Note. This article will be published in a forthcoming issue of the Journal of Applied Biomechanics. The article appears here in its accepted, peer-reviewed form, as it was provided by the submitting author. It has not been copyedited, proofread, or formatted by the publisher.

Section: Original Research

Article Title: A Kinetic and Kinematic Analysis of the Effect of Stochastic Resonance Electrical Stimulation and Knee Sleeve During Gait in Osteoarthritis of the Knee

Authors: Amber Collins², Troy Blackburn¹,³,⁴, Chris Olcott¹, Joanne M. Jordan¹,⁵, Bing Yu²,⁴, Paul Weinhold¹,²

Affiliations: ¹Department of Orthopaedics, University of North Carolina, Chapel Hill, NC. ²Department of Biomedical Engineering, University of North Carolina, Chapel Hill, NC. ³Department of Exercise and Sport Science, University of North Carolina, Chapel Hill, NC. ⁴Division of Physical Therapy, University of North Carolina, Chapel Hill, NC. ⁵Thurston Arthritis Research Center, University of North Carolina, Chapel Hill, NC.

Journal: Journal of Applied Biomechanics

Acceptance Date: June 21, 2013

©2013 Human Kinetics, Inc.
A kinetic and kinematic analysis of the effect of stochastic resonance electrical stimulation and knee sleeve during gait in osteoarthritis of the knee

Amber Collins\textsuperscript{2}, Troy Blackburn\textsuperscript{1,3,4}, Chris Olcott\textsuperscript{1}, Joanne M. Jordan\textsuperscript{1,5}, Bing Yu\textsuperscript{2,4}, Paul Weinhold\textsuperscript{1,2}

\textsuperscript{1}Department of Orthopaedics, University of North Carolina, Chapel Hill, NC, USA; \textsuperscript{2}Department of Biomedical Engineering, University of North Carolina, Chapel Hill, NC, USA; \textsuperscript{3}Department of Exercise and Sport Science, University of North Carolina, Chapel Hill, NC, USA; \textsuperscript{4}Division of Physical Therapy, University of North Carolina, Chapel Hill, NC, USA; \textsuperscript{5}Thurston Arthritis Research Center, University of North Carolina, Chapel Hill, NC, USA

\textbf{Funding:} This work was supported by the Arthritis Foundation

\textbf{Conflict of Interest Disclosure:} The authors have no conflicts of interest

\textbf{Correspondence Address:} Dr. Amber Collins  
120 Research Park IV  
Duke University Medical Center  
Durham, NC  27710  
919-681-3345  
Fax: 919-668-3422  
Email: amber.collins@dm.duke.edu
Abstract

Extended use of knee sleeves in populations at risk of knee osteoarthritis progression has shown functional and quality of life benefits; however, additional comprehensive kinematic and kinetic analyses are needed to determine possible physical mechanisms of these benefits which may be due to the sleeve’s ability to enhance knee proprioception. A novel means of extending these enhancements may be through stochastic resonance stimulation. Our goal was to determine whether the use of a knee sleeve alone or combined with stochastic resonance electrical stimulation improves knee mechanics in knee osteoarthritis. Gait kinetics and kinematics were assessed in subjects with medial knee osteoarthritis when presented with four conditions: control1, no electrical stimulation/sleeve, 75% threshold stimulation/sleeve, and control2. An increase in knee flexion angle throughout stance and a decrease in flexion moment occurring immediately after initial contact were seen in the stimulation/sleeve and sleeve alone conditions; however, these treatment conditions did not affect the knee adduction angle and internal knee abduction moment during weight acceptance. No differences were found between the sleeve alone and the stochastic resonance with sleeve conditions. A knee sleeve can improve sagittal-plane knee kinematics and kinetics, though adding the current configuration of stochastic resonance did not enhance these effects.

Keywords: biomechanics, joint, brace, knee, stimulation

Word Count: 3,582
Introduction

Osteoarthritis (OA) is the most prevalent form of arthritis in the United States with knee OA being one of the five leading causes of physical disability in the elderly\(^1\). Previous studies have reported that those with knee OA walk with greater impulsive loads, reduced knee flexion\(^2,3\), and greater external knee adduction moments\(^4\) during stance compared to control subjects. Hurwitz et al. found that radiographic measures of medial knee OA severity were predictive of peak knee adduction moments\(^5\). An increased adduction moment places higher compressive loads on the medial compartment of the knee\(^6,7\) and increased dynamic loads experienced on the medial side of the knee may contribute to the development or progression of medial knee OA. In fact, those with a varus deformity at the knee joint are at a fourfold increased risk of disease progression\(^8,9\).

Many studies have focused on the reduction of medial knee loads as a way to ameliorate pain and improve functionality. Specifically, medial unloading braces have been investigated as a way to reduce medial knee joint load by producing an external abduction/valgus moment via a three point bending system\(^10-13\). Interestingly, medial unloader braces that have been applied in a neutral alignment configuration (i.e. no valgus loading) have also shown an ability to reduce knee adduction excursion during walking, suggesting that aspects other than the valgus moment produced by the brace may contribute to reductions in knee adduction\(^10\). In addition to medial unloading braces, knee sleeves have been investigated for their potential benefits but with greater attention to balance and proprioceptive improvements\(^14-17\). However, little investigation into these effects in a population with knee OA has been performed.

While many studies have focused on the mechanical aspects of abnormal joint loading, few have addressed potential neuromuscular contributions\(^18\). One important concept to
understand is the role of abnormal proprioception in the initiation and development of knee OA. One theory is that proprioceptive deficits may have contributed to and/or resulted from knee OA\textsuperscript{19,20}. Specifically, Sharma et al. postulates that the afferent components of the neuromuscular reflex pathway are disrupted in those with knee OA, which results in harmful loading of the joint\textsuperscript{20}. Proprioceptive deficits are present in those with knee OA\textsuperscript{19,21-23} and in those with acute knee injuries\textsuperscript{24,25} which may increase their risk of developing knee OA. Deficits in proprioception may contribute to poor positioning of the lower extremity during dynamic activities. We speculate that poor proprioception may be associated with alterations in gait, such as greater knee adduction during the stance phase of gait. Dynamic knee adduction alignment is correlated with OA disease severity and the external adduction moment\textsuperscript{26}. Additionally, proprioception has been shown to relate to with knee flexion at initial contact\textsuperscript{27,28} and the rate of loading during gait\textsuperscript{28} and correcting these proprioceptive deficits may allow for more appropriate mechanics during dynamic tasks. Improving on proprioceptive impairments may lead to better spatial and temporal coordination of limb position, resulting in a more normal load distribution within the joint. Knee braces and sleeves have been shown to enhance proprioception\textsuperscript{29,30}, and extended use of sleeves in populations at risk of OA progression has resulted in functional and quality of life benefits\textsuperscript{13}. Additionally, Ramsey et al. showed that knee adduction excursion can be reduced with a neutral alignment brace\textsuperscript{10}. The proprioception enhancing benefits of a sleeve may be further enhanced through stochastic resonance (SR), a phenomenon in which the sensitivity of a given system to weak stimuli is improved through the introduction of low-level noise. In other words, SR stimulation in the form of random subsensory electrical noise causes sub-threshold sensorimotor signals to exceed threshold, allowing weak sensorimotor signals related to joint motion to become detectable\textsuperscript{31}. Subsensory SR stimulation has been
demonstrated to improve tactile sensation\textsuperscript{32}, muscle spindle output\textsuperscript{31}, postural control\textsuperscript{33,34}, and joint position sense\textsuperscript{34}. SR stimulation has also recently been demonstrated to improve joint position sense when combined with a neoprene knee sleeve in those with knee OA\textsuperscript{29}. By enhancing mechanoreceptor sensitivity through SR stimulation, it may be possible to improve the abnormal mechanics of gait and thus delay the progression of pain and functional deficits of OA.

The goal of this study was to determine if SR electrical stimulation combined with a neoprene knee sleeve would affect knee kinematics and kinetics in the sagittal and frontal planes during gait. We hypothesized that the knee adduction angle and resulting internal knee abduction moment would be reduced with the application of SR stimulation and sleeve in comparison to the control condition. Also, we hypothesized that knee flexion angle and the resulting internal knee extension moment would increase in the stimulation/sleeve condition compared to the control condition.

\textbf{Methods}

\textbf{Subjects}

Prior to testing, all subjects read and signed an informed consent document which was approved by the university’s biomedical institutional review board. A pre-power analysis was performed and determined that an N of 35 subjects could detect a 25% difference between groups for a power of 0.8, alpha of 0.05, and standard deviation of 50% of the control mean. As a result, 35 individuals (19 females, 16 males) with minimal to moderate (KL grade 1 to 3) medial knee OA were recruited from the university’s orthopaedic clinic (Table 1). Only those subjects 40 years or older with a BMI of 35 or less, no history of neurological or musculoskeletal disorders other than their knee OA, no implanted electronic devices, no lower limb joint
replacement, and no previous steroid injections within three months prior to screening were included for participation. Subjects with an orthopaedic physician’s diagnosis of knee OA were screened using standing radiographs of the knee in full extension.

Radiographs were assessed using a modified Kellgren and Lawrence grading scale. The medial and lateral compartments of the joint were both assessed to ensure greater narrowing in the medial side. During testing, the subject’s more severely affected knee was chosen for testing, but in instances where both knees were equally affected the subject’s dominant knee was tested.

Data were successfully collected from thirty-five patients (19 females, 16 males) with minimal to moderate, medial knee OA. Subject’s age, weight (kg), height (cm), BMI as well as measures of knee instability, pain, functionality, and stiffness (Western Ontario Macmaster-WOMAC and Self-Reported Instability) are also reported (Table 1).

**Study Design**

Initially, each subject’s threshold for detection of the SR stimulation was determined by applying the SR stimulation and incrementally increasing the amplitude until subjects indicated they detected the stimulation. The strength of treatment stimulation was set as 75% of the threshold for detection of the SR stimulation. The SR stimulation amplitude of 75% of detection threshold was chosen to be in line with previous studies that have demonstrated improvements in postural control with SR. Priplata et al. identified 75% of detection threshold to be the optimal level for improving postural control. Additionally, our previous study found no improvements in joint position sense while using an SR level of 60% of subject’s detection thresholds; therefore, a higher amplitude was chosen for the present study. Subjects were exposed to four testing conditions which occurred in the following sequence: control condition 1 without
simulation and without sleeve, counterbalance of treatment conditions: no stimulation/no sleeve and stimulation/sleeve, and control condition 2 without stimulation and without sleeve. The two control conditions were placed before and after the treatment conditions in order to test for the effect of fatigue or a learning effect of the testing conditions. The two treatment conditions were presented in a counterbalanced order to control for potential fatigue effects or lingering effects of the stimulation. For each testing condition, subjects were instructed to walk at their own self-selected, “fast” speed down a level walkway, ensuring the foot of their test limb landed appropriately on the force platform (model 4060nc, Bertec Corp., Columbus, OH, USA). Subjects were asked to walk at a fast, comfortable speed as previous studies have shown that fast walking results in a more reliable evaluation of some gait variables in subjects with knee OA\(^40\). To ensure less than a 10% change in walking speed between trials, an infrared timing system was used (Sparq XLR8 Digital Timing System, Nike).

In applying the SR stimulation, two pairs of electrodes were placed over the inferior and superior aspects of the knee joint, approximately 2 cm above and below the joint line. Each pair of electrodes delivered an alternating flow of current in the medial-lateral direction via an electrical stimulator (Afferent Corporation, Providence, RI, USA). Stimulation consisted of a Gaussian white noise signal (zero mean, 0-1000Hz bandwidth) at an amplitude of 75% of the subject’s detection threshold. Subjects were blinded as to when the SR stimulation was applied and also wore a neoprene knee sleeve during the no stimulation/sleeve and the 75% stimulation and sleeve treatment conditions. The sleeve was a wrap-around, hingeless knee stabilizing sleeve with velcro straps (Figure 1) and was fit based on the subject’s thigh circumference approximately 4 inches above the center of the patella per the manufacturer’s recommendations.
Motion sensors were placed superior and inferior to the brace. (Safe-T-Sport Model# 37-350, FLA Orthopaedics Inc., Miramar, FL, USA).

Data Collection and Reduction

Three-dimensional kinematics of the lower extremity were sampled at 144Hz via an electromagnetic motion capture system (Motion Star, Ascension Technology Corp., Burlington, VT, USA). Electromagnetic sensors were positioned on the sacrum, thigh, and shank. The thigh sensor was placed on the lateral aspect of the thigh midway between the hip and knee joints, and the shank sensor was placed on the anterior-medial portion of the tibia taking care to place both sensors outside of the range of the knee sleeve. A sacrum sensor was placed midway between the right and left posterior superior iliac spines. The global and segmental axis systems were established such that +x was in the direction the subject walked forward, +y was forward subject’s left, and +z was in vertical and upward direction. Three-dimensional coordinate data were lowpass filtered at 6 Hz (4th order Butterworth)\(^1\). Knee joint angles were calculated as the Euler angles of the shank reference frame relative to the thigh reference frame with a sequence rotation of (1) flexion-extension, (2) abduction-adduction, and (3) interior-external rotation. Kinematic outcome measures include maximum and minimum knee flexion and adduction angles during the stance phase of a gait cycle.

Ground reaction forces were sampled from a force plate (Model 4060nc, Bertec Corp., Columbus, OH, USA) at 1,440 Hz and lowpass filtered at 40 Hz (4th order Butterworth)\(^4\). Kinematic data and ground reaction forces were combined via inverse dynamics to produce internal moments and net forces acting on the knee joint. Kinetic variables of interest include maximum and minimum extension and valgus moments. Moments were normalized as the
percentage of the product of body weight (N) and height (m) while ground reaction forces were normalized as a percentage of body weight (N).

Five valid trials were recorded within each of the four testing conditions. Data were collected over a period beginning 3 seconds prior to initial ground contact and ending 2 seconds after toe off. The gait cycle was normalized to attain a 101 point time scale across the stance phase for each measure (Figure 2). The first half of stance was defined as the period from the point of ground contact through 50% of stance, and the second half of stance was defined as the period from 50% of stance through toe-off.

**Statistical Analysis**

All statistical analyses were performed using SigmaPlot (Systat Software Inc., San Jose, CA). All outcome measures were compared between the treatment conditions and the NE:NS1 control condition using a one-way repeated measures analysis of variance (ANOVA; p<0.05). Significant ANOVA models were evaluated post hoc via Student-Newman-Keuls tests. The two control conditions (NE:NS1 and NE:NS2) were compared via paired t-test (p<0.05) to determine whether there was a change across the testing session. If a change between the two control conditions was found the control conditions were averaged and a secondary repeated measures ANOVA was performed for the outcome measure with the control average as the new control reference value. In the instance when the two control conditions were not found to differ, the control condition 1 was used in initial repeated measures ANOVA analyses.
Results

Demographically, the distribution was fairly even with 16 males and 19 females. Our population presented with Kellgren Lawrence grades ranging from 1 to 3, was considered to be mild to moderately functionally impaired, and was not excessively obese or elderly.

The maximum and minimum knee flexion angles increased during the 1\textsuperscript{st} and 2\textsuperscript{nd} halves of stance in the no stimulation/sleeve and 75\% stimulation/sleeve conditions compared to the control 1 no stimulation/no sleeve condition (p<0.05). However, there were no differences between the no stimulation/sleeve and 75\% stimulation/sleeve conditions. (Table 2, Figure 2)

Both the maximum (p=0.068) and minimum (p=0.076) knee adduction angles during the 1\textsuperscript{st} half of stance were greater in the control condition compared with the treatment conditions, but these differences were not statistically significant (Figure 2, Table 2). The maximum and minimum knee adduction angle did not differ between the conditions during the 2\textsuperscript{nd} half of stance.

A difference between the two control conditions (no stimulation/no sleeve) was observed for one variable (p<0.05). Specifically, the minimum knee adduction angle during the 1\textsuperscript{st} half of stance decreased from the first to second control condition (p<0.05). No treatment effects were found (p=0.728) when a secondary statistical analysis was performed with the control average as the reference for this outcome measure.

The maximum internal knee flexion moment decreased in the no stimulation/sleeve and 75\% stimulation/sleeve conditions in comparison to the control condition during the 1\textsuperscript{st} half of stance (p<0.05, Table 2). The minimum internal knee flexion moments were not different during the 2\textsuperscript{nd} half of stance, but decreased in the 75\% stimulation/sleeve condition relative to the
control condition during the 1st half of stance (p<0.05). Maximum and minimum internal adduction moments were not different between conditions throughout stance.

No differences between the two control conditions were observed in the frontal plane moments. However, the minimum internal flexion moment of the 1st half of stance decreased from the first to the second control condition (p<0.05). A secondary statistical analysis of this outcome measure with control average as the reference detected a treatment effect (p<0.048) though posthoc testing did not demonstrate a significant difference between any of the groups.

**Discussion**

Several studies have demonstrated improvements in proprioception in individuals with knee OA\textsuperscript{29} or in healthy subjects\textsuperscript{17} while wearing a neoprene knee sleeve. In addition, extended use of sleeves in populations at risk of OA progression has resulted in functional and quality of life benefits\textsuperscript{13}. We hypothesized that proprioceptive improvements seen from the sleeve and SR could result in a return to more normal knee kinematics and moments during gait, specifically decreased knee adduction angle and internal knee abduction moment and increased knee flexion angle and internal knee extension moment. For the frontal plane motion, it was speculated that proprioceptive deficits may contribute to OA subjects unintentionally allowing knee adduction with weight acceptance and therefore also increasing the knee adduction moment as result.

Our finding that the internal abduction moment did not decrease with the treatment conditions did not support our hypothesis. While a reduced knee adduction angle was observed on average with the treatment conditions as compared to the control condition, these differences did not prove to be statistically significant. It is important to note the small magnitude of knee adduction angle differences found in previous knee OA studies. Previous work has shown the peak knee adduction angle during walking to differ by only 2° between knee OA subjects and
matched controls. Similarly, Ramsey et al. found an approximately $1.0^\circ$ change in knee adduction excursion during walking with the use of a neutral-aligned medial unloader brace relative to a baseline condition. However, this same study did not see differences in peak knee adduction angle. Fluoroscopic evaluations of medial unloader braces in valgus-alignment during gait have documented only a $2.2^\circ$ change in knee adduction immediately after heel strike.

Perhaps, the nature of the rigid, medial unloading braces used in these previous studies are what set them apart from the present study’s use of a nonrigid, neoprene knee sleeve; thus, greater differences in knee adduction angle would be expected due to the counter abduction moment produced in these medial unloading braces.

In support of our hypothesis, the treatment conditions increased the minimum and maximum of knee flexion angles for both phases of stance (Table 2). This increase in knee flexion with the treatment conditions relative to the control condition was greatest near initial contact (Figure 3). This is of importance as previous studies have shown that subjects with knee OA make initial contact with the ground during walking in greater knee extension and with higher knee loading rates. Previous research has also shown that increasing the knee flexion angle during impact loading can help attenuate impulsive loads. Thus, the greater knee flexion with the treatment conditions appears to be a return to a more normal kinematic pattern. While it cannot be known with certainty that the increased knee flexion is due to proprioceptive enhancement effects of the treatment conditions, past work has shown that proprioceptive acuity is directly related to knee flexion angles near initial contact and is inversely related to vertical ground reaction force loading rates. To further establish a link between the knee flexion angle improvements and proprioception we examined the data of 20 subjects of the current study who were also past participants in a joint position sense study. This analysis
found that the joint position sense error from a partial weight bearing task was moderately correlated (R=0.503, p=0.024) with the improvement in the minimum knee flexion angle observed with the application of the sleeve alone in the current study. This correlation suggests individuals with the poorest proprioceptive acuity will see the greatest improvement in knee flexion kinematics with the use of a sleeve. While we did observe greater maximum knee flexion during the end of the weight acceptance phase of stance with the treatment conditions, we did not find an increase in knee flexion from initial ground contact to the maximum knee flexion as has been found in some previous studies comparing matched control subjects to knee OA subjects during walking\textsuperscript{41,45}. The effects of the sleeve on knee flexion do not appear to be due to passive tension of the sleeve as knee flexion angles prior to initial contact were similar among conditions (Figure 3).

We also observed an attenuation in the peak internal flexion moment early in the stance phase (Figure 2). In a similar population of OA subjects we have found an attenuation of the heel strike transient peak and loading rates of the vertical ground reaction force with the same treatment conditions\textsuperscript{46} which may have also contributed to knee flexion moment attenuation. In support of our hypothesis, a greater internal knee extension moment was observed for the 75% stimulation/sleeve condition relative to the control during the first half of stance (Table 2), however the sleeve alone condition was not different from the control. It is believed the greater knee flexion observed with the 75% stimulation/sleeve condition acted to increase the moment arm of the ground reaction force to produce this greater internal knee extension moment. It is unclear at this point if this greater knee extension moment would be detrimental to the progression of OA.
It is possible that the design of our study was a limiting factor and that a greater effect may have been observed if the SR had been applied over a longer time period or alternative anatomical sites for the stimulus. It may be that mechanoreceptor sensitivity within the joint cannot be enhanced because of the joint degeneration associated with knee OA. Additionally, the procedure for determining each subject’s SR stimulation detection threshold should be further refined as studies have shown SR produces enhancements in sensitivity up to certain amplitudes; past that optimal amplitude SR may become ineffective.

The significance of this study lies in the potential of a neoprene knee sleeve to positively affect knee kinematics and kinetics during gait in individuals with knee OA. Compliance with long-term use is promising as knee sleeves represent a non-surgical option that is less cumbersome than medial unloading braces for those with OA who desire to maintain an active lifestyle. Our findings may also have applicability to subjects with acute knee injuries that cause a proprioceptive deficit and are at risk of development of knee OA.

In conclusion, our hypotheses that SR stimulation with a sleeve would decrease both knee adduction angles and increase knee flexion angle were partially supported in that knee flexion angle increased in the no stimulation/sleeve and 75% stimulation/sleeve conditions compared to the control, though a significant reduction in the adduction angle was not found. While there were no differences in the internal knee abduction moments the maximum internal knee flexion moments during early weight acceptance was reduced in the treatment conditions relative to the control which is worth further exploration. Overall, there were few differences in the evaluation measures between the treatment conditions themselves. From this, we may conclude that the current configuration of SR stimulation did not demonstrate an ability to enhance the effects of a sleeve alone and thus we believe the observed kinematic/kinetic differences may be more a result
of enhancements provided by the sleeve alone, leading to a greater sense of stability and a return to a more appropriate loading pattern.

Acknowledgements

We would like to thank Jeremy Jordan for his assistance with all data collections and Dr. Bikramjit Grewal for reading patient radiographs.
References


Figure 1. Wrap-around hingeless knee sleeve worn during the 75% stimulation/sleeve and no stimulation/sleeve conditions.
Figure 2. Average curves for all test subjects as a % of stance; the stance phase is defined as the point from heel contact through toe-off. (Left) Knee flexion/extension and adduction/abduction angles during gait. (Right) Knee flexion and adduction moments during gait. solid – control 1 no stimulation/no sleeve; dot-no stimulation/sleeve; dashed-75% stimulation/sleeve.
Figure 3. Knee flexion angle 100 ms prior to ground contact. solid – control 1 no stimulation/no sleeve; dot-no stimulation/sleeve; dashed-75% stimulation/sleeve.
Table 1. Mean (sd) demographics as well as subject reported pain, stiffness, functionality, and instability measures for all test subjects.

<table>
<thead>
<tr>
<th></th>
<th>Male (n=16)</th>
<th>Female (n=19)</th>
<th>Total (n=35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>60.1 (10.1)</td>
<td>63.2 (8.6)</td>
<td>61.7 (9.3)</td>
</tr>
<tr>
<td>Weight (kg.)</td>
<td>92.2 (12.0)</td>
<td>73.0 (12.8)</td>
<td>81.8 (15.6)</td>
</tr>
<tr>
<td>Height (cm.)</td>
<td>178.6 (8.7)</td>
<td>164.5 (5.1)</td>
<td>170.9 (9.9)</td>
</tr>
<tr>
<td>BMI</td>
<td>29.0 (4.0)</td>
<td>26.9 (4.1)</td>
<td>27.9 (4.1)</td>
</tr>
<tr>
<td>WOMAC Index (pain)</td>
<td>4.9 (4.3)</td>
<td>3.3 (2.7)</td>
<td>4.0 (3.6)</td>
</tr>
<tr>
<td>WOMAC Index (stiffness)</td>
<td>3.6 (2.0)</td>
<td>2.3 (1.6)</td>
<td>2.9 (1.9)</td>
</tr>
<tr>
<td>WOMAC Aggregate</td>
<td>15.4 (13.7)</td>
<td>9.7 (8.5)</td>
<td>12.3 (11.4)</td>
</tr>
<tr>
<td>Self-Reported Instability (part A)</td>
<td>23.9 (19.3)</td>
<td>15.3 (11.9)</td>
<td>19.2 (16.1)</td>
</tr>
<tr>
<td>Self-Reported Instability (part B)</td>
<td>3.3 (1.4)</td>
<td>4.2 (1.3)</td>
<td>3.7 (1.4)</td>
</tr>
</tbody>
</table>

Table 2. Mean (sd) maximum and minimum values of all data (non-normalized as a % of stance) during the 1st and 2nd half of stance. † indicates the presence of a significant difference between the treatment conditions and the control condition 1 no stimulation/no sleeve, p<0.05.

<table>
<thead>
<tr>
<th>Angle (degrees)</th>
<th>Wt. Acceptance-Mid Stance</th>
<th>Mid-Terminal Stance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No stim/ no sleeve</td>
<td>No stim/ sleeve</td>
</tr>
<tr>
<td>Adduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>max.</td>
<td>3.9 (5.6)</td>
<td>2.9 (6.6)</td>
</tr>
<tr>
<td>min.</td>
<td>-0.9 (5.5)</td>
<td>-1.8 (6.2)</td>
</tr>
<tr>
<td>Flexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>max.</td>
<td>25.4 (10.0)</td>
<td>26.8 (9.2)†</td>
</tr>
<tr>
<td>min.</td>
<td>10.6 (8.4)</td>
<td>12.6 (7.9)†</td>
</tr>
<tr>
<td>Internal Moment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%BW*ht</td>
<td>Adduction</td>
<td></td>
</tr>
<tr>
<td>max.</td>
<td>0.84 (0.67)</td>
<td>0.81 (0.66)</td>
</tr>
<tr>
<td>min.</td>
<td>-3.72 (2.31)</td>
<td>-3.76 (2.36)</td>
</tr>
<tr>
<td>Flexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>max.</td>
<td>2.32 (0.97)</td>
<td>2.08 (0.87)†</td>
</tr>
<tr>
<td>min.</td>
<td>-8.05 (3.46)</td>
<td>-8.30 (3.51)</td>
</tr>
</tbody>
</table>