ORIGINAL ARTICLE

The Assessment of Postural Control With Stochastic Resonance Electrical Stimulation and a Neoprene Knee Sleeve in the Osteoarthritic Knee

Amber T. Collins, PhD, J. Troy Blackburn, PhD, Chris W. Olcott, MD, Joanne M. Jordan, MD, MPH, Bing Yu, PhD, Paul S. Weinhold, PhD

ABSTRACT. Collins AT, Blackburn JT, Olcott CW, Jordan JM, Yu B, Weinhold PS. The assessment of postural control with stochastic resonance electrical stimulation and a neoprene knee sleeve in the osteoarthritic knee. Arch Phys Med Rehabil 2012;93:1123-8.

Objective: To determine whether the combination of stochastic resonance (SR) electrical stimulation and a neoprene knee sleeve could improve center of pressure (COP) measures of postural sway during single-leg stance in those with knee osteoarthritis (OA).

Design: Counterbalanced, repeated-measures intervention study of osteoarthritic adults during 6 different testing conditions: a control condition—control 1 (1); a counterbalance sequence of 4 treatment conditions—no stimulation with sleeve (2), 75% stimulation with sleeve (3), 100% stimulation with sleeve (4), and 150% stimulation with sleeve (5); and a second control condition—control 2 (6).

Setting: University sports medicine research laboratory.

Participants: Subjects (N=52) with radiographically determined, minimal-to-moderate medial knee OA.

Interventions: Neoprene knee sleeve and SR electrical stimulation.

Main Outcome Measures: COP displacement in the medial-lateral and anterior-posterior directions was collected to resolve the mean velocity, SD, range, and total path length.

Results: No significant differences were found in the study measures between the testing conditions. Additionally, no significant differences were found between the 3 stimulation conditions or between the sleeve-alone and stimulation conditions for any of the study measures.

Conclusions: There were no significant improvements in balance with the use of a neoprene knee sleeve. Additionally, there was no added benefit of the SR stimulation as applied in the current configuration in this population.

Key Words: Braces; Knee; Electric stimulation; Osteoarthritis; Rehabilitation.

OSTEOARTHRITIS (OA) is a debilitating disease and is especially common in the elderly, affecting roughly 10% of those older than 65 years.[1] Abnormal postural control[2] beyond that attributable to aging effects, as well as knee instability,[3] has been demonstrated in those with knee OA and may put this population at greater risk of falling. Postural control is a reflection of sensory input (including proprioception), central processing, neuromuscular responses, and lower limb muscle strength. The abnormal postural control associated with knee OA may be a direct result of proprioceptive deficits, which are also known to exist in this population and exceed those of general aging effects.[4-7] Age has been demonstrated to have a detrimental effect on balance,[8,9] but this may be compounded in knee OA by the further impairment in proprioception.

By improving proprioception, it is possible that balance itself may be improved. Birmingham et al[10] demonstrated improvements in proprioception with the use of a valgus-producing brace in those with knee OA during a non–weight-bearing joint position sense task. A more recent study[11] demonstrated that a neoprene knee sleeve produced a significant improvement in joint position sense in those with knee OA during a partial weight-bearing task. Improvements in sensory input (specifically proprioception) may translate into improvements in balance, which may result in a reduction in the risk of falls in those with knee OA who are elderly and are more susceptible to falling compared with a younger population without knee OA.

However, the effect of wearing a knee sleeve or brace on the control of balance of individuals with knee OA is limited to a few studies[10,12,13] with conflicting results. Chuang et al[12] demonstrated improvements in both static and dynamic balance with the use of a neoprene knee sleeve, and Hassan et al[13] showed significant reductions in postural sway with a loose elastic bandage. Conversely, Birmingham[10] did not see a significant effect on balance with the use of a valgus-producing brace. Based on the conflicting results in the current literature, it is unclear whether postural control can be affected with the use of a knee sleeve.

Stochastic resonance (SR) stimulation has been investigated as a tool for improving postural control in a variety of diseased

From the Departments of Biomedical Engineering (Collins, Yu, Weinhold), Orthopaedics (Blackburn, Olcott, Yu, Weinhold), and Exercise and Sport Science (Blackburn), the Center for Human Movement Science, Division of Physical Therapy (Yu), and the Thurston Arthritis Center (Jordan), University of North Carolina, Chapel Hill, NC.

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Reprint requests to Amber T. Collins, PhD, 126 Spencer Lab, University of Delaware, Newark, DE 19711, e-mail: *atcollin@udel.edu*.

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List of Abbreviations

ANOVA	analysis of variance
AP	anterior-posterior
COP	center of pressure
ML	medial-lateral
OA	osteoarthritis
SR	stochastic resonance
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index

Table 1: Demographics and Subject Reported Pain, Stiffness, Functionality, and Instability Measures for All Test Subjects

Variable	Total (N=52)
Age (y)	61.2±9.6
Weight (kg)	80.9±15.7
Height (cm)	170.4±9.8
BMI	27.8±4.3
Kellgren-Lawrence grade (1–3)	2.2±0.8
WOMAC Index	
Pain	4.1±3.4
Stiffness	2.7±1.8
Function	12.4±10.8
Aggregate	19.2±15.3
Self-reported instability	
Part A	3.8±1.3
Part B	8.7±20.2

NOTE. Values are mean ± SD.
Abbreviation: BMI, body mass index.

and injured populations.[14-18] SR is a phenomenon in which the sensitivity to weak stimuli is enhanced in sensory systems through the introduction of subsensory electrical or mechanical "noise." It was first introduced as a way of improving tactile[19] and muscle spindle[20] sensitivity, but has since been investigated as a way of enhancing postural control in those with functional ankle instability,[16] diabetic neuropathy,[18] and low back pain,[17] as well as in older adults[14] and those who have had a stroke.[15]

The purpose of this study was to determine whether SR electrical stimulation combined with a neoprene knee sleeve would improve postural control outcome measures in individuals with knee OA. We hypothesized that wearing a knee sleeve with SR electrical stimulation would significantly improve the postural control of individuals with knee OA when compared with a sleeve alone or a control condition. We further hypothesized that the effects of the combined knee sleeve and SR electrical stimulation therapy on postural control would be a function of the strength of the stimulation.

METHODS

Participants

Fifty-two subjects (30 women, 22 men) older than 40 years and with physician-diagnosed minimal to moderate (Kellgren-Lawrence grade 1–3) medial knee OA were recruited for participation in the study. All subjects were recruited from the clinical practice of the Department of Orthopaedics at the University of North Carolina at Chapel Hill. Individuals who had a body mass index of 35 or greater, had prior neurologic impairments, had a diagnosed musculoskeletal disease other than knee OA, had a pacemaker or other implanted electronic device, used a walking assistive device, or had lower limb joint replacement were excluded. Additionally, those subjects who had received steroid injections within 3 months before screening were excluded from participation. The severity of knee OA was assessed by a single orthopedist from standing anterior-posterior (AP) radiographs.[21,22] Based on standing radiographs, all knees were verified to have at least grade 1 OA with more severe joint space narrowing in the medial compartment compared with the lateral compartment. Table 1 illustrates the demographics, as well as the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and self-reported instability outcome measures, for all subjects. The use of human subjects was approved by the Biomedical Institutional Review Board at the School of Medicine of the University of North Carolina at Chapel Hill. Informed consent was obtained from each subject before testing.

Data Collection

Subjects completed several questionnaires, the first of which was a self-reported measure of the amount of instability they had experienced that was adapted from the Knee Outcome Survey Activities of Daily Living Scale.[23] Within this questionnaire, subjects were asked to rate how episodes of giving way, buckling, or shifting of the knee affected their daily activities (0–5 scale), with 0 indicating the symptom prevents them from all activity and 5 indicating they do not experience the symptom. The second part of this questionnaire was derived from a study[24] in which knee buckling was assessed in knee OA and asked subjects how many times they had experienced the symptom within the previous 3 months. Subjects then completed the Knee and Osteoarthritis Outcome Score survey to subjectively rate how they felt about their knee pain, function, stiffness, and overall quality of life within the week before testing.[25]

Two pairs of SR electrodes were adhered to the skin on the medial and lateral aspects of the knee approximately 2cm above and below the tibiofemoral joint line. The neoprene sleeve placed over the self-adhering electrodes helped ensure good coupling of the electrodes. One pair was placed on the superior aspect of the knee, with 1 electrode on both the medial and lateral sides, while the other pair was placed on the inferior aspect of the knee, with 1 electrode on both the medial and lateral sides. The placement of the SR electrode pairs was designed to create an alternating flow of current in the medial-lateral (ML) direction in both the superior and inferior aspects of the knee. The delivered stimulation consisted of a Gaussian white noise signal (zero mean, 0–1000Hz bandwidth). The electrodes remained in place during the entire testing session, and subjects were blinded as to whether or not the SR electrical stimulation was being delivered. Subjects were also fit for a neoprene knee sleeve[a] per the manufacturer's recommendations. Each subject's threshold for SR electrical stimulation detection was determined for both inferior and superior electrode pairs. The threshold for stimulation detection was determined as the stimulation amplitude at which the subject indicated the presence of electrical stimulation.

Each subject performed a single-leg balance task under 6 conditions: (1) no electrical stimulation and no sleeve (NE:NS1); a counterbalanced sequence of the following 4 treatment conditions—(2) no electrical stimulation with sleeve (NE:S), (3) 75% electrical stimulation with sleeve (E75:S), (4) 100% electrical stimulation with sleeve (E100:S), and (5) 150% electrical stimulation with sleeve (E150:S); and (6) no electrical stimulation and no sleeve (NE:NS2). In a population with knee OA, a 1-legged stance task is sufficiently difficult to determine whether improvements can be seen with the treatments while also ensuring that all subjects can safely perform the task. Conditions 1 and 6 were control conditions, with conditions 2 through 5 being treatment conditions. The subjects performed 3 successful trials of the balance task for each condition, with a 30-second break between trials and a 1-minute break between conditions. In each trial, subjects were asked to stand on a forceplate[b] with their affected leg, barefoot, and with their hands on their hips for 20 seconds (fig 1). The leg more severely affected with knee OA was tested in subjects with knee OA in both knees. Touchdown of the nontest limb was allowed during data collection; however, data during the period of touchdown were excluded from further analysis (see Data

Fig 1. Subject setup during the balance assessment demonstrating single-leg stance.

Reduction section). A successful trial was defined as one in which the subjects did not grab onto the supporting safety frame or shift the location of their foot on the forceplate. Forceplate data were collected at 1440 samples per channel per second for every successful trial for each subject.

Data Reduction

The trajectories of center of pressure (COP) were calculated for each successful trial, filtered through a zero-lag, fourth-order, low-pass Butterworth filter with a cutoff frequency of 20Hz. The mean COP velocities in the AP and ML directions, the ranges of COP displacement in the AP and ML directions, the SD of the COP locations in the AP and ML directions, and the path length of the COP in each trial were reduced from the collected forceplate data. The path length of the COP was divided by the duration of single-leg stance excluding time of touchdowns (normalized COP path length). COP measures were calculated only during periods in which the subject was in single-leg stance.

Statistical Analysis

The 2 control conditions (NE:NS1 and NE:NS2) were compared using a paired *t* test to assess whether outcome measures were significantly different across the testing session ($P<.05$). The average of the 2 control conditions (NE:NSavg) was used in subsequent statistical comparisons with the treatment conditions so as to minimize any treatment carryover effect being incorporated into the analysis. All data were transformed using the natural log transformation, to meet the normality assumption for parametric testing. An analysis of variance (ANOVA) with repeated measures was performed to compare each dependent variable between the 5 conditions (NE:NSavg, NE:S, E75:S, E100:S, E150:S), with post hoc testing performed using the Student-Newman-Keuls method of multiple comparisons. Although transformed data were used in statistical analysis, the means and SDs presented in tables and figures are of nontransformed data. Lastly, a correlation analysis was performed between the COP outcome measures in both control conditions (NE:NS1, NE:NS2) and the WOMAC indices (pain, stiffness, function, aggregate) and self-reported instability measures. A type I error rate of .05 was chosen as an indication of statistical significance. All statistical analyses were performed using SigmaPlot.[c]

RESULTS

Control Condition Comparison

Paired *t* tests revealed that the velocity of COP in both the AP and ML directions, as well as the COP normalized path length, was significantly reduced for the final control condition relative to the initial control condition (table 2) ($P<.001$ for all comparisons). The COP range in the AP direction, as well as the COP SD in the AP and ML directions, revealed significant reductions ($P<.05$ for all comparisons) relative to the initial control condition (see table 2). The COP range in the ML direction was not significantly different between control conditions.

Range of COP Displacement

Repeated-measures ANOVA revealed no significant differences in either the AP or ML COP displacement range between the testing conditions (AP, $P=.221$; ML, $P=.074$) (table 3).

SD of COP Location

No significant differences were seen in the SD of COP locations in either the AP ($P=.391$) or ML ($P=.135$) directions between the 5 conditions (see table 3).

Table 2: Outcome Variables for the 2 Control Conditions NE:NS1 and NE:NS2

Condition	COP Range-AP (mm)*	COP Range-ML (mm)	COP SD-AP (mm)*	COP SD-ML (mm)*	COP Velocity-AP (mm/s)*	COP Velocity-ML (mm/s)*	COP Normalized Path Length (mm)*
NE:NS1	39.93±16.93	28.81±4.40	7.22±2.48	6.07±1.21	33.95±20.46	33.53±10.37	53.13±23.40
NE:NS2	35.55±11.89	27.97±6.10	6.62±1.95	5.79±1.29	28.49±14.86	29.34±9.71	45.35±18.65

NOTE. Values are mean ± SD.
Abbreviation: NE:NS, no electrical stimulation and no sleeve.
*Significant difference between the 2 conditions ($P<.05$).

Table 3: COP Range and SD in the AP and ML Directions During Single-Leg Stance for All Test Subjects

Condition	COP Range-AP (mm)	COP Range-ML (mm)	COP SD-AP (mm)	COP SD-ML (mm)
NE:NSavg	37.74±12.99	28.39±4.63	6.92±2.02	5.93±1.14
NE:S	37.73±13.81	29.24±7.78	6.95±2.06	6.12±1.70
E75:S	36.93±15.08	27.83±5.75	6.81±2.18	5.90±1.57
E100:S	36.85±15.03	28.28±5.99	6.74±2.34	5.97±1.53
E150:S	36.22±13.28	27.40±5.33	6.82±2.04	5.80±1.38

NOTE. Values are mean ± SD.
Abbreviations: E75:S, 75% electrical stimulation with sleeve; E100:S, 100% electrical stimulation with sleeve; E150:S, 150% electrical stimulation with sleeve; NE:NSavg, the average of the 2 control conditions; NE:S, no electrical stimulation with sleeve.

COP Sway Velocity

No significant differences were detected in the AP or ML COP velocities between the 5 conditions (AP, P=.066; ML, P=.124) (figs 2 and 3).

COP Path Length

Repeated-measures ANOVA revealed a slight difference between conditions (P=.048). However, post hoc testing showed no significant differences between conditions (P>.05) (fig 4).

Regression Analysis

Significant correlations between the self-reported instability part B and the COP sway velocity in the AP direction (R^2=.080, P=.004), and between the self-reported instability part B and the COP path length (R^2=.052, P=.020) were detected; however, the correlation coefficients did not indicate strong relationships between the measures. No other significant correlations were found between selected COP kinematics and self-reported measures.

DISCUSSION

SR electrical stimulation is thought to improve mechanoreceptor sensitivity and by doing so may improve functionality in static and dynamic tasks that rely on accurate spatial and temporal information from mechanoreceptors. In the present study, our goal was to improve measures of static balance by applying SR in an affected joint where receptor sensitivity may be diminished. However, the results of this study do not support our hypothesis that the addition of SR electrical stimulation to a sleeve would improve postural control beyond that of a sleeve alone for individuals with knee OA. Also, the results of this study do not support our hypothesis that the effects of SR electrical stimulation on postural control would be a function of the magnitude of the stimulation.

The SR electrical stimulation did not produce significant improvements in balance relative to the sleeve-alone condition, contrary to previous studies[14-18] showing improvements in balance with SR stimulation without the presence of a sleeve. However, these studies were investigating balance control in populations that had diseases and injuries other than knee OA. It is possible the present study was not able to detect differences solely because of the nature of knee OA, specifically, possible degradation of mechanoreceptors within the joint. It is

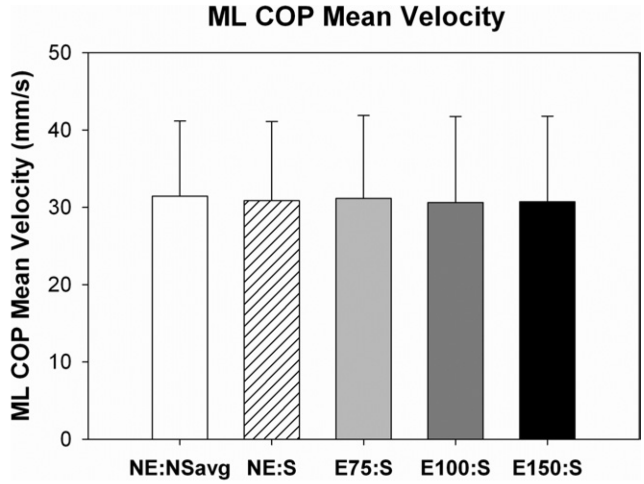

Fig 3. Mean ± SD of COP velocity (mm/s) in the ML direction during all 5 testing conditions. No significant difference between conditions was found (P>.05).

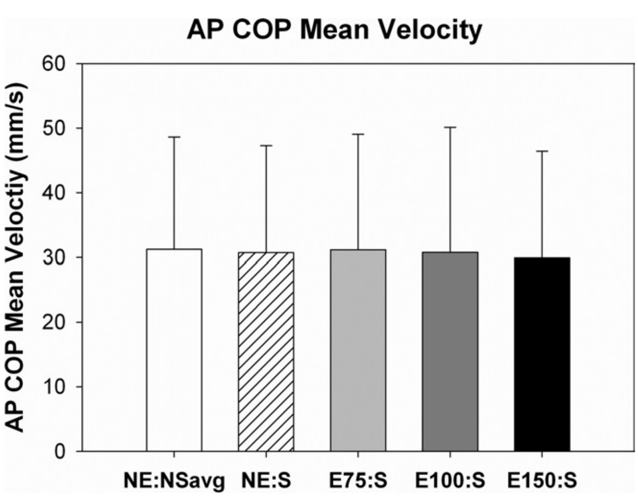

Fig 2. Mean ± SD of COP velocity (mm/s) in the AP direction during all 5 testing conditions. No significant difference between conditions was found (P>.05).

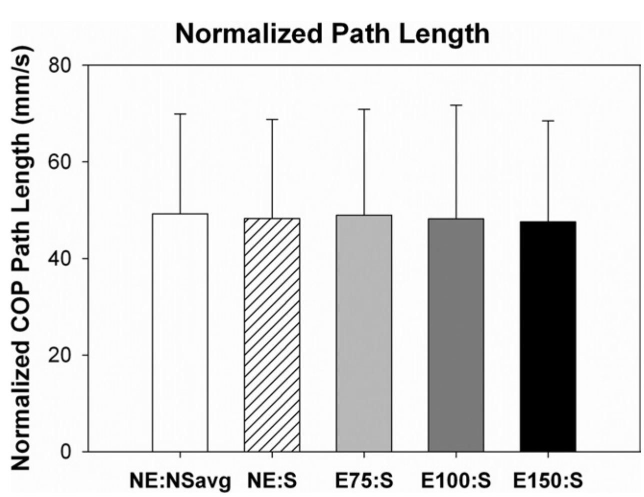

Fig 4. Mean ± SD of COP normalized total path length (mm) during all 5 testing conditions. No significant difference between conditions was found (P>.05).

possible that by targeting alternative SR entry points such as muscle spindles and even mechanoreceptors within and surrounding the ankle joint, a greater effect on postural control may be seen. Additionally, the direction of the SR current is something to be further explored. In the present study, our horizontally directed pattern attempted to encompass the entire joint, but it is possible that an alternative pattern such as a vertical one may be more effective. Lastly, the sleeve may have already been providing an SR effect through surface friction noise, resulting in no added benefit from the SR stimulation.

Wearing a knee brace/sleeve has been investigated as a possible way to improve balance, but results have been conflicting.[10,12,13,26,27] Specifically looking at knee OA, Chuang[12] saw a significant 28% reduction in balance scores, with lower scores indicating better balance performance, when subjects were wearing an elastic knee sleeve, while Hassan[13] found a smaller (3%) reduction in postural sway when subjects wore a loose elastic bandage. In contrast, in the current study, we found no improvement in postural sway when subjects were wearing a neoprene knee sleeve. The discrepancy in findings between studies may be a result of varying methods. Specifically, when subjects were placed on a stability platform, Chuang used a balance scoring system to quantify the position of the platform in 2 planes. Balance scores were quantified according to the platform's position with reference to the "zero" point. Similar to our study, balance was assessed based on the COP variation. However, Chuang used a balance scoring system in which the location was additive through the time period and lower balance scores indicated better balance performance. Additionally, subjects in the Chuang study received visual feedback regarding their COP location while performing the test. Because of the additive nature of these scores and the availability of visual feedback, a greater percent difference is expected between conditions in the Chuang study compared with our study.

Studies have also questioned the clinical significance of improvements in postural control with a brace or sleeve. In a study investigating postural control with the use of a custom-fit brace after anterior cruciate ligament reconstruction, Birmingham et al[27] questioned the clinical significance of the small improvements that were observed in an eyes-open, stable-surface, single-leg stance task. These improvements did not carry over into more strenuous balance tasks; thus, the authors questioned the clinical benefit of the subtle neuromuscular adaptations resulting from the use of a brace.

Correlational analysis revealed weak to moderate relationships between the self-reported instability measure and the COP velocity in the AP direction and total path length, indicating that the results of the self-reported instability questionnaire may serve as clinical predictors of poor postural control in subjects with knee OA.

Study Limitations

Our study is limited by the fact that a change in postural control was found across the testing session for the control conditions. Postural control improved from the first control condition (NE:NS1) to the second control condition (NE:NS2). This could be a result of subjects' infrequently performing a single-leg stance task on a daily basis such that a high learning curve was present in our study. However, by counterbalancing the order of the treatment conditions, we effectively ensured that a learning effect did not systematically influence the data. Alternatively, the difference across the control conditions could suggest a carryover effect of the sleeve or stimulation. It is also possible that a carryover effect of the sleeve or stimulation improved learning during the balance task. The use of the average of the control conditions as a reference for the statistical comparisons with the treatment conditions was a compromise to help account for any learning effect across the test session, although this may have dampened treatments effects.

Another limitation is that it is possible that knee proprioception is contributing less to maintaining single-leg stance, and SR application at the knee does not allow us to target the optimal location for mechanoreceptor sensitivity improvement. Additionally, abnormal postural control in this population may not solely be a result of mechanoreceptor insensitivity, but may be more of a central processing issue where localized SR would be ineffective. In a study by Shakoor et al,[28] vibratory perception threshold was assessed in those with hip OA and in age-matched controls along 5 lower extremity sites and 1 upper extremity site (radial head). Vibratory perception threshold was significantly greater at all sites in those with hip OA compared with controls, which the authors suggest is a result of generalized sensory deficits involving both the upper and lower extremities. Lastly, the SR amplitude may not have been at an optimal level, and the procedure used to determine threshold values may need to be refined. SR is most effective at a certain amplitude, past which point no improvements in sensitivity are present.[20] Our previous work investigating joint position sense in knee OA delivered an SR amplitude of approximately 50% of the subject's detection threshold, with no observed effect of the SR beyond the sleeve.[11] However, Priplata et al[29] demonstrated that an SR mechanical stimulation amplitude of 75% of threshold produced the largest reductions in postural sway parameters. Overall mean threshold values for the superior and inferior electrode pairs of all subjects was determined to be 141.5μA and 145.8μA, respectively, with delivered SR at 75%, 100%, and 150% of threshold. Our threshold test determined when a specific group of mechanoreceptors felt the stimulus, but these may not be the best-suited receptors to sensitize as a way to affect balance. During the 150% of threshold condition, subjects were not completely blinded to whether the stimulation was being applied. Despite the fact that the study investigator (A.T.C.) did not verbally indicate when the stimulation was applied, subjects were able to detect the stimulation in this condition. Additionally, some subjects were not sure if they were sensing the stimulation, which may have led to an incorrect threshold value determination, and thus the delivered stimulation may not have been at an optimal level.

CONCLUSIONS

The results of our study did not demonstrate the ability of a neoprene knee sleeve to reduce postural sway during a single-leg stance task in those with knee OA. Furthermore, the addition of SR electrical stimulation to the sleeve in the current configuration appeared to have no significant added benefit to improve postural control.

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Suppliers

a. Safe-T-Sport Model #37-350; BSN Medical Inc, 5825 Carnegie Blvd, Charlotte, NC 28209.
b. Model 4060nc; Bertec Corp, 6171 Huntley Rd, Suite J, Columbus, OH 43229.
c. Systat Software Inc, 1735 Techology Dr #430, San Jose, CA 95110.