Kinematic Analysis of Hip and Knee Angles During Landing After Imagery in Female Athletes

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Abstract

Sarafrazi, S., Bt. Abdulah, R.T., and Amiri-Khorasani, M. Kinematic analysis of hip and knee angles during landing after imagery in female athletes. J Strength Cond Res 26(9): 2356–2363, 2012—In sport settings, imagery is regarded as one of the most popular and effective techniques to enhance the learning strategies and performance of skills. However, its effect on the correction of improper technique such as landing, which causes injury, is not clear. Therefore, the purpose of this study is to investigate the effect of imagery on knee and hip flexion angle during jump landing in women. The landing motions were captured from 40 female physical education students (height: 166.05 ± 7.52 cm; mass: 55.75 ± 9.23 kg; age: 20.45 ± 1.66 years) using a 3-dimensional technique at 60 Hz by 3 video cameras. There was a significant difference between no imagery (27.04 ± 2.40°) and imagery (22.98 ± 1.95°) on knee valgus angle, and also, there was a significant difference between no imagery (44.88 ± 13.46°) and imagery (62.35 ± 8.34°) on the knee flexion angle (p ≤ 0.001). There is, in addition, a significant difference between the effect of no imagery (28.60 ± 4.88°) and imagery (39.73 ± 7.29°) on hip flexion angle (p ≤ 0.001). It seems that imagery can be used to correct motions and movements. Based on this finding, we concluded that imagery, probably, can be used as a training strategy to change athletic motion; however, the authors suggest further investigation into the efficacy of imagery in the prevention of anterior cruciate ligament injury.

Key Words: ACL, mental practice, angular analyzing, landing, lower extremity

Introduction

Imagery continues to be popular among both practitioners and academics in psychology and motor control. For many years, athletes have been reported to be using mental practice to rehearse motor skills. In fact, a large amount of literature, termed “mental practice” has been reviewed on numerous occasions and has a long tradition in sport and exercise psychology. Imagery seems to have an important role in movement preparation and movement training. Researchers have recently stipulated that imagery is both a skill and ability because imagery training leads to increases in the vividness, controllability, and exactness of the mental images. Imagery practices have tended to promote a multimodal image (e.g., one referring to visual, kinesthetic, auditory, olfactory, and gustatory stimuli). From the early studies on mental practice to the recent literature reviews on imagery, the basic conclusion has been that mental imagery can facilitate motor skill acquisition, and also the effectiveness of imagery practice has been based primarily on performance improvements shown using discrete motor skills such as basketball-free throws, tennis serves, golf puts, dart throws, and various laboratory tasks.

The psychoneuromuscular theory is one of the first that tried to describe the effects of motor imagery (MI) in motor performance. This theory proposed that when a subject is mentally practicing to accomplish a particular movement (MI), impulses are sent to target muscles activating them as in actual movement execution. The psychoneuromuscular explanation of mental practice is that the muscles involved in the skill being imagined become slightly activated to prepare for kinesthetic feedback that can be used to make skill adoptions in future experiment. Munroe et al. mentioned that previous research has demonstrated that imagery helps athletes learn new skills and strategies and thus increases their motivation, which may lead to continued involvement in sport. Imagery is also useful for coping with pain and injury. It can help speed up recovery of the injured area and prevent skills from deteriorating. Another use of
Imagery is for solving problems (34). Imagery can be used to help reexamine or analyze one’s own performance. A player who is not performing up to past or expected levels can use imagery to critically examine all the aspects of the performance to find the potentially confounding factor (34).

Imagery is also one of a number of psychological interventions aimed at enhancing the psychological well-being of injured athletes and facilitating their physical recoveries because imagery can aid the recovery of the injured body parts and enhance the rehabilitation process (21). Some injuries normally take a considerably long time to rehabilitate such as anterior cruciate ligament (ACL) injury, for which incidences and patterns collected for soccer, volleyball, and basketball; the rates of noncontact ACL tears are 2–4 times greater in female basketball and soccer athletes than in male athletes playing the same sports (11,13,14,15,33). People who have suffered an ACL injury also have a much higher risk of developing degenerative joint problems later on in life, so protection of the knee joint from ACL injuries thus becomes paramount (4,5).

The ACL is 1 of the 4 main ligaments in the knee joint. The function of the ACL is to stabilize the knee joint, prevent abnormal movements, and steer the movement of the knee. The ACL prevents forward translation of the tibia relative to the femur. In addition, sectioning studies have shown that the ACL prevents hyperextension and stabilizes the knee against tibia rotation (25). It is reported that ACL injuries are one of the most frequently seen knee joint problems (29). The majority of ACL injuries happen with a noncontact mechanism and can be potentially prevented (16). The majority of ACL injuries also happen to the dominant leg during noncontact occurrence (2). Rupture to the ACL is common in tasks involving abrupt deceleration, rapid directional changes, and sudden landing (35). From a kinematics perspective, a previous study showed that noncontact ACL injuries frequently occurred with small flexion knee angles accompanied by knee valgus during running, cutting, and landing tasks in soccer and basketball (19), although a greater hip flexion angle is recognized as a potential advantage in preventing injury to the ACL (29).

Landing is an often performed task in sports, and the performances of landing tasks in sports are important not only for the performance of the task itself but more so for the prevention of lower extremity injuries (36). The execution of 100–200 landings by a team during 1 game may help account for the 25–35% incidences of noncontact ACL injuries in women’s soccer that happen during landing (33). The literature shows that landings with great impact force may be a risk factor for knee injuries, especially ACL tears (36). Landing from a jump has often been implicated in the description of ACL injury mechanisms, although most often cutting and landing from a jump have been used as injury models (30). The landing position may also affect the ACL injury rate in female athletes. Female athletes, as a group, tend to land with a more upright posture, with greater hip extension, adduction, and internal rotation; more forward momentum; and with increased valgus at the knee. Because the foot is fixed during landing, any motion at the hip will be matched by an opposite motion at the knee. Therefore, landing with hip extension, adduction, and internal rotation will cause knee extension and especially knee valgus (2).

Researchers proposed that women perform athletic tasks in a manner that exposes the knee joint to greater amounts of ligament strain and other lower extremity injuries (30). One useful strategy for minimizing the risk of developing ACL injuries is a prehabilitation program with a focus on optimizing hip biomechanics during squatting, plyometrics, and agility training. In particular, training should concentrate on maintaining a flexed, externally rotated, and abducted hip throughout the range of motion, which helps prevent an excessive valgus moment from being transmitted to the knee (2). In an attempt to explain the disproportionate incidence of ACL injury in female athletes, biomechanical studies have evaluated gender differences in knee joint mechanics during the performance of athletic tasks. Women have been found to perform cutting and landing tasks with less knee and hip flexion and greater knee valgus when compared with men (29,32). At the time of injury, the knee is often near full extension with the tibia internally rotated relative to the body; therefore, women who land with decreased knee flexion may increase the forces on the ACL valgus (2). Most ACL injuries occur with the knee near full extension during a sharp deceleration or while landing a jump (33). Knee joint valgus is often involved as a hazardous position for the ACL and has recently been linked to ACL injury risk. Valgus loading can increase relative ACL strain and may be of levels high enough to bring about ligament failure (28). Therefore, there is a great need to study the cause of knee injuries and to devise and implement intervention programs to help reduce the players’ risk of injury. Probably, imagery can be used as an intervention program to prevent the risk of sustaining knee injuries especially ACL injury. The purpose of this study, therefore, is to examine the effects of imagery to knee valgus, hip flexion, and knee flexion during the jump-landing maneuver. We hypothesized that imagery would significantly demonstrate the decrease in knee valgus and the increase in hip and knee flexion during jump-landing maneuvers.

**Methods**

**Experimental Approach to the Problem**

The pretest and posttest experimental designs were as follows: The participants conducted 2 different landing protocols on 1 day during autumn. The test day was conducted >72 hours after a match or hard physical training to minimize the fatiguing effects from previous exercise. The landing protocols differed only in the exits of imagery before landing, whereas all other exercises used in the protocol were identical. The experimental group performed the imagery plan before the posttest, but the control group did...
not perform this. Imagery was the dependent variable, and the independent variables included were (1) knee valgus, (2) knee flexion, and (3) hip flexion.

Subjects

One hundred and twenty female athletes who were physical education students from a local university, after general recruitment, volunteered to participate in this research. They played actively in sports such as basketball, handball, and volleyball, and they were free from any lower extremity injuries. They were given the preliminary Movement Imagery Questionnaire_Revised (MIQ-R) test for visual and kinesthetic ability. All had some level of imagery ability. According to the literature, the top 40 participants (mean age: 20.45 ± 1.66 years; mean height: 166.05 ± 7.52 cm; mean mass: 55.75 ± 9.23 kg) for the MIQ-R were selected for this study (Table 1). This was to ensure that the samples have imagery ability. They were then assigned to 2 groups, no imagery group (NIG) and imagery group (IG). The calculated effect size for this sample is 0.9. The university institutional review board gave approval for all the procedures. The subjects were informed orally about the procedures they would undergo, and each read and signed a medical questionnaire and an informed consent form.

Procedures

The MIQ-R was conducted to evaluate the mental ability of the subjects (31). Morris et al. (21) reported that the reliability of the MIQ-R test was 0.83. This questionnaire contains explicit instructions asking for either kinesthetic or visual imagery of the subject’s movements along with explicit verbal reports about the image. The MIQ-R is an 8-item inventory that asks participants to image actions either visually or kinesthetically. They were required to imagine each movement by either “seeing” or “feeling” themselves execute those same movements as vividly as possible without actually physically doing them again. The subjects assigned a value to the vividness of their image on a 7-point Likert scale, in which 1 = very hard to see/feel and 7 = very easy to see/feel. The rating scales of the MIQ-R are presented in Figure 1. The total score for each subscale extends from 8 (the low imagery limit) to 56 (the high imagery limit).

In the first stage, as shown in Table 2, the subjects performed 10 minutes of adequate warm-up (4 minutes of jogging and 6 minutes of static stretching) before data collection. In the second stage, the subjects were allowed to practice 3 landing tasks until they felt comfortable with the test. At first, the NIG performed the landing task, and then, IG continued to perform the landing task from a wooden platform, measuring 0.30 m in height (30). This task consisted of a take-off and a 2-footed landing followed by a 2-footed take-off for the maximum height. For all the landings, the subjects began in a standardized take-off position in which the hands were placed on the iliac crests and toes of both feet were aligned along the leading edge of the wooden platform. The hands must remain on the iliac crests throughout the task to eliminate variability in landing mechanics because of arm swing. The subjects performed 3 consecutive landing tasks with the above-described markers.

In the third stage, both the groups were taught the correct landing technique. The instructor, who was an expert coach in track and field athletics, taught the correct landing technique by video with verbal description, which is presented in Table 3. After describing the correct landing, both the groups performed 3 sequential landing tasks. In addition to the landing technique that was taught to both groups, the NIG

<table>
<thead>
<tr>
<th>TABLE 1. Descriptive statistics of the individual structure of female physical education students.</th>
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<tr>
<td></td>
</tr>
<tr>
<td>Height</td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>Age</td>
</tr>
</tbody>
</table>

![Figure 1. Rating scales of Movement Imagery Questionnaire_Revised (MIQ-R).](image-url)
were taught imagery techniques to do the specific task. We asked the participants to close their eyes and imagine the correct landing task. The imagery technique includes concentrating on the feelings of the muscles (i.e., to mentally perceive muscle contractions during landing task) used to do the landing task or seeing themselves visually perform the correct landing task. In the imagery procedure, the instructor explained to the participants, as presented in Table 4. In the fourth stage, during the imagery program for the IG, the NIG started the landing task again as in the posttest. The IG, on the other hand, after imagery practice, took turns in performing the landing task again. All the subjects also performed 3 consecutive landing tasks.

Three digital video cameras (Panasonic NV-GS60, Tokyo, Japan) were used to capture the limb motion at 60 Hz. All the 3 video cameras adjusted the reference point as the landing point and were equally spaced to ensure that the spacing between 2 consecutive cameras covered an angle of 90° from the landing point. An external audio referring to foot–ground contact sound was used to synchronize the 3 video cameras. The 3 digital cameras were calibrated for a 2-m-long, 2-m-wide, and 2-m-high space (calibration volume) in which the subject performed the landing task. The resulting displacement-time data of each marker were smoothed from the start of the movement until impact using a fourth-order (low-pass) Butterworth digital filter with a zero phase lag. Reflective spherical markers (9 mm in diameter) were fixed on each subject on the right and left anterior superior iliac spines, lateral thighs, lateral femoral condyles, lateral shanks, lateral malleoli, second metatarsals, and sacrum of the subjects (Figure 2) (29).

Peak Motus version 9 videographic data acquisition system (Vicon Motion Systems, Lake Forest, CA, USA) was used to manually digitize the video records of the calibration frames and subjects’ performances. This software was also used to estimate 3-dimensional (3D) coordinates of 14 body landmarks for each trial from initial contact by legs to get back to stand posture. Some important kinematics parameters of hip and knee joints during landing were selected for analyses. This study focused on lower extremity, so it investigated the minimum hip flexion angle, minimum knee flexion angle, and maximum knee valgus angle from initial contact with ground until the stand up position. As illustrated in Figure 3, the 3D figure of unsuitable and suitable landings showed the differences between knee flexion, knee valgus, and hip flexion during landing.

**Statistical Analyses**
A 2-way repeated measure analysis of variance (ANOVA; 2 groups [IG vs. NIG] × 2 test [pretest vs. posttest]) was used to analyze the kinematics data. When appropriate, follow-up analyses included additional lower-order ANOVAs and paired-samples t-tests. SPSS software (version 15.0, Chicago, IL, USA) was used for all statistical comparisons. The alpha level was set at $p \leq 0.05$ to determine the statistical significance. Test-retest reliability values for the testing order of test intraclass correlation reliability were $\geq 0.95$, effect size was $\geq 0.90$, and power was $\geq 0.94$.

### Table 2. Timeline during each data-collection session.

<table>
<thead>
<tr>
<th>Group</th>
<th>First stage</th>
<th>Second stage</th>
<th>Third stage</th>
<th>Fourth stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No imagery group</td>
<td>Warm-up (10 min)</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Imagery group</td>
<td>*</td>
<td>Pretest (20 min)</td>
<td>Imagery (2 min)</td>
<td>Posttest (20 min)</td>
</tr>
</tbody>
</table>

*Activity included.

### Table 3. Landing description.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Landing by leaning slightly forward, maximum increase in hip and knee angles to prevent from any rotation in the femur and tibia</td>
</tr>
<tr>
<td>2</td>
<td>Landing on the balls of the feet with the knees flexed and the chest over the knee</td>
</tr>
<tr>
<td>3</td>
<td>Reminding to avoid any excessive side-to-side or forward-backward motion of the knees on landing</td>
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</tbody>
</table>
RESULTS

As presented in Figure 4, there was no significant difference between pretest (27.05 ± 2.36°) and posttest (26.84 ± 2.98°) on the knee valgus angle in the NIG (0.77% decreasing).

From the other point of view, there was a significant difference between pretest (27.04 ± 2.40°) and posttest (22.98 ± 1.95°) in knee valgus angle in the IG with \( p \leq 0.001 \) (15.01% decrease) (Figure 4).

**Table 4. Imagery description.**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>See yourself while you stand on the platform</td>
</tr>
<tr>
<td>2</td>
<td>Look down at your feet and see your toes on the platform</td>
</tr>
<tr>
<td>3</td>
<td>You bend forward in the track start position and focus forward on the ground</td>
</tr>
<tr>
<td>4</td>
<td>When your feet contact the ground you land by leaning slightly forward and land on the balls of your feet with the knees flexed and the chest over the knee</td>
</tr>
<tr>
<td>5</td>
<td>Finally you get back slightly to the standing posture</td>
</tr>
</tbody>
</table>

**Figure 2.** Fourteen reflective spherical markers that were attached on lower extremity land markers.

**Figure 3.** The three-dimensional figure of suitable and unsuitable landing images taken from peak motus (Vicon Motion Systems).
There was no significant difference, as illustrated in Figure 5, between pretest \((39.92 ± 10.57°)\) and posttest \((39.61 ± 10.63°)\) on the knee flexion angle in the NIG \((0.77\%\) decreasing). On the other hand, there was a significant difference between pretest \((44.88 ± 13.46°)\) and posttest \((62.35 ± 8.34°)\) in the knee flexion angle in the IG with \(p \leq 0.001\) \((38.92\%\) increasing) (Figure 5).

Figure 6 shows no significant difference between pretest \((30.32 ± 4.65°)\) and posttest \((30.97 ± 5.96°)\) in the hip flexion angle in the NIG \((2.14\%\) increase). However, there was a significant difference between pretest \((28.60 ± 4.88°)\) and posttest \((39.73 ± 7.29°)\) on hip flexion angle in the IG with \(p \leq 0.001\) \((38.91\%\) increase) (Figure 6).

**DISCUSSION**

The findings of this study showed that imagery significantly (1) decreased knee valgus by \(15.01\%\) \((2)\), increased knee flexion angle by \(38.92\%\), and (3) increased hip flexion angle by \(38.91\%\). These results are consistent with previous findings that showed imagery effect positively on performance and skills (1,12,18,23,24,26). These studies reported that imagery modifies different performance and skills, similar to this study in which imagery also modified lower joints kinematics during landing.

The theories that are described in sport psychology such as the psychoneuromuscular theory, symbolic learning theory, the triple code model and psychological explanations, all assert that imagery can help program athletes both physically and mentally. In addition, the increased neuromuscular activity in the muscle helps players make movements that are more fluid, smooth, and automatic (34) because, recently, the role of neuromuscular training programs has been investigated in the prevention of ACL injury (2). Grindstaff (7) suggested that neuromuscular training programs reduced the incidence of noncontact ACL injuries. He suggested that the optimal injury prevention program be progressive and include aspects of stretching, strengthening, polymetric, and agility exercises. Neuromuscular training programs for injury prevention also address factors that have been shown to improve athletic performance. One of these training programs could involve the use of imagery to map neuromuscular events. Louis et al. (18) in addition suggest that from a neurophysiological viewpoint, brain mapping techniques have provided converging evidence that imagined and executed movements share the
same neural substrate. Positron emission tomography, functional magnetic resonance imaging, electroencephalography, and magnetic encephalography studies of various MI tasks have found that MI can activate brain areas that at least partially overlap many or all of the brain areas activated by overt motor behavior (27). Researchers have found that the brain structures that form the corticostriatal and the corticocerebellar anatomical systems are particularly important for the acquisition and execution of motor skills. The neural motor network is activated while imaging motor actions. This activation includes not only premotor and motor areas such as premotor cortex, posterior parietal cortex, supplemental motor area, and primary motor cortex, but also subcortical areas of the cerebellum and the basal ganglia (24).

Mental practice of motor behavior such as the systematic and repetitive use of imagery is regarded as an effective tool to improve skill learning in sports. Mental training in sports has also been used to enhance transfer effects of a peak power training to sprint performance (24). Mental training has also been used for the rehabilitation of sport injuries (22). Positive effects were found for muscle tolerance after ankle sprains and in terms of significantly greater knee strength after ACL reconstruction, and also effects of mental training on performance are also found for other skill domains such as surgery and piano playing (24). Therefore, Motor imagery techniques might well be powerful enough to be taught as a new motor movement in prevention programs for athletes.

From the early studies on mental practice to the recent literature reviews on imagery, the basic conclusion has been that mental imagery can facilitate motor skill acquisition. The effectiveness of imagery practice has been based primarily on performance improvements shown using discrete motor skills such as basketball-free throws, tennis serves, golf putts, dart throws, and various laboratory tasks (1). Although imagery training has been demonstrated to achieve less training improvements than motor execution, it would be of interest to combine this training with execution training. Therefore, mental training can be seen as a complementary technique to execution training but should not be used as a substitute to movement execution (8,17). Imagery can be used to examine a skill to detect and correct a problem before the next physical practice session or competitive performance. This remembrance of performance can be used to help athletes determine how errors occurred and what caused them to make certain decisions. The athlete can mentally correct the errors and practice the correct response (21). Just as imagery can be used to review performance or detect and correct errors, it might be used to solve problems in performance. Players who are in a slump or having problems with technique, strategy, or psychological skills might use imagery to imagine when they were performing at their best and compare this with their current performance to find the factors causing the slump (21).

On the other hand, from the kinematics perspective, the current findings showed that imagery can correct the knee valgus and flexion and also hip flexion. Although the knee valgus angle, knee flexion angle, and hip flexion angle are risk factors of noncontact ACL injury during landing in women (20,29,33), probably imagery can correct motions to decrease noncontact ACL injury risk during landing in women. McLean et al. (20) mentioned that landing in a more extended hip and knee posture caused substantial increases in the number of ACL injuries, whereas landing with increased combined hip and knee flexion reduced this probability. A more flexed knee and hip angle possibly can be developed as a protective mechanism to absorb the ground reaction force just at landing (29). Previous studies purported that increased hip extension and particularly knee extension at landing are likely to increase ACL injury risk. Regardless, current outcomes suggest that training individuals to land with increased hip and particularly knee flexion during landing tasks, which is already purported in many current prevention modalities, is well warranted and should remain a key focus.

In summary, this finding showed that imagery decreased knee valgus angle and increased knee and hip flexion angle during landing. According to a previous finding and the present finding, high knee valgus angle, less knee flexion angle, and less hip flexion angle are the most important risk factors in noncontact ACL injury in women. Based on literature review, it seems that imagery can affect movement by neuromuscular event, and its effect is useful for the correction and adoption of new motions (e.g., greater knee valgus, less knee, and hip flexion during landing maneuver), which otherwise could lead to injury, especially, noncontact ACL injuries. The authors suggest that more research in this area is required to investigate the underlying mechanism of imagery on landing and to also prevent ACL injuries. More research is necessary with more measuring instruments such as force plates and also with research conducted on greater population with different sportive groups and ages. More isolated conditions may help to achieve better and clearer results in future investigations, because during this study, the research was not limited to subjects’ thinking, nutrition, and maximum effort.

Practical Applications

In conclusion, although there are considerable benefits to injured athletes using imagery, including maintaining skills, decreasing stress and anxiety, increasing self-confidence, relieving pain, and increasing motivation to recover and return to their sport (12) and with regard to the results of this finding, imagery may be used as a teaching strategy to correct wrong motions. Coaches should undoubtedly promote imagery use among athletes. Therefore, coach education is a viable mechanism for the implementation and delivery of injury prevention in community sports. It appears that imagery, probably, can be used in training to prevent noncontact ACL injury in female athletes. Based on these findings, imagery may be appropriate to initiate injury
prevention programs at an earlier age by correcting landing. Coaches and players have used imagery as mental practice and in training to improve performance and skill. According to present finding, we can suggest to coaches and players to use imagery to prevent noncontact ACL injuries in women. Probably, imagery can be used as a prevention exercise and in training to prevent all injuries by achieving other basic injury mechanisms. Finally, in landing sports, coaches, physical educators, athletic trainers, sport psychologists, and players who are well versed in imagery techniques and also have the basic knowledge of imagery principles, should use imagery to modify landing maneuvers after jumping, which may help them to decrease the risk of sustaining ACL injuries.

REFERENCES