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The Effects of Visual Biofeedback Information on Hyperextended Knee Control

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Purpose: A hyperextended knee is described as knee pain associated with an impaired knee extensor mechanism. Additionally, a hyperextended knee may involve reduced position sense of the knee joint that decreases the individual's ability to control end-range knee extension movement. The purpose of this study was to investigate the effects of visual biofeedback information for plantar pressure distribution on knee joint angle and lower extremity muscle activities in participants with hyperextended knees.
Methods: Twenty-three participants with hyperextended knees were recruited for the study. Surface electromyography signals were recorded for the biceps femoris, rectus femoris, gastrocnemius, and tibialis anterior muscle activities. The plantar pressure distribution was displayed and measured using a pressure distribution measuring plate. Knee joint angle kinematic parameters were recorded using a motion analysis system. The visual biofeedback condition was the point at which the difference between the forefoot and backfoot plantar foot pressure on the monitor was minimized. The Wilcoxon signed-rank test was used to determine the significance between the visual biofeedback condition and the preferred condition.
Results: The knee joint angle was significantly decreased in the visual biofeedback condition compared to that in the preferred condition ($p < 0.05$). The rectus femoris and gastrocnemius muscle activities were significantly different between the visual biofeedback and preferred conditions ($p < 0.05$).
Conclusion: The results of this study showed that visual biofeedback of information about plantar pressure distribution is effective for correcting hyperextended knees.

Keywords: Biofeedback, Gastrocnemius, Knee, Quadriceps Muscle

INTRODUCTION

Alignment of the entire lower extremity, including the hip, knee, ankle, and foot, should be considered when assessing an individual with knee pain.[1] In the sagittal plane, the femur and tibia should be aligned vertically, with a knee joint angle of approximately 180 degrees. In ideal alignment, the angle of the hip joint should be 180 degrees (measured by a line dividing the pelvis into two and a line bisecting the femur), and the ankle should be in a neutral position (with zero degrees of dorsiflexion in relaxed standing).[2]

Hyperextended knee, or genu recurvatum, describes malalignment or deformity of the knee joint with extension beyond neutral (knee extension greater than 5 degrees) and ankle plantarflexion.[3] Knee hyperextension affects the knee joint structure; it includes tibial bowing in the frontal and sagittal plane, altered compressive forces at the tibiofemoral and patellofemoral joints, posterior capsule stretching and ligament laxity, and muscle imbalance (quadriceps weakness/hamstring over-recruitment).[4] Additionally, the hyperextended knee may have reduced position sense of the knee joint, which reduces the individual's ability to control end-range knee extension movement.[5,6] An increase in knee hyperextension may lead to knee pain and knee osteoarthritis.[1]

Clinicians have reported not only inappropriate loading or weight bearing of the knee joint, but also of the ankle joint and foot by the plantarflexed foot in patients with hyperextended knees.[4] This problem is a

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main mechanical contributor to the development and progression of bone shape alterations and alignments.[2] Therefore, a hyperextended knee has the potential to develop into a chronic deteriorating problem, and adequate management and multifocused rehabilitation is essential.[7]

Treatment for knee hyperextension includes pharmacological therapy (drugs, cold spray, and transdermal patch), kinesio-taping (X-shape motion limitation or unloading taping technique), assistive devices (orthoses), surgical treatment, and therapeutic exercises (muscle imbalance correction, proprioceptive practice, gait, and functional training).[4,8-11] Previous studies have reported that conservative interventions, such as pharmacological therapy, taping, or knee bracing, may be used initially to facilitate knee control. However, there are issues associated with each treatment, including difficulty of use and side effects (e.g., skin problems, abuse).[4,12,13]

Therefore, safe and effective intervention is needed for individuals with hyperextended knees. An evaluative process and treatment program should consider muscle imbalance correction, proprioceptive practice, gait, and functional training for awareness of knee position during activities to help protect joint structures.[14,15] These interventions stimulate the sensory-motor system toward regaining normal alignment and functional use. An exercise program and the use of real-time biofeedback of information about weight bearing may be helpful for treating individuals with hyperextended knees. The purpose of this study was to investigate the effects of real-time biofeedback about foot weight-bearing distribution on the knee joint angle and lower limb muscle activities in individuals with hyperextended knees.

METHODS

1. Subjects

Potential participants with hyperextended knees (genu recurvatum) were examined and recruited according to the inclusion criteria. A total of 8 male and 15 female volunteers with hyperextended knees were recruited (mean age: 23.4 ± 1.6 years, height: 167.5 ± 8.3 cm, weight: 63.4 ± 14.1 kg). Participants were included if they had no previous history of knee, ankle, or hip surgery. The following screening criteria, based on previous literature, were used for participant selection: 1) knee hyperextension in the long-sitting position (more than 5 degrees), and 2) knee hyperextension beyond 10 degrees in the standing position. Informed consent was obtained from all participants.

2. Measuremets

1) Pressure distribution measuring plate

The Zebris FDM-S (Zebris Medical GmbH, Germany) was used to measure the distribution of plantar foot pressure. The system uses a pressure distribution measuring plate with 2,560 sensors, and the pressure is recorded by each sensor. The signal processing board sends the measured foot pressure signal to a computer program and acquires data at a 100 Hz sampling frequency. Figure 1 shows the measurement system. The distribution of plantar foot pressure was measured to determine the pressure difference between the forefoot and backfoot. In the biofeedback task, the notebook screen indicated the pressure difference in real time between the

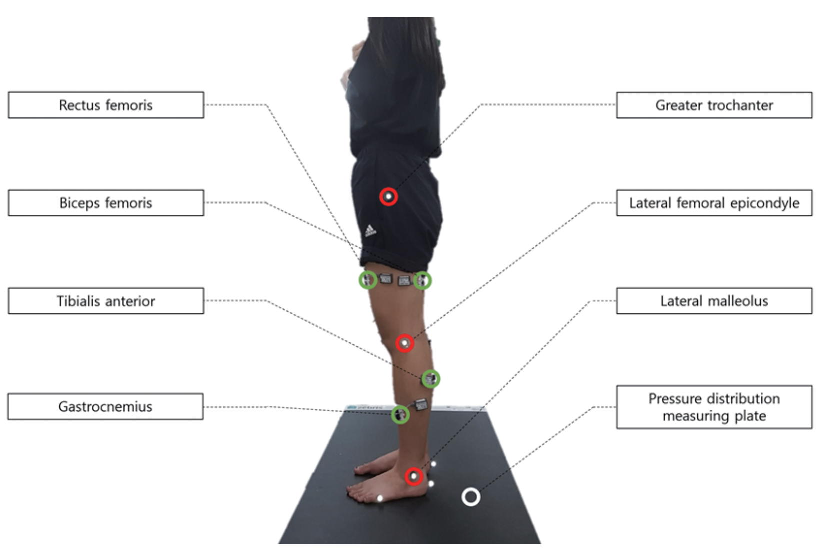

Figure 1. Measurement of the muscle activities and knee joint angle in the visual biofeedback condition.

forefoot and the backfoot, and the participant attempted to keep the plantar foot pressure difference between the forefoot and the backfoot to a minimum.

2) Camera

Each participant's knee joint angle was recorded using a Samsung Galaxy S6 mobile phone (Samsung Electronics, Korea). A height-adjustable tripod was adjusted to the height of the knee, and then the camera was adjusted to the level of the knee using the height-adjustable tripod. The camera was placed 1 m in front of the participant's foot, as measured with a tape measure. Three reflective surface markers (1.5 cm diameter) were attached at the greater trochanter, lateral femoral epicondyle, and lateral malleolus of the dominant-side leg to calculate the knee joint angle.[16] After attaching the surface markers, the examiners took the photograph and recorded the knee joint angle in the preferred and visual biofeedback conditions. The angle of the knee joint was calculated between two lines (greater trochanter~lateral femoral epicondyle and lateral femoral epicondyle~lateral malleolus) using ImageJ software (U.S. National Institutes of Health, Maryland, USA). The angle between the two lines was calculated automatically using ImageJ software. In a previous study, determination of knee joint angle in the sagittal plane using digital photography demonstrated good levels of intra- and inter-rater reliability.[16]

3) Electromyography

A surface electromyography (EMG) system (TeleMyo DTS, Noraxon, Scottsdale, AZ, USA) was used to measure the activity of the biceps femoris (BF), rectus femoris (RF), gastrocnemius (GCM), and tibialis anterior (TA). Data were analyzed using MyoResearch® XP Master Edition software (Noraxon Inc.). Filtered movement artifacts were eliminated using a digital band-pass filter (Lancosh FIR) in 20-450 Hz. The sample rate was set to 1,000 Hz. The root mean square was used to process EMG signals with a moving window of 50 ms. EMG signals were recorded for 5 seconds (2-4 seconds used for data analysis).

Two surface electrodes with a distance of 2 cm were positioned on the BF, RF, GCM, and TA. Two electrodes were placed in the middle of each muscle belly, parallel to the muscle fibers. The electrode sites were shaved, and rubbing alcohol was used to reduce skin impedance. To measure each muscle's EMG signal, electrodes were placed according to Criswell.[17] The reference voluntary isometric contraction (RVIC) of the RF, BF, TA, and GCM was used for normalization; the RVIC was measured when participants were in a comfortable standing position.18 The data for each trial were expressed as a percentage of the calculated mean root mean square (RMS) of the RVIC (%RVIC). During the EMG data collection process, two EMG data sets of the TA and GCM were lost.

3. Procedure

Each participant stood comfortably on the Zebris FDM-S. The participants performed two tasks in this posture. Before performing the tasks, the participants were educated and familiarized with the two tasks to be carried out for 5 minutes. The first task was to adopt the preferred condition—that is, to stand comfortably without muscle effort. At this time, the changes in the hyperextended knee, EMG signal, and plantar pressure

Figure 2. The visual biofeedback condition.

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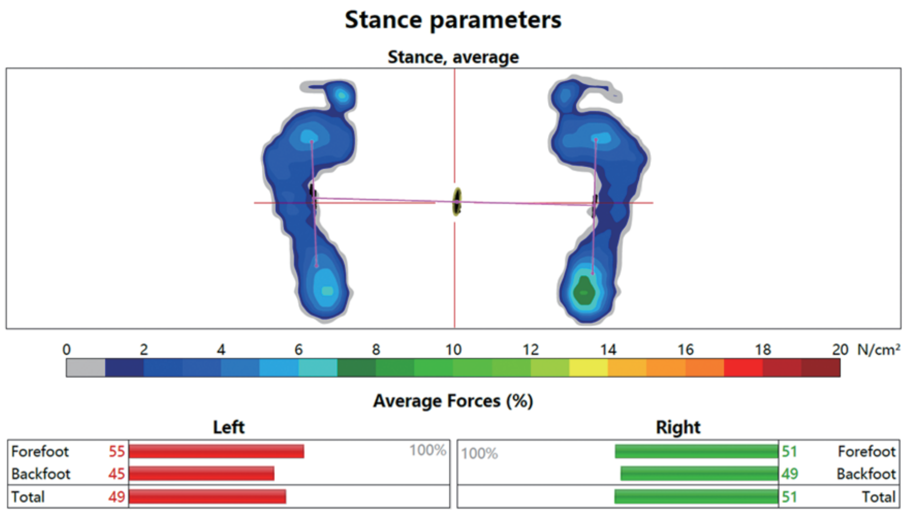

Figure 3. Display for plantar foot pressure on the notebook screen during the visual biofeedback condition.

Table 1. Comparison of knee joint angle and EMG signal with and without the visual-biofeedback condition

	Preferred condition	Visual biofeedback condition	t	p
Knee joint angle (º)	168.4±2.3	175.4±4.4	-9.563	<0.001*
Rectus femoris (%)	2.55±3.03	1.22±0.89	2.836	0.008*
Biceps femoris (%)	1.19±0.65	1.32±0.55	-0.927	0.361
Tibialis anterior (%)	2.68±3.59	1.60±1.84	2.299	0.029*
Gastrocnemius (%)	1.01±0.55	2.28±1.53	-4.308	<0.001*

were measured. The second task was to adopt the visual biofeedback condition. During this condition, the participants simultaneously viewed their plantar foot pressure on the notebook screen along with the video (Figure 2). If a difference was observed between the forefoot and backfoot pressure of the participant during standing, the participant was instructed to minimize the difference (approximately 50% of the ratio between the forefoot and backfoot) to provide biofeedback (Figure 3). The changes in the EMG signal and hyperextended knee angle were measured when there was little pressure difference between the forefoot and backfoot after biofeedback was provided about the plantar pressure distribution. The two tasks were assigned randomly through lot drawing, and the time between the two tasks was 10 minutes.

4. Statistical analysis

A paired t-test was used to determine the significance between the visual biofeedback and preferred conditions. The level of significance was set at $\alpha < 0.05$. All statistical analyses were performed with SPSS ver. 18 (IBM Corp., Armonk, NY, USA).

RESULTS

Of the 46 legs of the 23 participants, 30 that met the inclusion criteria were included in this study. The paired t-test results for the visual biofeedback and preferred conditions are shown in Table 1. The knee joint angle significantly increased in the visual biofeedback condition compared to the preferred condition ($p < 0.05$). RF, TA, and GCM muscle activities were significantly different between the visual biofeedback and preferred conditions ($p < 0.05$).

DISCUSSION

We compared the effects of visual biofeedback for foot weight-bearing distribution on the knee joint angle and lower limb muscle activities in participants with hyperextended knees. Knee joint angle significantly increased in the visual biofeedback condition compared to the preferred condition ($p < 0.05$). RF and GCM muscle activities were significantly different between the visual biofeedback and preferred conditions ($p < 0.05$).

The results of this study prove our hypothesis. Knee joint proprioception is essential to neuromotor control for the knee joint,14 and somatosensory input from weight bearing helps to increase the accuracy of knee joint positioning.[4,19] Thus, maintaining optimal knee joint alignment was difficult for participants with hyperextended knees. Maintaining optimal knee joint alignment involves the integration of sensory information from multiple sources, including the visual, somatosensory, and vestibular systems.[20] One way to improve postural control is to give the individual supplementary sensory information regarding their body's displacements and orientations, such as visual sensory cues.[21] Providing visual biofeedback for foot weight-bearing distribution can alter muscle activities and abnormal joint position in participants with hyperextended knees.[22] Real-time biofeedback of information for foot weight-bearing distribution can help participants learn how to control the knee joint during standing. It provides real-time feedback on changes in plantar forces between the forefoot and backfoot. The participants were asked to keep the plantar foot pressure difference to a minimum between the forefoot and the backfoot, which induced tibia anterior progression. Thus, knee joint alignment was close to the vertical axis compared to the preferred condition.

Plantar force information about the foot's weight-bearing sites (forefoot versus backfoot) is known to play a crucial role in the regulation of knee joint alignment.[23,24] Therefore, biofeedback intervention provides individuals with additional information about their body function with the purpose of developing changes in behavior that lead to better and enhanced performance.[25] At this point, we believe that designing and developing a biofeedback system for correcting knee hyperextension (e.g., plantar force information provided by plantar soles) would be beneficial for rehabilitating knee hyperextension.

Visual feedback intervention not only improved knee joint alignment, but also decreased RF activity and increased GCM activity. To maintain ideal knee joint alignment, co-contraction of the knee muscles is essential.[26] Therefore, visual feedback intervention may have balanced the BF by lowering the activity of the RF. Also, the GCM is a flexor of the knee joint.[27] When an individual with a hyperextended knee performs knee flexion to align the forefoot and backfoot through visual feedback, the activity of the GCM may increase.

This study had several limitations. First, it was cross-sectional, so longitudinal follow-up is warranted to determine the long-term effects of biofeedback training for participants with hyperextended knees. Further studies should investigate the long-term effects of biofeedback training for foot weight-bearing distribution on the hyperextended knee. The second limitation of this study is that the knee joint angle and muscle activities were measured in the static condition. Further studies are needed to determine the effects of biofeedback on hyperextended knee measures during dynamic conditions.

The results of this study showed that the visual biofeedback of information about plantar pressure distribution is effective for correction of knee hyperextension. Therefore, we believe that developing a real-time biofeedback system that provides information from the plantar sole would improve hyperextended knee outcomes. In the rehabilitation process for a hyperextended knee, the individual with the hyperextended knee should be an active learner and practice until the skill of controlling the optimal knee position is mastered.

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REFERENCES

1. Sharma L, Song J, Felson DT et al. The role of knee alignment in disease progression and functional decline in knee osteoarthritis. JAMA. 2001; 286(2):188-95.
2. Peterson-Kendall F, Kendall-McCreary E, Geise-Provance P et al. Muscles testing and function with posture and pain. US, Lippincott Williams & Wilkins Ltd, 2005:49-118.
3. Kerrigan DC, Deming LC, Holden MK. Knee recurvatum in gait: a study of associated knee biomechanics. Arch Phys Med Rehabil. 1996;77 (7):645-50.
4. Sahrmann S. Diagnosis and treatment of movement impairment syndromes. Missouri, Mosby. 2002:42-4.
5. Hall M, Ferrell W, Sturrock R et al. The effect of the hypermobility syndrome on knee joint proprioception. Rheumatology. 1995;34(2):121-5.
6. Sahin N, Baskent A, Cakmak A et al. Evaluation of knee proprioception and effects of proprioception exercise in patients with benign joint hypermobility syndrome. Rheumatol Int. 2008;28(10):995-1000.
7. Fish DJ, Kosta CS. Genu recurvatum: identification of three distinct mechanical profiles. J Prosthet Orthot. 1998;10(2):26-32.
8. Isakov E, Mizrahi J, Onna I et al. The control of genu recurvatum by combining the swedish knee-cage and an ankle—foot brace. Disabil Rehabil. 1992;14(4):187-91.
9. Comerford M, Mottram S. Kinetic control-e-book: The management of uncontrolled movement. Chatswood, Elsevier Health Sciences, 2012:3-5.
10. Klotz MC, Wolf SI, Heitzmann D et al. The influence of botulinum toxin a injections into the calf muscles on genu recurvatum in children with cerebral palsy. Clin Orthop Relat Res. 2013;471(7):2327-32.
11. Larson CM, Bedi A, Dietrich ME et al. Generalized hypermobility, knee hyperextension, and outcomes after anterior cruciate ligament recon-

https://doi.org/10.18857/jkpt.2021.33.3.162

struction: prospective, case-control study with mean 6 years follow-up. Arthroscopy. 2017;33(10):1852-8.
12. Wu WT, Hong CZ, Chou LW. The kinesio taping method for myofascial pain control. Evid-Based Compl Alt. 2015;2015:950519.
13. Martin ST, Kessler M. Neurologic interventions for physical therapy-e-book. Elsevier Health Sciences, 2020:250.
14. Loudon JK, Goist HL, Loudon KL. Genu recurvatum syndrome. J Orthop Sports Phys Ther. 1998;27(5):361-7.
15. Rubinstein JR RA, Shelbourne KD, VanMeter CD et al. Effect on knee stability if full hyperextension is restored immediately after autogenous bone-patellar tendon-bone anterior cruciate ligament reconstruction. Am J Sports Med. 1995;23(3):365-8.
16. Nguyen AD, Boling MC, Slye CA et al. Various methods for assessing static lower extremity alignment: implications for prospective risk-factor screenings. J Athl Train. 2013;48(2):248-57.
17. Criswell E. Cram's introduction to surface electromyography. London, Jones & Bartlett Publishers, 2010:363-74.
18. Lee DK, Kim JS, Kim TH et al. Comparison of the electromyographic activity of the tibialis anterior and gastrocnemius in stroke patients and healthy subjects during squat exercise. J Phys Ther Sci. 2015;27(1):247-9.
19. Chae YW, Park JW, Park S. Effects of knee malalignment on static and dynamic postural stability. J Kor Phys Ther. 2015;27(1):7-11.
20. Massion J, Alexandrov A, Frolov A. Why and how are posture and movement coordinated?. Prog Brain Res. 2004;143:13-27.
21. Wiesmeier IK, Dalin D, Maurer C. Elderly use proprioception rather than visual and vestibular cues for postural motor control. Fron Aging Neurosci. 2015;7:97.
22. Vuillerme N, Chenu O, Demongeot J et al. Controlling posture using a plantar pressure-based, tongue-placed tactile biofeedback system. Exp Brain Res. 2007;179(3):409-14.
23. Kavounoudias A, Roll R, Roll JP. The plantar sole is a 'dynamometric map'for human balance control. Neuroreport. 1998;9(14):3247-52.
24. Meyer PF, Oddsson LI, De Luca CJ. The role of plantar cutaneous sensation in unperturbed stance. Exp Brain Res. 2004;156(4):505-12.
25. Lally F, Crome P. Understanding frailty. Postgrad Med J. 2007;83(975):16-20.
26. Heiden TL, Lloyd DG, Ackland TR. Knee joint kinematics, kinetics and muscle co-contraction in knee osteoarthritis patient gait. Clin Biomech. 2009;24(10):833-41.
27. Muscolino JE. Know the body: muscle, bone, and palpation essentials-e-book. Elsevier Health Sciences, 2013:404-7.