

# References

1. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery: two-thirds of patients have not returned by 12 months after surgery. The American journal of sports medicine 2011;39(3):538-43.

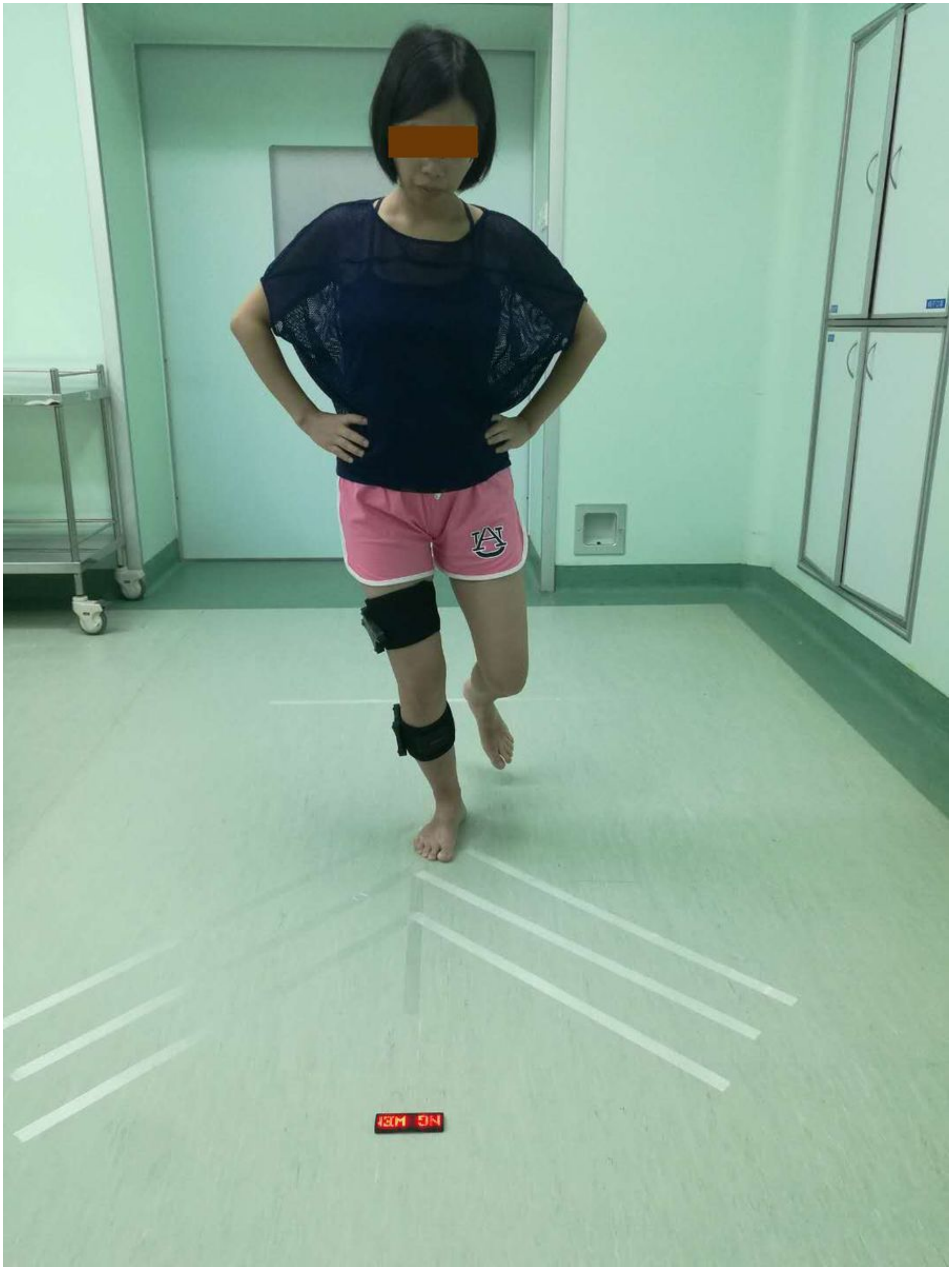
2. Bonfim TR, Paccola CAJ, Barela JA. Proprioceptive and behavior impairments in individuals with anterior cruciate ligament reconstructed knees. Archives of physical medicine and rehabilitation 2003;84(8):1217-23.
3. Risberg MA, Grindem H, Øiestad BE. We need to implement current evidence in early rehabilitation programs to improve long-term outcome after anterior cruciate ligament injury. Journal of Orthopaedic & Sports Physical Therapy 2016;46(9):710-13.
4. Setuain I, Izquierdo M, Idoate F, Bikandi E, Gorostiaga EM, Aagaard P, et al. Differential effects of 2 rehabilitation programs following anterior cruciate ligament reconstruction. Journal of sport rehabilitation 2017;26(6):544-55.
5. Suarez T, Laudani L, Giombini A, Saraceni VM, Mariani PP, Pigozzi F, et al. Comparison in joint-position sense and muscle coactivation between anterior cruciate ligament–deficient and healthy individuals. Journal of sport rehabilitation 2016;25(1):64-69.
6. Furlanetto TS, Peyré-Tartaruga LA, Pinho ASd, Bernardes EdS, Zaro MA. Proprioception, body balance and functionality in individuals with ACL reconstruction. Acta ortopedica brasileira 2016;24(2):67-72.
7. Gokeler A, Welling W, Zaffagnini S, Seil R, Padua D. Development of a test battery to enhance safe return to sports after anterior cruciate ligament reconstruction. Knee surgery, sports traumatology, arthroscopy 2017;25(1):192-99.
8. Ordahan B, Küçükşen S, Tuncay I, Sallı A, Uğurlu H. The effect of proprioception exercises on functional status in patients with anterior cruciate ligament reconstruction. Journal of back and musculoskeletal rehabilitation 2015;28(3):531-37.
9. Zhang Y, Huang W, Yao Z, Ma L, Lin Z, Wang S, et al. Anterior cruciate ligament injuries alter the kinematics of knees with or without meniscal deficiency. The American journal of sports medicine 2016;44(12):3132-39.
10. Zhang Y, Yao Z, Wang S, Huang W, Ma L, Huang H, et al. Motion analysis of Chinese normal knees during gait based on a novel portable system. Gait & posture 2015;41(3):763-68.
11. van Meer BB, Meuffels DD, Reijman MM. A Comparison of the Standardized Rating Forms for Evaluation of Anterior Cruciate Ligament Injured or Reconstructed Patients. 2017.
12. Dhillon MS, Bali K, Prabhakar S. Proprioception in anterior cruciate ligament deficient knees and its relevance in anterior cruciate ligament reconstruction. Indian journal of orthopaedics 2011;45(4):294.
13. Gokeler A, Benjaminse A, Hewett TE, Lephart SM, Engebretsen L, Ageberg E, et al. Proprioceptive deficits after ACL injury: are they clinically relevant? Br J Sports Med 2012;46(3):180-92.
14. Brindle TJ, Mizelle J, Lebiedowska MK, Miller JL, Stanhope SJ. Visual and proprioceptive feedback improves knee joint position sense. Knee Surgery, Sports Traumatology, Arthroscopy 2009;17(1):40-47.
15. Van der Harst J, Gokeler A, Hof A. Leg kinematics and kinetics in landing from a single-leg hop for distance. A comparison between dominant and non-dominant leg. Clinical biomechanics 2007;22(6):674-80.

16. Ross MD, Langford B, Whelan PJ. Test-retest reliability of 4 single-leg horizontal hop tests. Journal of Strength and Conditioning Research 2002;16(4):617-22.
17. Nagai T, Sell TC, House AJ, Abt JP, Lephart SM. Knee proprioception and strength and landing kinematics during a single-leg stop-jump task. Journal of athletic training 2013;48(1):31-38.
18. Lephart SM, Kocher MS, Fu FH, Borsa PA, Harner CD. Proprioception following anterior cruciate ligament reconstruction. Journal of Sport Rehabilitation 1992;1(3):188-96.
19. Borsa PA, Lephart SM, Irrgang JJ, Safran MR, Fu FH. The effects of joint position and direction of joint motion on proprioceptive sensibility in anterior cruciate ligament-deficient athletes. The American journal of sports medicine 1997;25(3):336-40.
20. Ristanis S, Stergiou N, Patras K, Vasiliadis HS, Giakas G, Georgoulis AD. Excessive tibial rotation during high-demand activities is not restored by anterior cruciate ligament reconstruction. Arthroscopy: The Journal of Arthroscopic & Related Surgery 2005;21(11):1323-29.
21. Mir SM, Talebian S, Naseri N, Hadian M-R. Assessment of knee proprioception in the anterior cruciate ligament injury risk position in healthy subjects: a cross-sectional study. Journal of physical therapy science 2014;26(10):1515-18.

## Figures

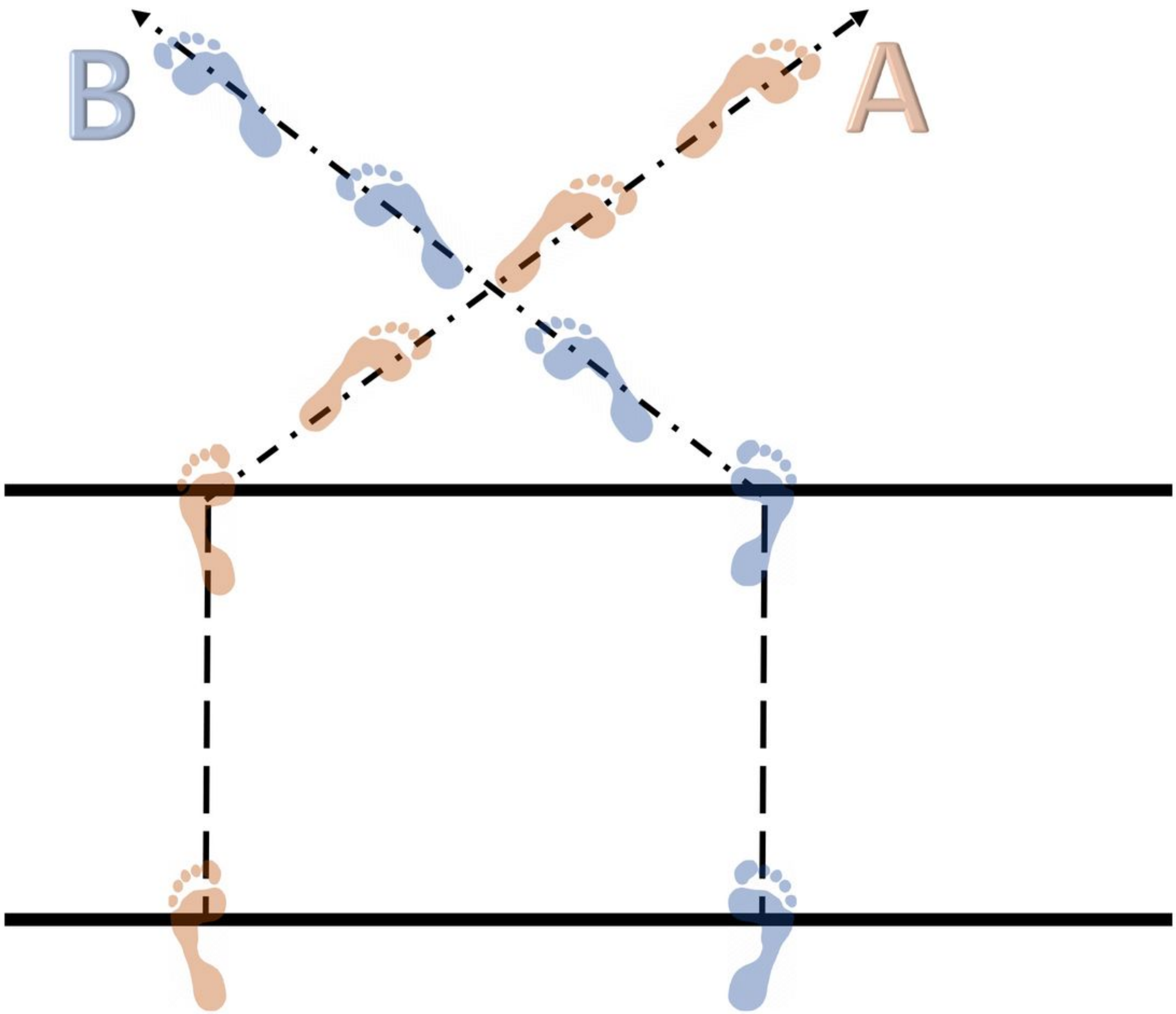
**Figure 1**

Proprioceptive training: open eyes in a single-leg stance using the involved limb on a cushion.



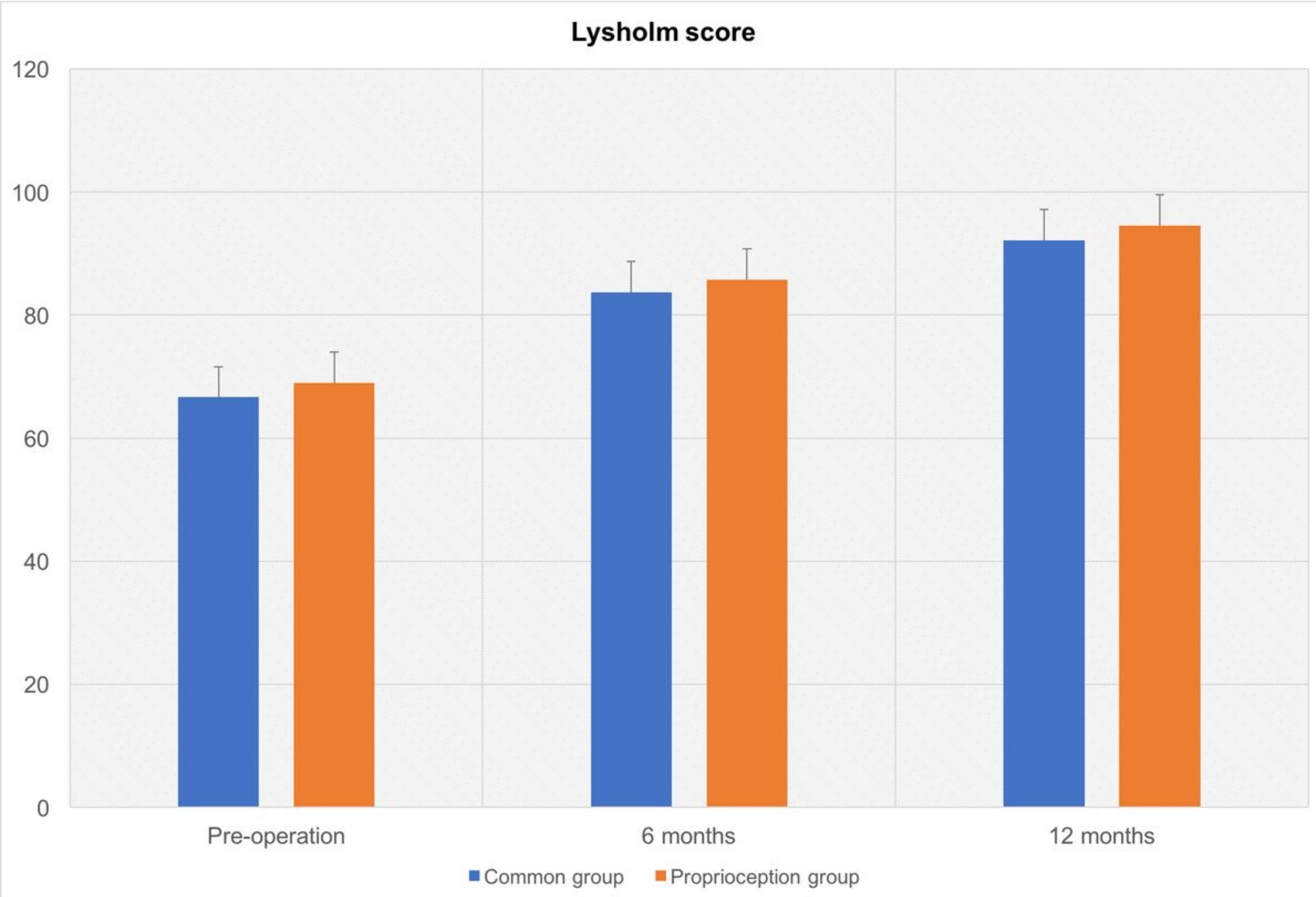
## Figure 2

A demonstration of jump-stop, unanticipated cut maneuver motion during testing procedure.



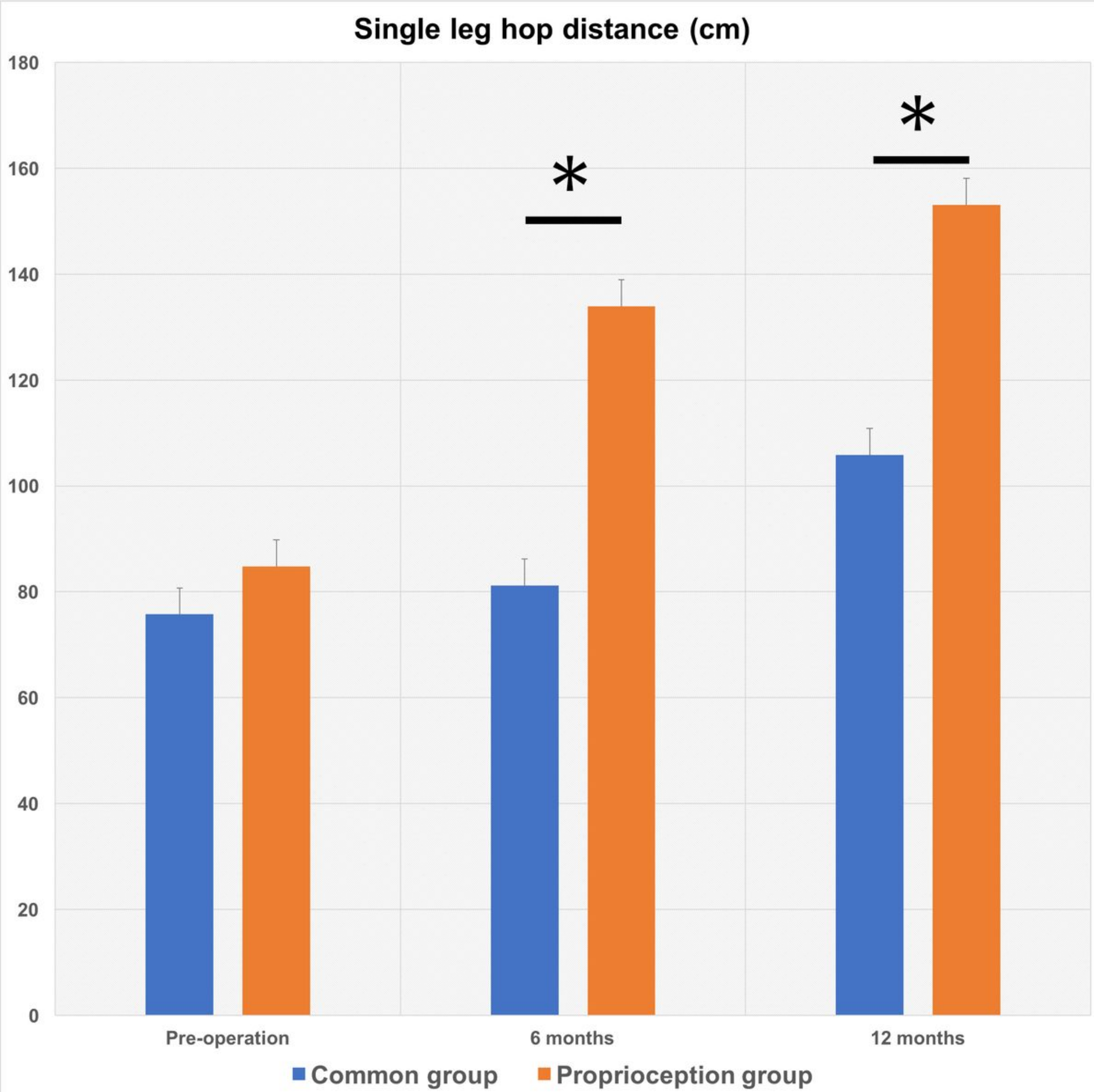

## Figure 3

A crossover cut was performed when patients were landing to collect knee knees. A: The path direction after crossover cut for left feet; B: The path direction after crossover cut for right feet



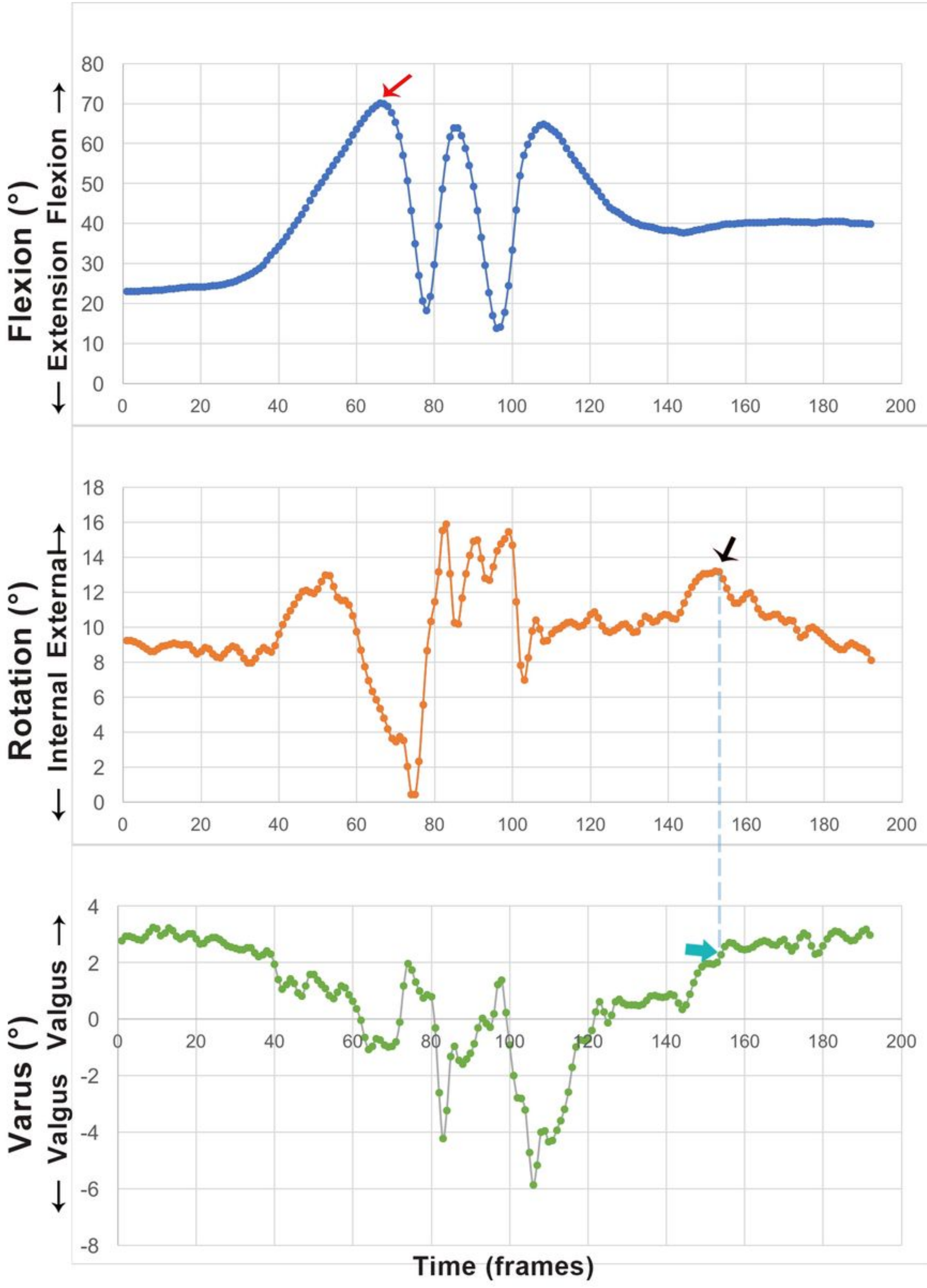

## Figure 4

Lysholm scores measured in the common training group and the proprioception training group. *: denote as P <0.05



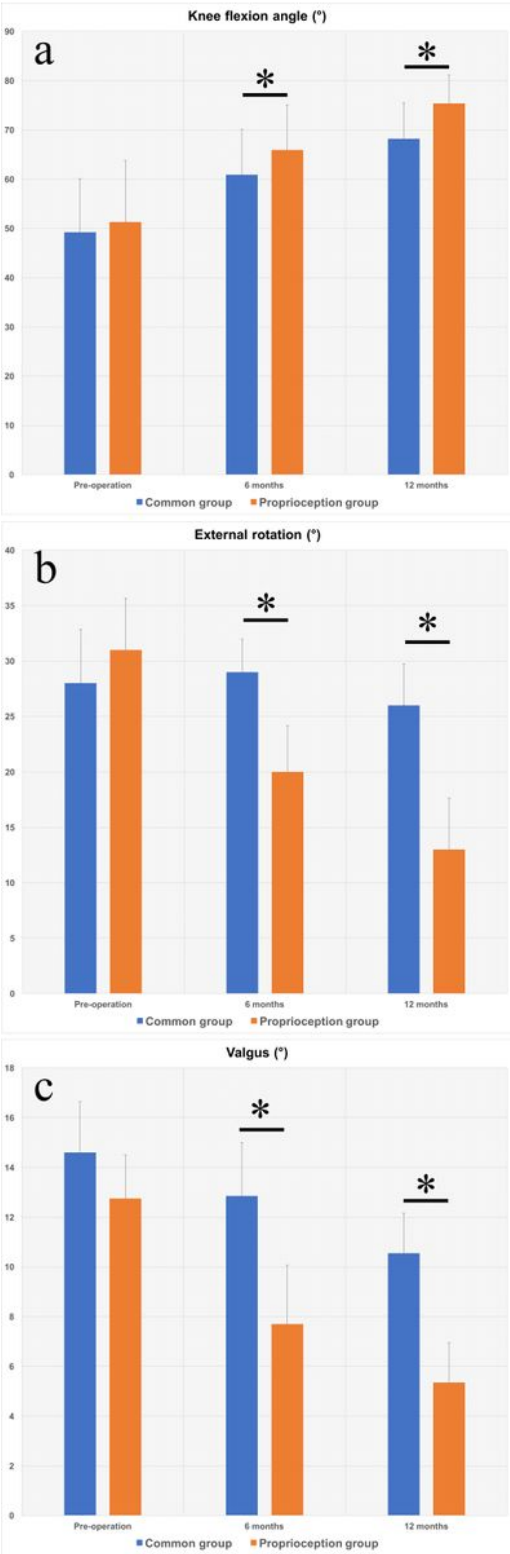

## Figure 5

Hop distances measured in the common training group and the proprioception training group. *: denote as P <0.05




## Figure 6

Representative curves of the maneuver-cutting step kinematics. The arrows indicate the data extraction at key event timing were collected and analysed. Red arrow: peak flexion angles during single leg hop test; Black arrow: peak external rotation angles at toe off when cutting; Jungle arrow: peak valgus at toe off when cutting.




## Figure 7

Kinematics measured in the common training group and the proprioception training group during motion tasks.