Back to Table of Contents

A "SMART" PRESSURE INSOLE FOR GAIT RETRAINING OUTSIDE OF THE LABORATORY

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INTRODUCTION

Load distribution shifts from the lateral to the medial compartment is related to an increase in knee adduction moment (KAM) [1] and is associated with knee osteoarthritis (OA) [2]. Previously, reductions in KAM occur when barefoot plantar pressure is medialized [3]. This supports the role of altering kinematics of the foot to redistribute loads across the knee joint.

Successfully gait retraining to medialize plantar pressure and lower KAM have been achieved in the laboratory via auditory feedback provided by a high-resolution insole with specifically arranged sensor areas [4]. However, such a plantar pressure-detecting system is comprised of multiple electronics and cables and therefore is unsuitable for gait training in the community. With the ultimate goal of translating pressure-based feedback training into the clinical setting for sufferers of knee OA , the current study employed a pair of fully integrated, slim 13-sensor insoles (OpenGo, Moticon GmbH, Munich, Germany) for measuring and recording real-time plantar pressure distribution (**Figure 1**). A smartphone receives sensor data via ANT wireless technology and provide instant, auditory feedback. Further exploration of using this sensor insole to provide auditory feedback to lower KAM outside of the laboratory is warranted.

In this study, we hypothesize that gait training using auditory feedback from a cable-less, commercially available insole in the in the community will reduce KAM.

METHODS

This single-day, IRB-approved study tested 11 healthy subjects (25.64 ± 4.67 yrs; 5M, 6F; 22.95 ± 2.83 kg/m^2), who self-reported an absence of pain in their lower extremities during the last 48 hours. All subjects wore a pair of standardized, flexible shoes (Dr. Comfort, FlexOA, Mequon, WI, USA) that contained the insoles. Kinematics, kinetics, and plantar pressure was evaluated for the dominant leg (all right sided).

Figure 1. Moticon OpenGo cable-less pressure insoles and their sensor distribution

The testing procedure included a baseline walking assessment, in-lab training and subsequent gait test with feedback, continuation of training outside the lab, and final assessment of memorized gait modification without feedback. For the baseline test, all subjects completed five walking trials at a self-selected speed with their normal gait pattern on a leveled 6-m walkway with their plantar pressure recorded using the insoles. The mean maximum pressure of both sensor S5 and S9 (**Figure 1**) on the lateral side of the foot was calculated. For both sensors, 75% of the mean maximum pressure was set as the training threshold. Each subject received instructions to subtly alter their walking style avoiding the auditory tone from the smartphone. Subjects practiced until they could successfully avoid the feedback tone for several consecutive steps. Then, three walking trials were assessed as the subjects were performing the modification with feedback. Each subject was then instructed to further practice the gait modification while going for a one-mile walk around campus. During this walk, feedback was received through headphones. Upon return to the lab, each subject was asked to walk with the internalized gait modification without feedback. Five marker-based trials were completed while plantar pressure was recorded as well.

Motion capture was performed using a ground embedded force plate (Bertec, Columbus, OH, USA) to measure ground reaction forces and 12 optoeletric cameras (Qualysis, Gothenburg, Sweden) to capture lower extremity kinematics. A modified Helen Hayes marker set was applied to the lower extremities. Raw kinetics and kinematics were processed in Visual3D (C-Motion, Inc., Germantown, MD, USA) with model templates customized using joint offset for all subjects.

Statistical analyses were performed using IBM SPSS Statistics 22 (SPSS Inc., Chicago, IL). A *p*-value of 0.05 indicated significance. Descriptive statistics were calculated for variables of interest and one-way ANOVA with post hoc Bonferroni were used.

RESULTS AND DISCUSSION

On average, subjects reduced lateral plantar pressure by 58.96% and 33.58% for S5 and S9, respectively (**Table 1**). Speed, stride, or cadence did not change across three tested conditions (**Table 2**). Compared with normal walking, subjects reduced KAM1 by 15.46 % (0.32%BW*Ht, p = 0.051) and KAM2 by 25.18% (0.71%BW*Ht, p = 0.017) while performing the gait modification cued by feedback. After the additional on-campus training and removing the feedback function on the phone, subjects maintained a 17.87% reduction of KAM1 (0.37%BW*Ht, p = 0.010) and 25.53% of KAM2 (0.72%BW*Ht, p = 0.009). It was encouraging that the KAM reduction was sustained even without feedback after training. Additionally, knee flexion moment (KFM) did not change while subjects were modifying their gait.

	Reduction of Pressure (%)	
Subject	S5	S9
1	94.12	31.68
2	74.36	32.74
3	-43.03	28.71
4	27.88	20.63
5	47.37	22.73
6	11.97	66.22
7	76.23	29.01
8	92.29	4.51
9	91.82	47.62
10	80.37	61.76
11	95.19	23.72
Mean	58.96	33.58
SD	44.10	18.26

Table 1. Reduction of pressure from baseline after on-campus gait training and removal of feedback

CONCLUSIONS

A commercially available, cable-less insole was capable in training healthy volunteers to medialize plantar pressure and decrease KAM. Further studies have to follow and test the technology on OA patients.

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	Normal Walking		Medialized Pressure with Feedback			Medialized Pressure		
	Mean	SD	Mean	SD	Significance	Mean	SD	Significance
Spatialtemporal Parameters								
Speed (m/s)	1.33	0.17	1.22	0.22	0.336	1.26	0.16	0.745
Stride (m)	1.41	0.11	1.34	0.15	0.367	1.35	0.11	0.630
Cadence (steps/min)	55.84	3.19	54.05	4.47	0.705	55.27	4.11	1.000
Loading Parameters (%BW*Ht)								
KAM1	-2.07	0.41	-1.75	0.32	**0.051**	-1.70	0.35	**0.010**
KAM2	-2.82	0.69	-2.11	0.79	**0.017**	-2.10	0.60	**0.008**
KFM	2.97	1.09	2.77	0.89	1.000	2.83	1.15	1.000

Table 2. Spatiotemporal and kinetics variables of subjects walking in three conditions