

EMG Activity With Use of a Hands-Free Single Crutch vs a Knee Scooter

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Abstract

Background: Foot and ankle injuries frequently require a period of nonweightbearing, resulting in muscle atrophy. Our previous study compared a hands-free single crutch (HFSC) to standard axillary crutches and found increased muscle recruitment and intensity while using the HFSC. Knee scooters are another commonly prescribed nonweightbearing device. The purpose of this study is to examine the electromyographic (EMG) differences between an HFSC and knee scooter, in conjunction with device preference and perceived exertion.

Methods: A randomized crossover study was performed using 30 noninjured young adults. Wireless surface EMG electrodes were placed on the belly of the rectus femoris (RF), vastus lateralis (VL), lateral gastrocnemius (LG), and gluteus maximus (GM). Participants then ambulated along a 20-m walking area while 15 seconds of the gait cycle was recorded across 3 conditions: walking with a knee scooter, an HFSC, and with no assistive device. Mean muscle activity and peak EMG activity were recorded for each ambulatory modality. Immediately following testing, patient exertion and device preference was recorded.

Results: The RF, LG, and GM showed increased peak EMG activity percentage, and the LG showed increased mean muscle activity while using the HFSC compared with the knee scooter. When comparing the knee scooter and HFSC to walking, both showed increased muscle activity in the RF, VL, and LG but no difference in the GM. There was no statistical difference in participant preference, whereas the HFSC had a statistically significant higher perceived exertion than the knee scooter ($P < .001$).

Conclusion: In this group of young, healthy noninjured volunteers, the HFSC demonstrated increased peak EMG activity in most muscle groups tested compared with the knee scooter.

Level of Evidence: Level II, prospective comparative study.

Keywords: nonweightbearing, lower extremity injury, knee scooter, hands-free single crutch, iWALKFree, electromyography, assistive device, ambulatory aid

Introduction

Foot and ankle injuries are a common cause of disability.^{13,17} Although injury type and severity are variable, injuries of the foot and ankle often require patients to undergo a period of nonweightbearing to facilitate healing.^{8,14,17,28} The ability to ambulate while maintaining nonweightbearing status is achieved through the use of assistive devices such as standard axillary crutches, knee scooters, or wheelchairs. The amount of time a patient must use these devices is related to injury severity and the presence of other comorbidities.^{8,17,28,34} Although the prolonged periods of nonweightbearing are

necessary for healing, prolonged immobilization of the lower extremity can cause other unwanted effects such as increased swelling or stiffness.^{8,17,19,32} Further, limb immobilization

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causes muscle atrophy, with the most rapid decreases to muscle size and strength occurring early on during nonweight-bearing.^{2,8,27,32} This loss of strength and muscle mass can lead to increased impairment and prolong the time to return to normal activity.^{8,27,32}

The type of ambulatory assistive device prescribed can affect the extent to which muscle atrophy is experienced because of the variability in limb positioning, muscle activation, and blood flow to the extremity.^{1,12,23,27,35} A study by Sanders et al examined the relationship between electromyographic (EMG) activity in lower extremity muscles while using different ambulatory assistive devices, including a knee scooter, standard axillary crutches, and a novel prosthetic device.²⁷ It found that use of these devices resulted in different levels of muscle activity compared with normal walking gait.²⁷ Some muscles involved in stabilizing the lower extremity while using assistive devices demonstrated higher levels of activity than normal walking.²⁷ However, the gastrocnemius of the immobilized limb was shown to have significantly lower activity during the use of every device, with the lowest activity occurring while using the knee scooter.²⁷ This diminished EMG activity may help explain muscle atrophy that occurs during nonweightbearing.²⁷ Decreased muscle activity presents further risks as this decrease can reduce blood flow in the extremity and can reduce the force applied to venous walls, resulting in stagnation or reduced flow that can result in deep vein thrombosis.^{1,12,35}

Although the knee scooter remains a popular ambulatory aid, there is the potential for negative secondary effects of its use and it has the requirement of being piloted by 3 of 4 limbs.¹⁶ Newer ambulatory devices, like the hands-free single crutch (HFSC), have been created to increase functional recovery in patients requiring nonweightbearing treatment. The iWALKFree (iWALKFree, Mansfield, Ontario, Canada) is an HFSC that does not require upper-extremity usage, a limiting factor for use of both standard axillary crutches and the knee scooter.²⁴ The HFSC mobilizes both lower extremities for ambulation, while using redirected forces to keep the injured lower limb nonweightbearing.²² A previous study reported that the HFSC is preferred to standard axillary crutches, owing to decreased perceived exertion and increased comfort.²²

Although comfort, functionality, and patient preference are promising benefits of the HFSC, the extent of muscle activation, and thus potential for muscle atrophy, are unknown. In our previous study, we examined the EMG activity during ambulation using the HFSC and standard axillary crutches.¹¹ The HFSC demonstrated increased muscle activity and intensity, including activity in the lateral gastrocnemius (LG).^{10,11} Although the HFSC has been compared to walking and standard axillary crutches, it has not yet been compared to the knee scooter. Thus, the aim of the current study was to investigate the EMG activity while using an HFSC and a knee scooter, while also comparing

Table 1. Demographic Data.

Variable	Mean	SD	Range
Age, y	24.57	3.7	19-37
Height, m	1.75	0.08	1.6-1.96
Weight, kg	74.38	13.66	42.72-105.2
Leg dominance, n			
Right	28		
Left	2		
Sex, n			
Female	21		
Male	9		

them to walking. We hypothesize that the HFSC will show increased muscle EMG activity compared with use of the knee scooter.

Methods

The current study was a randomized crossover study that used 30 healthy volunteers (21 females and 9 males; Table 1). Data was collected in a university research laboratory. The sample size of 30 was based on and consistent with previous studies that tested physiological muscle conductivity, including our previous study.^{5,11,27,30,31} Data was collected over the course of 2 days. Participants had a mean age of 24.6 years (range, 19-37), mean height of 175.4 cm (range, 160-195.5), and weight of 74.38 kg (range, 42.72-105.20). Leg dominance was established by asking participants which leg they would use to kick a soccer ball (28 right and 2 left). Demographic data can be seen in Table 1.

Participants were included in the study if they were between the ages of 19 and 60 years. Participants were excluded from the study if they had sustained a foot or ankle injury in the last 2 weeks, had a lower extremity injury that would limit their ambulatory ability, had any injury that would limit their ability to use their muscles to walk for 30 seconds, or if they had a radiculopathy.

This study was approved by the Institutional Review Board at Creighton University (IRB 2002087). Participants provided informed consent prior to data collection followed by collection of demographic information. Prior to EMG electrode placement, the skin was shaved, lightly debrided with sandpaper, and cleaned with an alcohol swab. EMG activity (Trigno Avanti) was measured with electrodes placed superficially in parallel alignment with the muscle fibers on the rectus femoris (RF), vastus lateralis (VL), LG, and gluteus maximus (GM) (Figure 1). EMG placement was based on SENAMI Guidelines.²⁹ To ensure consistency, the EMG electrodes were placed on all participants by the same investigator.

Next, participants walked without an assistive device, with a knee scooter, and with an HFSC in a randomized order.



Figure 1. Trigno Avanti wireless Bluetooth sensors placement on a participant wearing the hands-free single crutch (iWALKFree). The left sensor is attached to the skin overlying the belly of the lateral gastrocnemius, the middle is over the belly of the vastus lateralis, and the right electrode is overlying the belly of the rectus femoris. The gluteus maximus sensor cannot be seen in this image.

Randomization was carried out using a random number generator, assigning each walking condition (no assistive device, HFSC, and knee scooter) a number. For each condition, participants were instructed to ambulate at a self-selected normal velocity. Participants then ambulated along a 20-m walking area while 15 seconds of the gait cycle was recorded. Participants were given as much time as needed to rest between trials. Before ambulating with the knee scooter (Figure 2) or the HFSC (Figure 3), participants were fitted to the devices to allow for optimal locomotion.¹⁵ Each participant was fitted by the same investigator to optimize consistency. Participants were given as much time as needed to become comfortable ambulating using the 2 assistive devices. Testing did not start until verbal affirmation was given that the participant felt comfortable ambulating with the devices. After completing all 3 conditions, participants were asked to fill out a perceived exertion scale from 0 to 10 for each assistive device and select which assistive device they preferred using.

Data Analysis

EMG data were recorded with a bandwidth of 20 to 450 Hz, range of 11 mV, and a sampling rate of 2148 Hz.⁹ Raw signals were processed with a Butterworth filter. EMG data



Figure 2. Participant using a knee scooter. The nonweightbearing leg is held in a horizontal position while the contralateral leg provides propulsion. One sensor can be seen attached to the skin overlying the rectus femoris.

were recorded by the EMG Acquisition Works program and then exported to the EMG Works Analysis program. The mean muscle activity and peak EMG activity were recorded for each muscle and ambulatory device. The root mean square (RMS) was calculated to normalize the EMG data and make it largely independent of the participants and measuring devices used in this study, as per standardized in the literature.⁷ Peak EMG activity was determined across each condition, normalized to the walking with no assistive device condition,⁷ and expressed as a percentage (% Peak EMG Activity), as shown in the equation below:

$$\% \text{ Peak EMG Activity} = \frac{\text{Peak EMG Activity}_i^j}{\text{Peak EMG Activity}_{walking}^j} \quad 1$$

where superscript $j \in \{RF, GM, LG, VL\}$; $j \in RF, GM, LG, VL$ denotes the muscles and subscript $i \in \{HFSC, \text{Knee Scooter}, \text{Walking}\}$; $i \in HFSC, \text{Knee Scooter}, \text{Walking}$ denotes the ambulatory devices. For notational simplicity, we dropped the subscript and superscript for the % Peak EMG Activity.

Statistical Analysis

Means and SDs were calculated for demographic data and outcome variables. Outcome variables included electromyographic

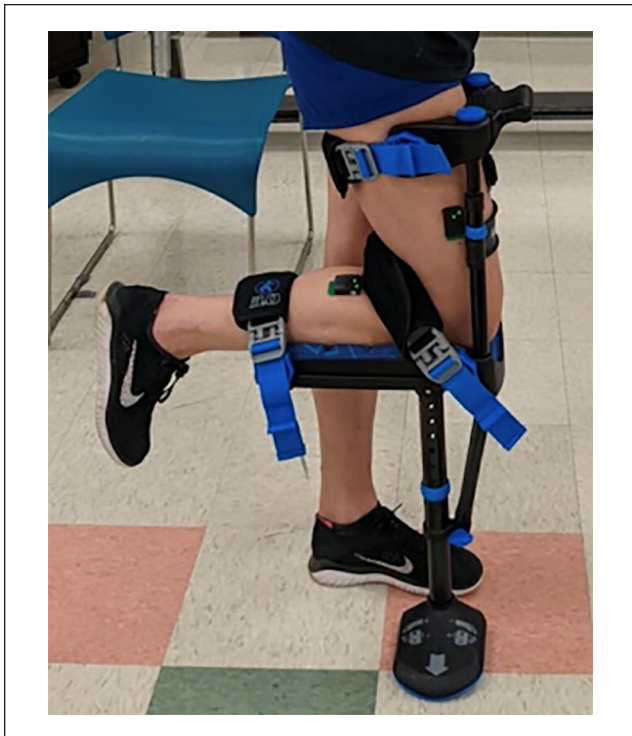


Figure 3. Hands-free single crutch (HFSC [iWALKFree]) and Trigno Avanti wireless Bluetooth sensors attached to the dominant leg of a participant. The HFSC holds the nonweightbearing leg in a horizontal position, allowing for bipedal gait with no loadbearing through the injured area. The sensors are attached to the skin overlying the lateral gastrocnemius (left), vastus lateralis (middle), and rectus femoris (right). The gluteus maximus sensor cannot be seen in this image.

(EMG) RMS muscle activity, the peak EMG activity percentage, and level of perceived exertion. The independent variable was device (no assistive device, knee scooter, and HFSC). Device preference between the knee scooter or HFSC was determined using frequency counts. Separate repeated measures analyses of variance were used to determine differences between devices with appropriate post hoc analyses using paired *t* test. Effect sizes (Cohen *d*) were also calculated for each outcome measure to provide insights into the magnitude of differences and interpreted as small (0.20), moderate (0.50), or large (0.80).⁶ Statistical significance was set a priori at $P < .05$. All statistical analyses were conducted using SPSS software (version 26.0; IBM Corp).

Results

When comparing the peak electromyographic (EMG) activity percentage between the HFSC and knee scooter, there was significantly greater normalized EMG muscle activity when using the HFSC (Table 2) in the RF ($P = .01$, $d = 0.48$), LG

Table 2. PEA Percentage for All 4 Muscles While Using the HFSC and Knee Scooter, Relative to the Walking Without an Assistive Device Condition.

Muscle	PEA Percentage		P Value
	HFSC	Knee Scooter	
Rectus femoris	3.1*	1.82*	.01
Vastus lateralis	2.39	2.1	.17
Lateral gastrocnemius	1.07*	0.44*	.02
Gluteus maximus	1.28*	0.95*	.02

Abbreviations: HFSC, hands-free single crutch; PEA, peak electromyographic activity.

*Statistically significant increase in PEA percentage ($P < .05$).

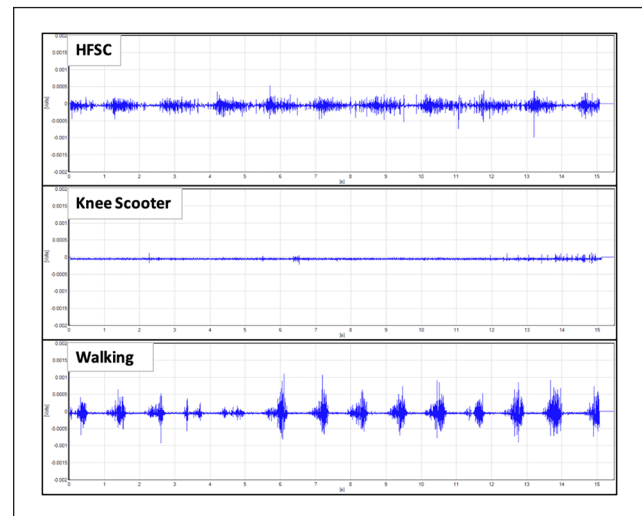


Figure 4. Example of the electromyography graphs recorded from the lateral gastrocnemius of 1 participant in the study. All graphs are set to the same scale. The top graph was recorded while using the hands-free single crutch (HFSC), the second while using the knee scooter, and the third while walking without an assistive device. The graphs show that the HFSC demonstrates increased muscle intensity when compared to the knee scooter and levels of cyclic contraction similar to walking.

($P = .02$, $d = 0.44$), and GM ($P = .02$, $d = 0.47$). The VL did not demonstrate a statistical difference in the peak EMG activity percentage ($P = .17$, $d = 0.26$). Sample EMG data from a single participant is provided (Figure 4) for the LG and highlights differences between conditions.

Mean EMG RMS muscle activity (Table 3, Figure 5) was significantly different across conditions for the RF ($P = .01$), VL ($P = .001$), and LG ($P < .001$). No significant difference was seen in mean RMS muscle activity between conditions for the GM ($P = .49$) (Table 3, Figure 5). When comparing the HFSC and knee scooter, only the LG demonstrated significantly greater EMG RMS muscle activity with the HFSC relative to the knee scooter ($P = .003$; $d = 0.59$). There was no significant difference in mean EMG RMS muscle activity

Table 3. Mean RMS Muscle Activity and SDs for the 4 Muscles Using Each Ambulatory Method (HFSC, Knee Scooter, and Walking Without an Assistive Device).

Muscle	RMS (SD) Muscle Activity*, mV		
	HFSC	Knee Scooter	Walking
Rectus femoris	0.052 ^c (0.047)	0.051 ^b (0.038)	0.032 ^{b,c} (0.013)
Vastus lateralis	0.079 ^c (0.071)	0.079 ^b (0.045)	0.038 ^{b,c} (0.019)
Lateral gastrocnemius	0.063 ^{a,c} (0.017)	0.055 ^{a,b} (0.016)	0.077 ^{b,c} (0.017)
Gluteus maximus	0.031 (0.012)	0.029 (0.014)	0.029 (0.013)

Abbreviations: HFSC, hands-free single crutch; RMS, root mean square.

*Statistical significance is marked with a superscript *a* for HFSC/knee scooter, *b* for knee scooter/walking, and *c* for HFSC/walking comparison.

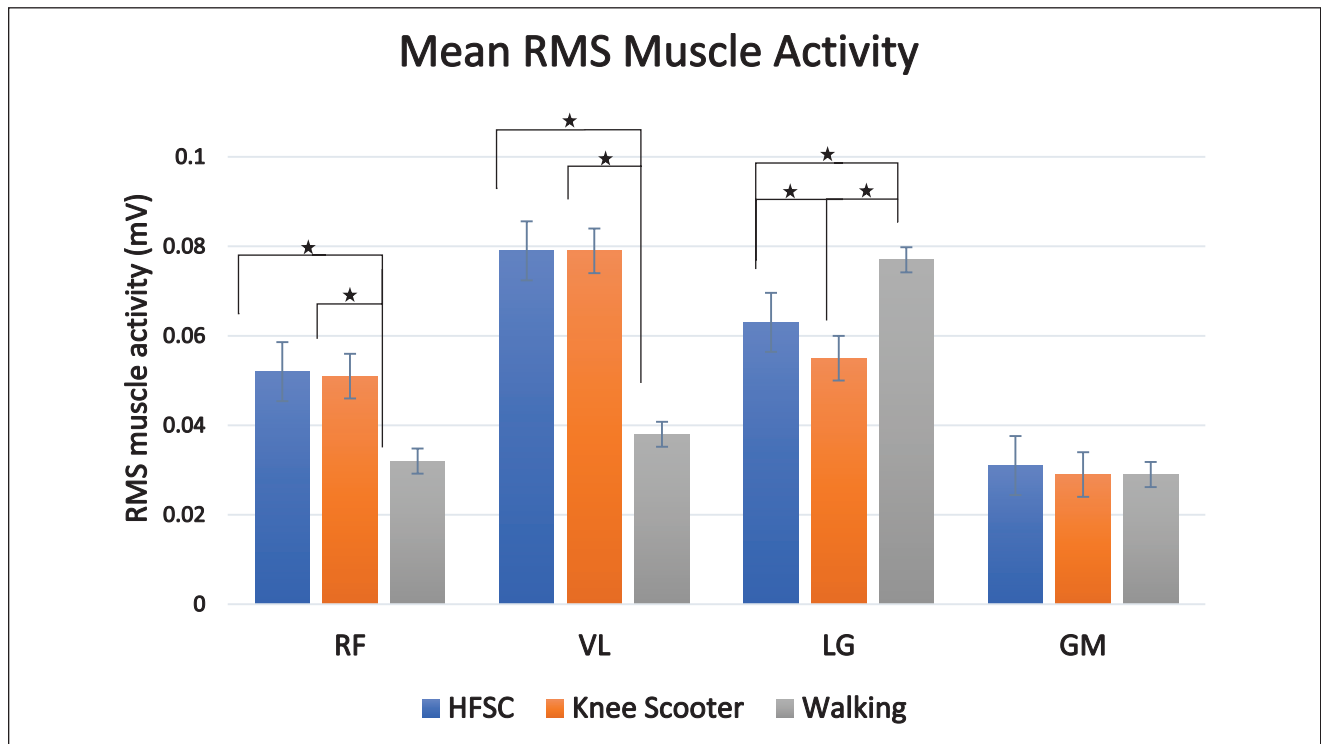


Figure 5. Side-by-side comparison of the mean RMS muscle activity in each muscle while using the 3 different ambulatory modalities (hands-free single crutch [HFSC], knee scooter, and walking without an assistive device). Statistical significance is marked with an asterisk.

between the HFSC and knee scooter for the RF ($P = .78$; $d = 0.05$), VL ($P = .98$; $d = 0.01$), or GM ($P = .23$; $d = 0.23$). When comparing mean EMG RMS muscle activity while using the HFSC to walking without an assistive device, there was significantly greater mean EMG RMS muscle activity in the RF ($P = .02$; $d = 0.44$) and VL ($P = .01$; $d = 0.59$) and significantly lower mean EMG RMS muscle activity in the LG ($P = .01$; $d = -0.64$). There was no significant difference ($P = .31$; $d = 0.19$) in GM mean EMG RMS muscle activity between the HFSC and walking without an assistive device. When comparing mean EMG RMS muscle activity while using the knee scooter to walking without an assistive device, there was significantly

greater mean EMG RMS muscle activity in the RF ($P = .01$; $d = 0.51$) and VL ($P = .001$; $d = 0.97$) and lower mean EMG RMS muscle activity in the LG ($P = .001$; $d = -1.30$). There was no significant difference ($P = .79$; $d = 0.05$) in GM mean EMG RMS muscle activity between the knee scooter and walking without an assistive device.

There was a significant difference in the perceived level of exertion ($P < .001$; $d = 1.25$), with the HFSC (3.9 ± 1.9 ; range 0-7) being perceived as requiring more effort than the knee scooter (1.4 ± 1.1 ; range 0-3). The majority of participants preferred the knee scooter (53%) relative to the HFSC (47%), but there was not a significant ($P = .86$) difference for preference between assistive devices.

Discussion

The results of our study demonstrate increased muscle activity and recruitment while maintaining cyclic contractions consistent with bipedal gait pattern when using the HFSC compared to a knee scooter. The RF, LG, and GM all had statistically significant increases in the percentage of peak EMG activity while using the HFSC compared to the knee scooter with effect sizes near .50, making it likely that there is a meaningful increase in muscle activity while using the HFSC. The LG also showed a statistically significant increase in mean RMS muscle activity while using the HFSC compared with the knee scooter, with an effect size greater than 0.50, meaning that there is a meaningful increase in muscle activity in the LG while using the HFSC. Results for the HFSC mean RMS muscle activity and the peak EMG activity percentage independently are consistent with the results we obtained in our previous study.¹¹ When comparing the mean RMS muscle activity while using either the HFSC or knee scooter to walking without an assistive device, both comparisons showed the same relationships of statistically significant increase in RF and VL muscle activity, no difference in GM activity, and statistically significant lower LG activity. These muscles were selected for examination to stay consistent with our previous study.^{10,11}

The heightened intensity and recruitment of these muscles while using the HFSC could potentially translate to decreased levels of muscle atrophy and increased blood flow leading to heightened venous return during nonweight-bearing recovery. Increased muscle activation has been shown to lead to increased muscle retention and mass.^{2,4,20,27} The HFSC increased muscle activity when compared to a knee scooter, which means it may increase muscle retention during nonweightbearing recovery from a lower extremity injury. Having heightened levels of muscle activity can potentially allow for greater retention of muscle mass when paired with procedures that allow for an early accelerated rehabilitation protocol.²¹ The heightened cyclic muscle contractions could also potentially facilitate vascularization of the lower extremity, while reducing potentially slowed venous return.¹² Knee scooters hold the lower extremity, from the knee down, on a horizontal platform. This position has been shown to potentially contribute to deep vein thrombosis owing to decreased blood flow observed via ultrasonography.³ The HFSC also holds the same area of the lower extremity on a horizontal platform, but increased levels of muscle activity in the lateral gastrocnemius could potentially allow for more regular levels of blood flow when compared with using a knee scooter.

Our results are consistent with a recent study by Reb et al that used ultrasonography to evaluate the effects of knee position and pedal musculovenous pump activation on popliteal venous flow.²⁶ They foremost identified that pedal

musculovenous pump activation produced a consistently larger positive effect than knee flexion on popliteal venous flow.²⁶ They also concluded that PMP activation is a valuable venous stasis countermeasure, substantiating our claim that with increased lateral gastrocnemius activity the HFSC could in fact reduce venous stasis.²⁶ The authors go on to identify that the knee position and lack of muscle contraction with the use of standard axillary crutches led to significantly decreased activation of the pedal musculovenous pump stimulated time-averaged peak velocity, which could potentiate venous stasis.²⁶ The lack of cyclic muscle contraction and pedal musculovenous pump activation with standard axillary crutches is also consistent with our previous study that clearly established minimal EMG activity while using standard axillary crutches as compared to an HFSC.¹¹

Although this study shows that the HFSC increases muscle activity overall and increased mean muscle activity in the LG in nonweightbearing conditions as compared to a knee scooter, we do not know if this will directly lead to decreased levels of atrophy, faster recovery, and increased lower extremity blood flow in individuals with lower extremity injury. Increased load on and activity of a muscle is known to lead to decreased atrophy,² but many factors impact a patient's recovery time line and muscle retention while nonweightbearing.^{4,20} Furthermore, even though we found that participants retained cyclic contractions while nonweightbearing, we did not directly measure muscle size over time or blood flow and therefore are only able to draw connections based on the knowledge that increased muscle activation leads to increased muscle retention and heightened venous return.^{4,12,20} Future studies should be done to examine the clinical outcomes of patients using these devices and examine the impact they have on the rate of recovery, muscle retention, and blood flow.

The gait cycle involves a highly coordinated neuromuscular balance altering eccentric and concentric contractions while maintaining balance throughout the bipedal gait. This coordination is rapidly altered with immobilization creating structural neuroplastic changes in the gray and white brain matter in as little as 16 days.¹⁸ The local processing units within the sensorimotor cortex are changed during immobilization, effecting visual motor adaptation. Our study demonstrates the HFSC maintains cyclic EMG activity of the RF, VL, GM, and LG owing to their involvement in the stance and swing phase of the gait cycle. By maintaining in-phase cyclic muscle activation, we have established these neuro-motor pathways remain active regardless of immobilization and weightbearing status while using an HFSC, which is consistent with previous studies.³³ The neuroplasticity while using an HFSC is further demonstrated by the GM demonstrating no significant change in EMG activity. The GM is a primary extensor of the hip while maintaining a balanced pelvis. To a lesser extent, but no less

important, the LG consistently demonstrated cyclic in-phase contraction regardless of it contributing to propulsion, thus further demonstrating unchanged neuromotor pathways.

The majority of participants preferred the knee scooter (53%) relative to the HFSC (47%), though it was not a statistically significant difference. This is not surprising as the HFSC is a relatively new ambulatory aid and not as well known as the knee scooter. Our results with the HFSC are promising and within keeping of prior prosthetic adaptation studies demonstrating early (less than 1 hour) improved self-selected walking speeds and energy return in 1.5 weeks, as the user learns how to load and unload the device.^{25,36} Although we were not critically evaluating safety, all subjects were able to complete the study unassisted without any adverse events (eg, falls). Participants also did not require much time to learn how to ambulate using the HFSC. Further longitudinal studies are needed to evaluate preference during activities of daily living. Participants also reported a statistically significant higher perceived exertion while using the HFSC compared to the knee scooter. This is consistent with the results seen in this study, as increased exertion correlates with the increased muscle contraction and intensity in the gait cycle while using the HFSC. A previous study examined patient preference and perceived exertion while using the HFSC and standard axillary crutches via the 6-minute walk test. It found that participants preferred and had less perceived exertion for the HFSC.²²

This study is limited in its generalizability because the age range of the participants only encompassed younger adults and none were impaired by injury. Future studies should be done to assess if the results of this study are reflected in all age ranges. Another limitation is that participants only walked with the device for a short period of time. Future studies will be needed to evaluate if the muscular activity remains the same in the long term or if it will change as users become more familiar with the device over time. This research also used the newest and best available EMG system, leading to scarce literature available for comparison to this study. A strength of this study is that a single trained EMG investigator conducted all recordings and EMG profiling. Additionally, all EMG electrodes were placed by the same investigator, allowing for consistent and precise placement of electrodes that led to accurate and consistent recordings of muscle activity.

Conclusion

This current study illustrates that an HFSC can maintain muscle activity similar to walking without an assistive device for most of the muscle groups tested and may enhance the cyclic contractions in the lateral gastrocnemius when compared to a knee scooter.

Ethical Approval

This study was approved by the Institutional Review Board at Creighton University (IRB 2002087).

Declaration of Conflicting Interests


The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Kevin D. Martin, DO, FAAOS, FAANA, reports consulting fees: iWALKFree. ICMJE forms for all authors are available online.

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