

# Effects of Visual Biofeedback Using a Laser Beam on the EMG ratio of the Medial and Lateral Vasti Muscles and Kinematics of Hip and Knee Joints during a Squat Exercise

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**Abstract.** [Purpose] The purpose of this study was to examine the effects of visual biofeedback on the EMG ratio of the medial and lateral vasti muscles and on the lower extremity joint angles during squat exercises performed by subjects with femoral anteversion. [Subjects] Seventeen subjects (5 men, 12 women) with femoral anteversion participated in this study. [Methods] Subjects performed a double-leg squat with and without visual biofeedback using a laser beam fixed to a patella strap. The peak angles of hip internal rotation and knee valgus were analyzed using a 3D motion analysis system, and the vastus medialis oblique/vastus lateralis (VMO/VL) activity ratio was calculated using the value recorded by surface electromyography during the squat exercises. [Results] Significant decreases were found in the hip internal rotation angle and knee valgus angle, and a significant increase in the VMO/VL activity ratio was observed on the dominant side when performing a double-leg squat with visual biofeedback using a laser beam. [Conclusions] We suggest that laser-beam visual biofeedback would be used as an effective for improving VMO muscle strength and reducing the angle of hip internal rotation and knee valgus during squat exercises.

**Key words:** Kinematics, Squat, Visual biofeedback

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## INTRODUCTION

Poor neuromuscular control and unbalanced muscle activity are major factors related to knee injuries, such as patellofemoral pain syndrome (PFPS) and anterior cruciate ligament (ACL) rupture<sup>1)</sup>. To prevent these injuries, many clinicians and researchers have emphasized selective muscle activity of the vastus medialis oblique (VMO) and knee alignment during exercise programs and functional activities<sup>2,3)</sup>. Weight-bearing exercises are effective at improving the functions of lower-extremity muscles, especially dynamic squat exercises, which have been incorporated into various training and conditioning programs<sup>4)</sup>. The double-leg squat is commonly used in knee rehabilitation settings, and the addition of isometric hip adduction during the double-leg squat would facilitate selective VMO activity<sup>5)</sup>. Weakness of the quadriceps muscle may result in loss of functional abilities, because the quadriceps plays an important role both in level walking and in using stairs. In particular, a weak VMO, relative to the vastus lateralis (VL) muscle, can result in patella malalignment; thus, selective strengthening of the VMO has been the focus of several studies<sup>6,7)</sup>.

Individuals performing weight-bearing exercises tend to engage in excessive hip internal rotation and knee valgus<sup>8)</sup>. Engaging in weight-bearing tasks with hip adduction and internal rotation may lead to excessive medial knee displacement and knee valgus alignment<sup>9)</sup>. Sigward and Powers<sup>10)</sup> reported that internal rotation of the hip caused the center of the knee joint to move medially with respect to the center of pressure. Willson et al.<sup>11)</sup> found the greater frontal plane angle was greater in females than in males, and was significantly associated with hip external rotation torque. Femoral anteversion indicates increased medial displacement due to hip rotation, which influences patella alignment and induces increased pressure at the point of patellofemoral contact. Additionally, femoral anteversion acts as a major contributor to hip internal rotation<sup>12)</sup>. Accordingly, people with femoral anteversion may experience more frequent knee injuries during squat exercises because knee valgus or an abducted knee position may be associated with a combination of hip internal rotation and adduction<sup>13)</sup>. Femoral alignment has complex effects on the function of the lower extremity because the femur contributes to the action of both the hip and knee joints. Structural alteration at the patellofemoral

**Table 1.** Subject characteristics

Parameters	All (n=17)	Men (n=5)	Women (n=12)
Age (years)	21.3 $\pm$ 1.6	23.2 $\pm$ 0.8	20.6 $\pm$ 1.2
Weight (kg)	56 $\pm$ 7.7	65.6 $\pm$ 6.2	52.1 $\pm$ 4.2
Height (cm)	165.9 $\pm$ 6.2	174.1 $\pm$ 1.2	161.9 $\pm$ 4.2

Mean  $\pm$  SD.

compartment may lead to changes in the biomechanical relationships in both joints<sup>7,14</sup>.

To prevent knee injuries, it is important to strengthen the VMO muscle, the activity of which keeps the lower limb in neutral alignment<sup>2</sup>). However, it is difficult to prevent hip internal rotation and knee valgus during squats performed by people with femoral anteversion, due to the lack of appropriate feedback. Biofeedback is essential for optimal control of human motor functioning, because it is the process by which the nervous system detects both sensory and motor signals<sup>15</sup>). Visual guidance influences neuromuscular control of movement during certain tasks and also facilitates selective muscle activation. Cynn et al.<sup>16</sup>) demonstrated the effects of lumbar stabilization using a pressure biofeedback unit during hip abduction in side-lying. Oh et al.<sup>17</sup>) also found that an abdominal drawing-in maneuver using a pressure biofeedback unit was effective at strengthening selective hip muscles during prone hip-extension exercise. It is difficult to control the internally rotated hip and valgus knee while performing squats, and biofeedback techniques may be effective for selective muscle facilitation.

Many researchers have studied treatment protocols for functional recovery and selective activation of the VMO<sup>18,19</sup>). However, most studies have only examined variations in exercise types or positions, and only a few have suggested methods for selective VMO strengthening using feedback techniques during dynamic exercises<sup>20</sup>). Thus, the purpose of this study was to measure the angles of hip internal rotation and knee valgus and the electromyographic ratio of the medial and lateral vasti muscle activity during a double-leg squat with and without biofeedback. We hypothesized that visual biofeedback using a laser beam during squat performance would increase the activity of the VMO and reduce hip internal rotation and knee valgus compared with squats performed without visual biofeedback.

## SUBJECTS AND METHODS

Seventeen young people (5 men, 12 women) without a history of knee pathology were recruited from Inje University, Korea (Table 1). The subjects were selected using the Craig test. This test is a method for assessing femoral anteversion, which is estimated from the angle formed between vertical and the maximal passive medial hip rotation. For the present study, only subjects with over 20° medial hip rotation were chosen<sup>21</sup>). All subjects read and signed an informed consent form approved by the Inje University Ethics Committee for Human Investigations

prior to their participation.

A board and a patella strap with a laser beam were prepared for visual feedback. The board, which was 60 cm long and 45 cm wide, was attached to a wall, and a vertical line 1.7 cm wide was drawn in the center of the board. A plastic cylinder, 4.5 cm long and 1.3 cm in diameter, designed to focus a 4.4 cm diameter laser beam was attached to a patella strap. Kinematic data from the hip and knee joints were acquired using six cameras and a VICON MX-T20 motion analysis system (VICON Motion System, Ltd., Oxford, UK) (sampling rate 100 Hz) controlled by Nexus software (ver. 1.4). The investigator attached 16 reflective markers on subjects' bilateral anterior and posterior superior iliac spine, lateral thigh, femoral epicondyle, tibia, malleolus, second metatarsal head, and posterior calcaneus according to the VICON Plug-In-Gait marker placement protocol. Markers were placed by the primary investigator, an experienced operator of this system. Polygon software (ver. 3.1) was used for synchronizing time and analyzing the kinematic data. The peak angles of hip internal rotation and knee valgus during squat performance were averaged over three trials.

The activities of the VMO and VL muscles of the dominant lower extremity (preferred leg for kicking a ball)<sup>11</sup>) were measured using a wireless electromyography (EMG) system (Delsys, Inc., 650 Beacon St., Boston, MA 02215, USA) with surface electrodes fixed at an inter-electrode distance of 10 mm. The EMG signals were rectified and low-pass filtered using a zero-lag Butterworth filter with a cutoff frequency of 10 Hz. The electrode placements for the two muscles were as follows: VL, 3-5 cm above the patella at an oblique angle just lateral to the midline; VMO, an oblique angle 2 cm medial to the superior rim of the patella. The electrodes were aligned parallel to the respective muscle fibers. The skin impedance to the electric signal was reduced by shaving body hair and cleansing the skin with 70% isopropyl alcohol prior to placing the electrodes<sup>22</sup>). The sampling rate of 1,000 Hz was synchronized with kinematic data, and the root mean square (RMS) values of the raw data were calculated. For normalization, maximal EMG signals were acquired during a maximal voluntary isometric contraction (MVIC) maneuver, which was performed for 5 s in the manual muscle-testing position described by Kendall et al.<sup>23</sup>). The EMG data for squatting were collected for 4 s while 70° knee flexion.

Prior to performing the squats, the MVIC maneuver was performed with electrodes attached to the investigated muscle. Then, the 16 reflective markers for the kinematic data were placed on the reference sites. The primary

**Table 2.** The peak angle of hip internal rotation and knee adduction (n=17)

Parameters	Mean $\pm$ SD	
	Without feedback	With feedback
Hip internal rotation angle	19.39 $\pm$ 10.59*	12.1 $\pm$ 11.82
Knee valgus angle	16.95 $\pm$ 11.54*	9.59 $\pm$ 10.48

\*p&lt;0.05.

**Table 3.** The EMG activity ratio of the vastus medial oblique and vastus lateralis (n=17)

Parameters	Mean $\pm$ SD	
	Without feedback	With feedback
VMO/VL ratio	0.92 $\pm$ 0.39*	1.04 $\pm$ 0.44

\*p&lt;0.05, EMG: electromyogram, VMO: vastus medialis oblique, VL: vastus lateralis.

investigator described the two experimental conditions (with and without visual biofeedback) and taught the squat method to all subjects. Each subject was instructed to stand with hips and knees fully extended using a neutral foot position with the feet shoulder-width apart, toes pointing forward, and hands crossed over the chest. Both wrists were loaded with sandbags weighting 10% of the subject's body mass to maintain postural stability while minimizing trunk compensation<sup>24</sup>). Subjects were asked to squat from the starting position until a bell sounded; the bell was set by the Nexus program to ring when the knee flexion angle was 70° (half squat). After the 70° knee flexion was maintained for 4 s, subjects rose to the starting position. The time was controlled by a metronome set at 1 beat/s. Kinematic data and EMG activities were recorded simultaneously during the isometric squat exercise.

Subjects were trained to squat with visual biofeedback using a laser beam. A strap with a laser attached for visual biofeedback was worn on the subject's dominant leg. Subjects performed squatting while attempting to control the red ray from the laser-beam projector so that it moved along the vertical line drawn on the board. The pre-training provided enough time for the subjects to become familiar with the proper position of the lower extremity. When the primary investigator judged that each subject was sufficiently well trained in controlling the red ray from the laser-beam projector so that it moved vertically along the line on the board five times continuously during squat performance, the testing began. The two tasks (squats with and without feedback) were administered in a randomized order to minimize any learning effect.

The peak angles of hip internal rotation and knee valgus and the VMO/VL muscle activity ratio with and without visual biofeedback were analyzed using SPSS software (Chicago, IL, USA). The significance between the two conditions was tested using the paired t-tests, with significance chosen as p<0.05.

## RESULTS

The hip internal rotation angle (p=0.000) and knee valgus angle (p=0.000) were significantly lower during performance of double-leg squats with visual biofeedback than in the same exercise without biofeedback. The peak angles of hip internal rotation during squat performance with and without visual biofeedback were 12.10  $\pm$  11.82° and 19.39  $\pm$  10.59°, respectively, and the peak angles of knee valgus were 9.59  $\pm$  10.48° and 16.95  $\pm$  11.54°, respectively (Table 2).

The VMO/VL muscle activity ratio was significantly higher (p=0.011) during the performance of squats with visual biofeedback than in squats without biofeedback. The VMO/VL ratios during the performance of squats with and without visual biofeedback were 1.04  $\pm$  0.44 and 0.92  $\pm$  0.39, respectively (Table 3).

## DISCUSSION

A squat exercise is commonly performed to strengthening the lower extremity muscles, and it is theorized that dynamic knee valgus motion is one of the risk factors of knee injury during weight-bearing exercises. Thus, recent research has focused on neutral knee alignment during various weight-bearing tasks<sup>8,10,25</sup>). The purpose of this study was to examine the effects of visual biofeedback using a laser beam during the performance of squats by subjects with femoral anteversion.

A neutral limb alignment is important to activate muscles and to load the joints correctly<sup>2)</sup>. Sharma et al.<sup>26)</sup> and Tanamas et al.<sup>27)</sup> emphasized that knee alignment plays a significant role in the progression of osteoarthritis (OA). Medial OA is increased by knee varus, and lateral OA is increased by knee valgus; furthermore, the cumulative effects of malalignment may limit physical function. Weakness of the hip abductors and external rotators that help to maintain pelvic stability during weight-bearing, may

lead to increased medial femoral rotation and knee valgus moments<sup>28)</sup>. We hypothesized that activities of the hip abductor and external rotator muscles would be facilitated by encouraging subjects to control a laser beam so that cause it moved along a vertical line, since it should result in decreased angles of hip internal rotation and knee valgus. This hypothesis is supported by the findings of a study by Davis<sup>29)</sup>, who demonstrated the effectiveness of video feedback in reduction of hip internal rotation showing that the activities of hip abductors and external rotators were increased in runners with PFPS.

Altered body postures or structures such as excessive femoral anteversion, foot pronation, Q-angle, and tibial torsion have been shown to be associated with PFPS, although some studies have produced findings that challenge the relationship between PFPS and femoral anteversion<sup>30,31)</sup>. Femoral anteversion directly influences patella tracking, which may induce increased pressure at the point of patellofemoral contact, resulting in joint degeneration during repetitive daily activities<sup>32)</sup>. The quadriceps, especially the vastus medialis, provide dynamic patellofemoral joint stabilization<sup>33)</sup>. When the vastus medialis and gluteus medius act as synergists, the patella is stabilized within the femoral trochlea, and the femoral internal rotation-adduction associated with the loading response is decreased during the weight-acceptance stage of the gait cycle<sup>21)</sup>. Thus, imbalanced activation between the VMO and VL due to a weakened VMO may lead to instability in the patellofemoral joint and lateral tracking of the patella<sup>34)</sup>. Previous research has shown that VMO and VL muscle activities increase during isometric exercises in a neutral position and with the hip externally rotated, and hip medial rotation decreases VM activity<sup>35,36)</sup>. In the present study, the application of visual biofeedback significantly increased the VMO/VL muscle activity ratio. Maintaining a position that moves a beam that is fixed on the mid-patella tendon along a vertical line during the performance of squats requires reduced hip internal rotation, and this may increase VMO activity.

The visual, somatosensory, and vestibular sensory systems play a major functional role in controlling posture and balance, and a variety of sensor types have been used to provide sensory information to the brain for postural control<sup>37)</sup>. Visual feedback has been implicated as an influence on the amplitude of force variability and can increase force variability during isometric contraction<sup>38)</sup>. All participants in this study were trained to adjust their motion so that the laser beam moved vertically during the performance of squats. Training with a target pattern to increase motor skill performance is a useful motor learning tool, and a lower-limb task using such a pattern has been shown to improve correct movement as reflected in reductions in tracking errors<sup>39)</sup>. Repetitive training that detects errors and corrects the abnormal movement immediately by visual feedback increases the learning effect<sup>40)</sup>. Madhavan and Shields<sup>20)</sup> reported that training with visual feedback during performance of a single-leg squat improved movement accuracy, and altered strategies of muscle activation. Our major findings indicate that

adding visual biofeedback using a laser beam while performing a double-leg squat is an effective strategy for facilitating VMO muscle activation and reducing the angles of hip internal rotation and knee valgus. This strategy may be useful for various weight-bearing exercises for knee rehabilitation.

Our data cannot be generalized because all subjects in this study were young, and most of them were females. Muscle activities of the gluteus medius and the pelvic deltoid, including the tensor fascia lata, gluteus maximus, and iliotibial tract, were not investigated. Further studies are needed to assess not only the muscle activity of the hip and ankles muscles, but also the kinetic data of the lower extremity joints.

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