Variations in Patterns of Muscle Activity Observed in Participants Walking in Everyday Environments: Effect of Different Surfaces

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ABSTRACT

Purpose: The purpose of this study was to examine variations in lower limb surface electromyography (EMG) activity when individuals walked on different outdoor surfaces and to characterize the different potential motor strategies. ***Method:*** Forty healthy adult participants walked at a self-selected speed over asphalt, grass, and pavement. They then walked on an indoor treadmill at the same gait speed as observed for each outdoor condition. The EMG activity of the vastus lateralis (VL), tibialis anterior (TA), biceps femoris (BF), and gastrocnemius lateralis (GL) muscles was recorded, and the duration and intensity (root mean square) of EMG burst activity was calculated. ***Results:*** Walking on grass resulted in a longer TA burst duration than walking on other outdoor surfaces. Walking on pavement was associated with increased intensity of TA and VL activation compared with the indoor treadmill condition. The variability of EMG intensity for all muscle groups tested (TA, GL, BF, VL) was greatest on grass and lowest on asphalt. ***Conclusions:*** The muscle activity patterns of healthy adult participants vary in response to the different qualities of outdoor walking surfaces. Ongoing development of ambulatory EMG methods will be required to support gait retraining programs that are tailored to the environment.

Key Words: ambulatory assessment; electromyography; environment design; gait; technology assessment biomedical; wearable devices.

RÉSUMÉ

Objectif : examiner les variations à l'activité électromyographique (ÉMG) de surface des membres inférieurs lorsqu'une personne marche sur diverses surfaces extérieures et caractériser les diverses stratégies motrices potentielles. ***Méthodologie :*** au total, 40 participants adultes en santé ont marché à la vitesse de leur choix sur de l'asphalte, du gazon et du pavé. Ils ont ensuite marché sur un tapis roulant intérieur à la même vitesse que sur chaque surface extérieure. Les chercheurs ont enregistré l'activité ÉMG des muscles vaste latéral (VL), tibial antérieur (TA), biceps fémoral (BF) et gastrocnémien latéral (GL) et ont calculé la durée et l'intensité (moyenne quadratique) de la salve d'activité ÉMG. ***Résultats :*** la marche sur le gazon provoquait une salve d'activité du muscle TA plus longue que la marche sur les autres surfaces extérieures. La marche sur le pavé était liée à une augmentation de l'intensité d'activation des muscles TA et VL par rapport à celle sur le tapis roulant intérieur. La variabilité de l'intensité ÉMG de tous les muscles testés (TA, GL, BF, VL) était plus élevée sur le gazon et plus faible sur l'asphalte. ***Conclusion :*** les tracés d'activité musculaire de sujets adultes en santé varient selon diverses qualités des surfaces de marche extérieures. Les méthodes ÉMG ambulatoires devront évoluer de manière à soutenir les programmes de rééducation de la démarche adaptés à l'environnement.

Mots-clés : appareils portatifs; démarche; électromyographie; évaluation ambulatoire; surfaces de marche

Using surface electromyography (EMG) in gait laboratories is an established technique to clinically evaluate gait disorders.[1] By measuring variations in the electrical activity of muscle fibres, EMG provides insight into the timing and intensity of muscle bursts and can help clinicians examine pathological (e.g., paresis or spasticity) and functional (e.g., adaptive or compensatory) changes in patterns of muscle activity during gait.[2,3] Evaluations carried out in gait laboratories, however, provide only a snapshot of a person's locomotor profile,[4] and the extent to which these evaluations

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can predict further injury or falls risk is questionable.[5,6] Thus, there is a broad clinical demand for methods that support the analysis of movement in everyday environments.[4,7]

Recent advances in wearable sensor technology provide the opportunity to record EMG signals under ecologically valid conditions.[8–11] A small number of studies have attempted to characterize motor behaviour using these techniques: for example, Roy and colleagues used wearable EMG sensors to classify daily life movements (feeding, locomotion, etc.) and distinguish clinical features (tremor and dyskinesia) in patients with neurological disorders.[12,13] Studies examining patterns of muscle activation during walking in outdoor contexts, however, remain scarce.[14] To develop pertinent clinical approaches to examining muscle burst timing during everyday walking, ongoing work is needed to understand how different patterns of muscle activation correspond with particular environmental conditions.[15]

Previous studies have described changes in lower limb EMG activity when participants walked on different surfaces in experimental laboratory settings. These studies have shown, that uneven and slippery conditions may solicit a general prolongation in muscle burst duration.[16,17] In the present study, we examine how patterns of lower limb muscle activity vary across different terrains typically encountered in day-to-day walking. The first surface, asphalt, is highly regular. The second, pavement, is more irregular, with greater surface roughness, and the presence of macroscopic particles (e.g., sand) cause variations in the coefficient of friction.[18] The third surface, grass, has comparatively lower rigidity at the surface layer and potential variations in the surface roughness of the ground.

We hypothesized that variations in the duration and intensity of EMG activity would be more apparent on the comparatively irregular pavement and grass surfaces than on the more regular asphalt surface. Given that lower limb muscle activity is related to walking speed,[19] we also carried out further testing at corresponding gait speeds on an indoor treadmill. We used this measure to verify that the differences in EMG patterns seen between an outdoor walking surface and the associated treadmill trial were specific to the surface rather than the gait speed.

METHODS

Participants

We recruited a convenience sample of 40 healthy participants (17 women, 23 men; mean age 22.8 [SD 2.2] years, mean height 174.2 [SD 5.9] cm; Table 1). The Université Catholique de Louvain ethics committee approved the study protocol (Agreement No. B403201523492). We obtained written consent from the participants before testing.

Experimental setup

The EMG telemetry system (FREEEMG 1000, BTS Bioengineering Corp., Milan, Italy) recorded data at a frequency of 1 kilohertz on the vastus lateralis (VL), tibialis anterior (TA), biceps femoris (BF), and gastrocnemius lateralis (GL) of the non-dominant leg (determined using Item 1 of the Waterloo Footedness Questionnaire).[20] This choice of muscle groups reflects prime movers in sagittal plane mechanics, important for forward locomotion. Each participant's skin was shaved and cleaned before electrode placement, and electrode placement complied with the recommendations established by Perotto.[21] A global positioning system watch worn on the participants' wrist measured outdoor gait speed. Testing against a manual stopwatch over a distance of 100 metres confirmed the accuracy of this device (bias, 0.005 ms^{-1}; limits of agreement: -0.13 ms^{-1}, 0.14 ms^{-1}).

Table 1 Participant Characteristics ($N = 40$)

	Mean (SD)		
Gender	Age, y	Weight, kg	Height, cm
Women ($n = 17$)	22.53 (2.21)	59.29 (6.90)	167.53 (4.91)
Men ($n = 23$)	23.04 (2.16)	75.75 (9.66)	180.96 (6.79)

Experimental procedure

The participants walked at a spontaneous gait speed, wearing their habitual footwear, on three flat outdoor surfaces: asphalt (A), grass (G), and pavement (P; see online Figure S.1). We instructed them to walk forward, in a straight line, from a designated location to a fixed target in front of them. The order of the trials was randomly allocated, yielding one of six possibilities (AGP, APG, GAP, GPA, PAG, PGA). We carried out the trials in favourable weather and with sufficient light. The location of the chosen paths minimized potential interactions with other pedestrians or distractions in the visual field (heavy traffic, bike path, etc.). Because we conducted this experiment on a university campus, there was continuous, ambient background noise, common to urban environments (birds, distant traffic, etc.). After this trial, the participants walked on an indoor treadmill at the same gait velocities as they did outdoors. We recorded the EMG signals for 60 seconds in each condition.

Electromyography signal processing

The raw EMG signals were rectified, and the linear envelope was processed using a fifth-order low-pass Butterworth filter with a cutoff frequency of 20 Hertz. For each of the four conditions (asphalt, grass, pavement, and treadmill), 20 successive bursts of EMG activity were identified using the method described by Van Boxtel and colleagues (shown in online Figure S.2).[22] Then, we collated the durations of the individual muscle bursts for each condition.

We then calculated the root mean square (RMS) value for each burst using Equation 1.

$$RMS = \sqrt{\frac{\sum_{i=0}^{n=1} X_i^2}{n}}, \quad (1)$$

where i = number of frame, X = EMG signal, and
n = number of selected frames.

The mean and the coefficient of variation (CV) were calculated for each parameter on the 20 successive bursts (burst duration, RMS). CV is a measure of relative variability and was calculated using Equation 2.

$$CV = \frac{standard\ deviation}{mean}. \tag{2}$$

Statistical analysis

We examined the differences in gait speed in the outdoor conditions using repeated-measures analysis of variance (RM-ANOVA). We similarly examined mean and CV values for EMG burst duration and RMS using one-way RM-ANOVA (outdoor surface condition with three levels: asphalt, grass, and pavement). When data were not normally distributed, we used non-parametric equivalents (by rank). Multiple comparisons during post hoc analysis were corrected using the Bonferroni or Dunn method (with asphalt as the control condition) when required. We used paired t-tests to compare walking on outdoor surfaces with walking on a treadmill at the corresponding gait speed. The threshold for statistical significance was set at $p = 0.05$. We performed statistical analyses using IBM SPSS Statistics, Version 25.0 (IBM Corporation, Armonk, NY) and SigmaPlot (Systat Software Inc., San Jose, CA).

RESULTS

Gait speed across outdoor surfaces

Spontaneous gait speed varied across the three outdoor surfaces, $F_{(2,39)} = 1.35$, $p = 0.010$, with participants walking at a mean speed of 1.33 (SD 0.19) ms^{-1} on asphalt, 1.31 (SD 0.22) ms^{-1} on grass, and 1.2 (SD 0.31) ms^{-1} on pavement. Post hoc testing confirmed that gait speed was greater on asphalt than on pavement ($p = 0.008$).

Muscle activity patterns across outdoor walking surfaces

The mean duration of TA activity varied according to surface, $\chi^2_{(2,\ N = 39)} = 10.364$, $p = 0.006$, with a median value for mean burst duration of 0.68 second on asphalt, 0.72 second on grass, and 0.68 second on pavement. Type of surface also had a significant effect on the CV of burst duration for VL, $\chi^2_{(2,\ N = 39)} = 6.867$, $p = 0.032$, and TA, $\chi^2_{(2,\ N = 39)} = 6.606$, $p = 0.037$, with CV values increasing from asphalt to grass to pavement, respectively. Post hoc testing indicated that the CV of duration of VL activity was greater on pavement than on asphalt ($p = 0.026$).

The variation of EMG intensity similarly changed from one surface to another. RM-ANOVA yielded significant differences for the CV of RMS values in each muscle group ($p < 0.001$). Post hoc testing indicated that the CV of RMS values was greater on grass than on asphalt ($p < 0.001$ for each muscle) and greater on pavement than on asphalt ($0.002 < p < 0.011$ for the different muscles tested).

Figure 1 illustrates the intensity of EMG burst activity in the four muscle groups as the participants walked on the three outdoor surfaces and the treadmill. Figure 1a shows significant differences in the CV of RMS values in each muscle group for the outdoor surfaces. Figure 1b

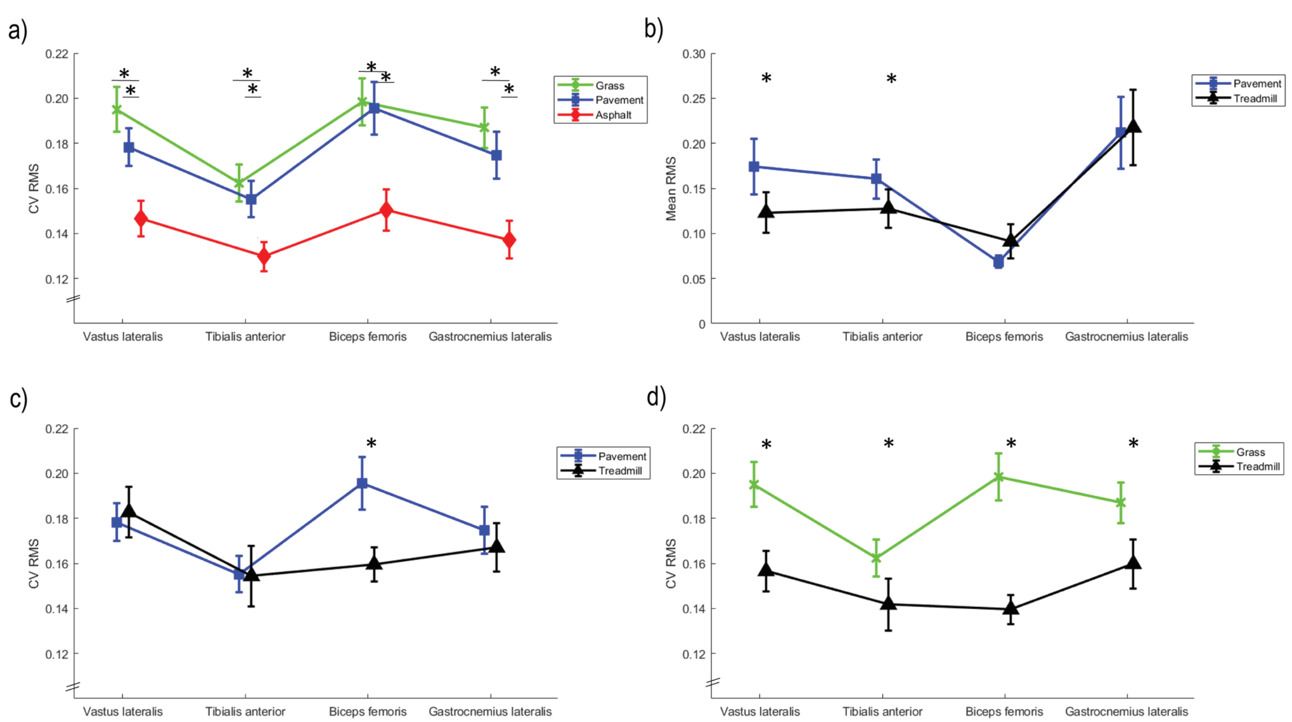

Figure 1 Intensity of EMG burst activity in the muscle groups for the outdoor surfaces and the treadmill: (a) summary of the CV of RMS values for each muscle group across the outdoor surfaces; (b) paired t-test between the outdoor surface and treadmill at the same speed;(c) CV of RMS for the BF between the pavement and treadmill conditions; and (d) CV of RMS values for all muscle groups between the grass and treadmill conditions.

* Significant difference ($p < 0.05$).

EMG = electromyography; CV = coefficient of variation; RMS = root mean square; BF = biceps femoris.

Table 2 Muscular Strategies on Outdoor Surfaces

EMG activity, parameter, and muscle	Outdoor surface, median (25th–75th percentile)			ANOVA *p* -value	Post hoc *p* -value	
	Asphalt	Grass	Pavement		Asphalt vs. grass	Asphalt vs. pavement
Intensity: RMS, mV						
Mean						
Walking speed, ms^{-1}	1.33 (1.23–1.46)	1.28 (1.17–1.36)	1.19 (0.94–1.44)	0.01	0.546	0.006
Vastus lateralis	0.089 (0.056–0.233)	0.089 (0.055–0.201)	0.099 (0.059–0.194)	0.53	–	–
Tibialis anterior	0.105 (0.071–0.190)	0.112 (0.069–0.171)	0.099 (0.073–0.194)	0.53	–	–
Biceps femoris	0.066 (0.038–0.112)	0.061 (0.040–0.099)	0.053 (0.037–0.100)	0.51	–	–
Gastrocnemius lateralis	0.108 (0.044–0.407)	0.102 (0.514–0.321)	0.091 (0.045–0.199)	0.53	–	–
CV						
Vastus lateralis	0.13 (0.11–0.18)	0.19 (0.15–0.23)	0.17 (0.15–0.21)	< 0.001*	< 0.001	0.004
Tibialis anterior	0.13 (0.10–0.15)	0.16 (0.12–0.19)	0.14 (0.12–0.19)	< 0.001*	< 0.001	0.005
Biceps femoris	0.13 (0.11–0.18)	0.19 (0.15–0.24)	0.18 (0.16–0.24)	< 0.001*	< 0.001	0.002
Gastrocnemius lateralis	0.13 (0.09–0.18)	0.18 (0.15–0.23)	0.16 (0.13–0.20)	< 0.001*	< 0.001	0.008
Activation duration, s						
Mean						
Vastus lateralis	0.47 (0.33–0.83)	0.47 (0.36–0.79)	0.50 (0.33–0.81)	0.43	–	–
Tibialis anterior	0.68 (0.51–0.82)	0.72 (0.59–0.82)	0.68 (0.57–0.83)	0.006*	0.006	0.019
Biceps femoris	0.60 (0.47–0.66)	0.56 (0.48–0.67)	0.55 (0.49–0.65)	0.28	–	–
Gastrocnemius lateralis	0.64 (0.49–0.74)	0.68 (0.55–0.77)	0.68 (0.54–0.81)	0.79	–	–
CV						
Vastus lateralis	0.13 (0.08–0.18)	0.15 (0.10–0.19)	0.15 (0.09–0.21)	0.032*	0.187	0.020
Tibialis anterior	0.13 (0.09–0.18)	0.14 (0.09–0.18)	0.15 (0.11–0.18)	0.037*	1.000	0.073
Biceps femoris	0.15 (0.12–0.19)	0.17 (0.13–0.22)	0.17 (0.15–0.23)	0.15	–	–
Gastrocnemius lateralis	0.15 (0.11–0.18)	0.15 (0.120.19)	0.15 (0.12–0.20)	0.85	–	–

Notes: Dash indicates no significant difference and no post hoc test performed.
* $p < 0.05$.
ANOVA = analysis of variance; EMG = electromyography; RMS = root mean square; CV = coefficient of variation.

shows significant differences in the mean RMS values for the VL and TA between the pavement and treadmill conditions, and Figure 1c shows a significant difference for the CV of RMS values for the BF between the pavement and treadmill conditions. Figure 1d shows a significant difference for each muscle group for the CV of RMS values between the grass and treadmill conditions.

Table 2 provides further details on these results.

Comparison of muscle activity patterns between outdoor surfaces and indoor treadmill

The participants' EMG intensity when walking on pavement was different from that observed at matched gait speed on an indoor treadmill. The median value of mean RMS for the VL was 0.099 millivolt on pavement compared with 0.079 millivolt on the treadmill ($p = 0.015$), whereas the median value of mean RMS for the TA was 0.099 millivolt on pavement compared with 0.089 millivolt on the treadmill ($p = 0.006$).

When the participants walked on grass, the BF median intensity was 0.18 millivolt, greater than the 0.15 millivolt observed on the treadmill ($p = 0.004$). The CV of intensity was greater on grass than on the treadmill for the ensemble of muscles tested (VL, $p = 0.002$; BF, $p = 0.013$; TA, $p < 0.001$; GL, $p = 0.011$). The median CV of the GL burst duration was also greater on grass (0.15 s) than in the treadmill condition (0.11 s; $p = 0.02$).

We observed no differences between the participants walking on asphalt and those walking on the treadmill for any of the parameters tested. Figures 1b–1d illustrate significant findings, and Tables 2–5 provide further details of the statistical comparisons between outdoor walking surfaces and indoor treadmill walking at the corresponding gait speed.

DISCUSSION

Consistent with our initial hypothesis, EMG activity changed when participants walked on different outdoor walking surfaces. Our principal finding was that the CV of EMG intensity (RMS) varied for each muscle group tested (VL, BF, TA, and GL; see Figure 1a).

Changes in muscle activity in response to outdoor walking surfaces

Walking on pavement resulted in increased RMS values of EMG activity in the TA and VL. When they make contact

Table 3 Muscular Strategies on Asphalt versus Treadmill

EMG activity, parameter, and muscle	Median (25th–75th percentile)		Paired two-tailed p -value
	Asphalt	Treadmill vs. asphalt	
Intensity: RMS, mV			
Mean			
Vastus lateralis	0.089 (0.056–0.233)	0.087 (0.057–0.181)	0.13
Tibialis anterior	0.105 (0.071–0.190)	0.110 (0.068–0.190)	0.44
Biceps femoris	0.066 (0.038–0.112)	0.047 (0.033–0.092)	0.42
Gastrocnemius lateralis	0.108 (0.044–0.407)	0.097 (0.046–0.313)	0.63
CV			
Vastus lateralis	0.13 (0.11–0.18)	0.13 (0.12–0.17)	0.42
Tibialis anterior	0.13 (0.10–0.15)	0.13 (0.09–0.16)	0.76
Biceps femoris	0.13 (0.11–0.18)	0.13 (0.12–0.16)	0.76
Gastrocnemius lateralis	0.13 (0.09–0.18)	0.14 (0.11–0.15)	0.30
Activation duration, s			
Mean			
Vastus lateralis	0.47 (0.33–0.83)	0.47 (0.35–0.80)	1.00
Tibialis anterior	0.68 (0.51–0.82)	0.63 (0.49–0.76)	0.53
Biceps femoris	0.60 (0.47–0.66)	0.57 (0.47–0.68)	0.83
Gastrocnemius lateralis	0.64 (0.49–0.74)	0.65 (0.57–0.78)	0.14
CV			
Vastus lateralis	0.13 (0.08–0.18)	0.12 (0.09–0.16)	0.78
Tibialis anterior	0.13 (0.09–0.18)	0.15 (0.11–0.18)	0.24
Biceps femoris	0.15 (0.12–0.19)	0.17 (0.13–0.22)	0.73
Gastrocnemius lateralis	0.15 (0.11–0.18)	0.13 (0.09–0.17)	0.15

EMG = electromyography; RMS = root mean square; CV = coefficient of variation.

with the ground, these muscles work together, ensuring stability from heel strike to the transfer of weight after initial contact.[1] The increased intensity of their activity on pavement is likely to reinforce dorsiflexion and knee extension through these points in the gait cycle. These results may be compatible with those of another study that noted specific kinematic changes for the knee and ankle in healthy participants and patients with Parkinson's disease who walked on a cobblestone surface.[23] Increased amplitude of the knee through the sagittal plane and increased ankle joint stability may be considered adaptation strategies to this irregular surface, and they may cause divergent concentric or eccentric muscle contractions across the knee and ankles. Whether these changes in EMG intensity compensate for the hardness (and corresponding shock when participants place their foot) or irregularity of the surface underfoot remains to be determined.

Walking on grass resulted in longer burst duration for the TA. An increased EMG duration through stance phases has been associated with strategies for enhanced gait stability. For example, TA burst duration increases on slippery walkways, and a co-contraction of the GL and TA inhibits unintended variations in ankle motion.[17] The TA also supports dorsiflexion, thus ensuring foot clearance; however, because it is typically active through the entire duration of the swing phase,[1] it is less likely that the increased burst duration observed on grass would be associated with this phase. The CV of EMG intensity was consistently greater for grass than for the other surfaces for all muscles. Instead of producing a fixed change in muscle firing patterns, walking on grass appears to involve punctual changes in muscle activation. This finding reflects the small, continuous variations in the camber and roughness of grassy outdoor surfaces. Punctual modifications in EMG intensity at the level of the knee and ankle are potentially associated with changes in surface regularity through the antero-posterior and medio-lateral axes, respectively.[24]

The absence of significant differences in EMG activity between asphalt and the indoor treadmill condition underscores the relatively consistent properties of this outdoor surface.

Electromyography data from everyday walking environments for improved patient care

Improving individuals' gait stability in everyday settings means identifying and training their adaptive neuromuscular responses. The changes in EMG activity that we observed appear consistent with mechanisms for ensuring gait stability. We presume that this ability to regulate EMG activity would be diminished in people with pathology of the locomotor system. People with recurrent ankle injuries have

Table 4 Muscular Strategies on Pavement versus Treadmill

EMG activity, parameter, and muscle	Median (25th–75th percentile)		Paired two-tailed *p* -value
	Pavement	Treadmill vs. pavement	
Intensity: RMS, mV			
Mean			
Vastus lateralis	0.099 (0.059–0.194)	0.079 (0.047–0.152)	0.015*
Tibialis anterior	0.099 (0.073–0.194)	0.089 (0.061–0.135)	0.006*
Biceps femoris	0.053 (0.037–0.100)	0.040 (0.032–0.102)	0.48
Gastrocnemius lateralis	0.091 (0.045–0.199)	0.087 (0.038–0.285)	0.07
CV			
Vastus lateralis	0.17 (0.15–0.21)	0.17 (0.13–0.22)	0.12
Tibialis anterior	0.14 (0.12–0.19)	0.13 (0.11–0.18)	0.14
Biceps femoris	0.18 (0.16–0.24)	0.15 (0.13–0.18)	0.004*
Gastrocnemius lateralis	0.16 (0.13–0.20)	0.15 (0.11–0.21)	0.13
Activation duration, s			
Mean			
Vastus lateralis	0.50 (0.33–0.81)	0.49 (0.36–0.75)	0.64
Tibialis anterior	0.68 (0.57–0.83)	0.68 (0.52–0.84)	0.97
Biceps femoris	0.55 (0.49–0.65)	0.61 (0.52–0.74)	0.07
Gastrocnemius lateralis	0.68 (0.54–0.81)	0.71 (0.52–0.80)	0.71
CV			
Vastus lateralis	0.15 (0.09–0.21)	0.13 (0.09–0.19)	0.06
Tibialis anterior	0.15 (0.11–0.18)	0.15 (0.09–0.19)	0.78
Biceps femoris	0.17 (0.15–0.23)	0.17 (0.12–0.20)	0.17
Gastrocnemius lateralis	0.15 (0.12–0.20)	0.15 (0.10–0.19)	0.13

* $p < 0.05$.
EMG = electromyography; RMS = root mean square; CV = coefficient of variation.

difficulty managing frontal plane dynamics,[25] so they would likely exhibit deficient EMG firing patterns on surfaces that induce lateral instability. Older adults have a tendency to increase agonist–antagonist co-activation during stance phases.[26] Age-related decline in gait function would potentially involve individuals exhibiting stereotypical patterns of co-contraction to maintain their joint stability in anticipation that the surface they are walking on is irregular.

A potential benefit of ecological EMG data is the ability to verify how the neuromuscular exercises used in rehabilitation are generalized to everyday life situations. Gait retraining after a musculoskeletal lesion typically involves progressions combining bilateral and unilateral exercises with varying degrees of surface instability and dynamic movement. However, these interventions are not necessarily associated with changes in kinematic patterns during laboratory gait analyses.[27] EMG data from everyday life situations may prove to be more sensitive to the different mechanisms (e.g., feed-forward movement processing, proprioceptive neuromuscular correction) that contribute to adaptive patterns of muscle activation.

In addition to their diagnostic and evaluative purposes, wearable EMG sensors have the potential to become a viable tool in gait rehabilitation. Previous clinical studies have suggested that task-oriented biofeedback approaches effectively support motor learning. For example, EMG biofeedback training for patients with neurological conditions has been associated with a significant improvement in joint power, stride length, and gait speed compared with conventional gait rehabilitation methods.[28,29] One can imagine that real-time feedback on patterns of muscle activity over varying terrains might provide a particular advantage in consolidating novel motor strategies for enhanced gait stability in daily life environments.

This study has several limitations that may be attributed to both methodological choices and current technological barriers. First, the design of our study would have been improved by including a further experimental condition in which participants were required to walk at a specific gait speed over each outdoor surface; this would have improved the validity of directly comparing EMG parameters across the surfaces. Second, using a counterbalanced trial order as opposed to a randomised trial order may have further reduced potential biases related to sequencing the conditions. Third, adding more EMG sensors (e.g., to the peroneus) may have given us greater insight into muscle activation that provided support against lateral instability. More important, to be used as a truly valid ecological gait assessment tool, EMG sensors must be coupled with additional sensors (accelerometers, foot switches) that are capable of distinguishing the different phases of the gait

Table 5 Muscular Strategies on Grass versus Treadmill

EMG activity, parameter, and muscle	Median (25th–75th percentile) Grass	Treadmill vs. grass	Paired two-tailed *p* -value
Intensity: RMS, mV			
Mean			
Vastus lateralis	0.089 (0.055–0.201)	0.088 (0.047–0.171)	0.21
Tibialis anterior	0.112 (0.069–0.171)	0.104 (0.061–0.164)	0.15
Biceps femoris	0.061 (0.040–0.099)	0.049 (0.031–0.089)	0.07
Gastrocnemius lateralis	0.102 (0.514–0.321)	0.084 (0.040–0.285)	0.17
CV			
Vastus lateralis	0.19 (0.15–0.23)	0.15 (0.12–0.17)	0.002*
Tibialis anterior	0.16 (0.12–0.19)	0.13 (0.09–0.15)	0.013*
Biceps femoris	0.19 (0.15–0.24)	0.14 (0.11–0.16)	< 0.001*
Gastrocnemius lateralis	0.18 (0.15–0.23)	0.14 (0.12–0.18)	0.011*
Activation duration, s			
Mean			
Vastus lateralis	0.47 (0.36–0.79)	0.48 (0.36–0.79)	0.73
Tibialis anterior	0.72 (0.59–0.82)	0.69 (0.52–0.79)	0.23
Biceps femoris	0.56 (0.48–0.67)	0.59 (0.51–0.72)	0.31
Gastrocnemius lateralis	0.68 (0.55–0.77)	0.65 (0.49–0.81)	0.73
CV			
Vastus lateralis	0.15 (0.10–0.19)	0.14 (0.10–0.17)	0.53
Tibialis anterior	0.14 (0.09–0.18)	0.16 (0.09–0.18)	0.79
Biceps femoris	0.17 (0.13–0.22)	0.16 (0.11–0.20)	0.25
Gastrocnemius lateralis	0.15 (0.12–0.19)	0.11 (0.07–0.17)	0.02*

* $p < 0.05$.
EMG = electromyography; RMS = root mean square; CV = coefficient of variation.

cycle.[30] This would considerably improve the functional interpretation of variations in muscle activity. Finally, EMG signal processing remains a time-consuming process, and clinicians need software that facilitates data analysis. Evaluating muscle activity during gait in daily life situations will thus require greater clinical resources and the development of user-friendly methods of data analysis.

CONCLUSIONS

Healthy adult participants modify their patterns of lower limb muscle activity according to the characteristics of outdoor walking surfaces. We propose that an improved understanding of EMG activity across different terrains can be useful in planning and evaluating the effectiveness of gait rehabilitation. Ongoing collaborative work between physiotherapists and medical engineers is necessary to further develop EMG methods for analysing gait in everyday environments.

KEY MESSAGES

What is already known on this topic

With the development of onboard sensor technology, it is now possible to record electromyography (EMG) data in everyday situations. Still, these methods are not sufficiently mature to be used in clinical gait assessment.[4] A central problem is interpreting these data in non-standardised conditions.[31]

What this study adds

This study demonstrates that individuals' patterns of muscle activation change over different walking surfaces. Modifications in burst duration or intensity may reflect the specific properties of each surface, and an increased variation in the EMG parameters would result from punctual changes in surface quality. Onboard EMG sensors could be used to evaluate muscular responses during walking.

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