Biointerfacial Characterization of Neuromuscular Activity.

Michael Wininger BS[1], Don Yungher BS[1], JB Barr PT DPT[2], A Joseph Threlkeld PT PhD[2], William Craelius PhD[1]

[1]Department of Biomedical Engineering, Rutgers, The State University of New Jersey

[2]Department of Physical Therapy, Creighton University

Introduction

Motivation: Gait analysis with EMG is a difficult and often laborious process[1]. An ideal interface should extract maximal information from the neuromuscular system (NMS) non-invasively and at the same time provide high-bandwidth bi-directional communication with the NMS. **Goals: 1)** Develop a minimally-invasive technology which will monitor an individual's muscular activity through a simple and comfortable interface. **2)** Examine the correspondence between electrical activities pertaining to volitional activity and the subsequent muscular response. **Design:** The Myokinetic Interface (MKI) is a wearable sleeve array of force-sensitive resistors (FSR's) which decode in near real-time with linear trainable filters, to be worn comfortably around the distal limb, covering major muscle groups, recording their pressure distributions. **Results:** Close correlation between MKI and EMG was found in preliminary work on the application of MKI to the lower limb in gait analysis: MKI was found to be highly repeatable, and offers a counter-argument to the concept of electromechanical delay in skeletal muscle. **Projection:** We are currently adapting the technology to people with a spinal cord injury, Parkinson's Disease or following a stroke as a biofeedback aid. Additionally, we are evaluating other materials for incorporation into the man-machine interface including piezoelectric polymers poly-L lactic acid (PLLA) and poly-vinylidine fluoride (PVDF).

Methods

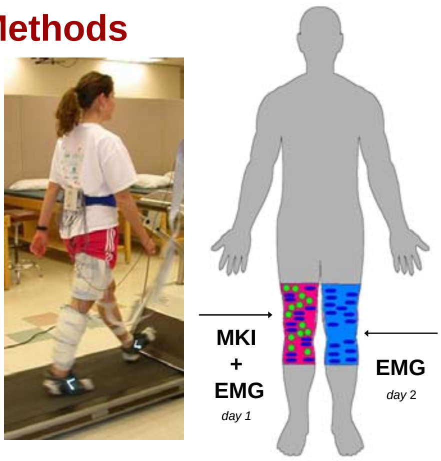


Figure: Subject donned MKI and EMG on same (day 1) and different (day 2) legs, and walked on a treadmill at 1.8, 3.0, and 6.0mph.

EMG → Filter:~3Hz → threshold

MKI → threshold

threshold → On/off times → ANOVA, VR

-8 EMG tracks over the major anterior and posterior thigh muscles.

-33 MKI tracks: 17 ant/post thigh, 16 shank

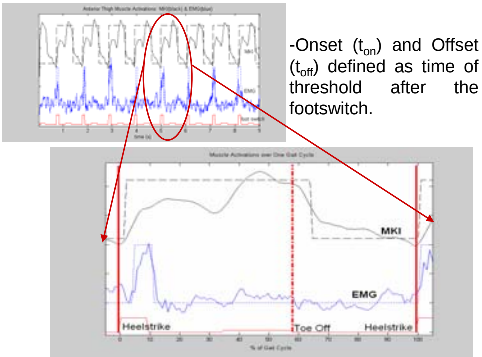
-Healthy female, mid-20's, trained treadmill walker

-EMG and MKI on same (day 1) and different leg (day 2)

-EMG filtered with a simple 7-wt linear filter, MKI unfiltered.

Results

Muscle Activity Timing



-Onset (t_{on}) and Offset (t_{off}) defined as time of threshold after the footswitch.

Each step (determined by foot switch) is evaluated of on-set and off-set timing.

	EMG	MKI
t_{on} (msec)	18.8 ± 37.6	15.0 ± 5.35
t_{on} (% of cycle)	1.77 ± 3.54	1.41 ± 0.50

Timing of Muscle Activity Onsets, as measured by EMG and MKI, mean ± std.dev.

$$Z_{obt} \equiv \frac{(\bar{X}_1 - \bar{X}_2) - \overbrace{(\mu_1 - \mu_2)}^{presume\ 0}}{\sigma_{\bar{x}_1 - \bar{x}_2}} \qquad Z_{obt} = 0.2648 \ll \pm \underbrace{1.96}_{\alpha = 0.05}$$

Z-scores show stasitical certainty in muscle activity timing.

Repeatability

The Variance Ratio (VR) quantifies the repeatability[3] of the wave-forms over multiple (8) gait cycles:

$$VR = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n}(X_{ij} - \bar{X}_i)^2/k(n-1)}{\sum_{i=1}^{k}\sum_{j=1}^{n}(X_{ij} - \bar{X})^2/(kn-1)}$$

	VR
MKI	0.028
EMG(raw)	0.877
EMG(enveloped)	0.555

Variance Ratio (where identical signals → 0 and random noise → 1) calculated for EMG and MKI.

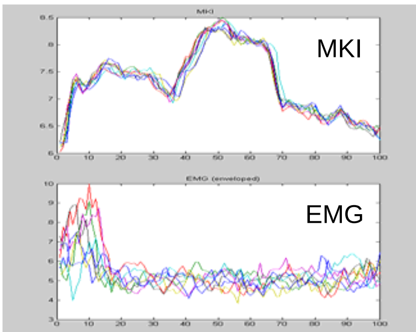


Figure: Overlays of signals from eight gait cycles: raw MKI (top) and EMG (bottom)

-MKI is demonstrably more repeatable than EMG[2].

Statistical Compatibility

-Timing statistics for the 3mph:

	EMG (msec)(mean ± s.d.)	MKI (msec)(mean ± s.d.)
t_{on}	18.8 ± 37.6	15.0 ± 5.35
t_{off}	129 ± 24.2	691 ± 8.35
duration	110 ± 38.9	676 ± 7.44

	EMG (% of cycle)(mean ± s.d.)	MKI (% of cycle)(mean ± s.d.)
t_{on}	1.77 ± 3.54	1.41 ± 0.50
t_{off}	12.1 ± 2.28	65.1 ± 0.79
duration	10.4 ± 3.67	63.7 ± 0.70

-One-way classification (ANOVA) calculates the inter-rater compatibility between the MKI and EMG.

$$\bar{X} \equiv \frac{1}{2n}\sum_i^n(\vec{X}_i) + \sum_i^n(\vec{Y}_i)$$

$$r' = \frac{\sum|(X - \bar{X})|\sum|(Y - \bar{X})|}{\left(\sum(|X - \bar{X}|)^2) + (\sum(|Y - \bar{X}|)^2\right)}$$

Results were calculated for two days at moderate speed, and one day at high speed over 9 steps:

	6mph	3mph(1)	3mph(2)
t_{on}	0.8764	0.8347	0.9586
t_{off}	0.9930	0.9905	0.9935
dur	0.9304	0.9896	0.9907

This correlation value indicates that there is reasonable-to-excellent agreement between methods for quantifying timing within the gait cycle, when systematic biases are eliminated.

Conclusion

-MKI is more repeatable than the standard means of detection of neuromuscular volition.

-MKI waveform outlasts EMG in-whole or in-part due to the muscle activation

-For timing, the EMG and MKI exhibit moderate to excellent compatibility.

-Z-score shows that simultaneity of muscle activity timing is well within the range of statistical certainty.

Feature	EMG	MKI
Detects both superficial and deep muscular activity	No	Yes
Operates without precise electrode placement	No	Yes
Eliminates electrodes and gel	No	Yes
Easily donnable by users	No	Yes
Useable in MRI	No	Yes
Useable raw signals	No	Yes

Future: By providing a non-invasive and readily usable means of detection of muscular volition, many diagnostic and rehabilitative procedures can be conducted more conveniently, more affordably, and requires less expertise to operate and interpret. We are developing the MKI for use in control of prosthetic devices, gait analysis and as biofeedback in stroke rehabilitation. *Extension:* By evaluating PLLA and PVDF for their piezoelectric properties in these strain conditions, it may be possible to adapt the principles of the MKI for neuromuscular assessment *in vivo* and the MKI itself for use in MRI.

References

[1]**Wininger M**, Kim N-H, Dougherty J, Craelius W, A Novel Biointerface for Detection of Volition and Muscle Activity, *Proceedings of the 2nd Annual New Jersey Bioengineering Showcase: March 2005.*

[2]Yungher D, **Wininger MT**, Threlkeld AJ, Barr JB, Craelius W. Myokinetic vs EMG Analysis of Muscular Activity During Gait, *Progress in Motor Control V, 17-20August2005.*

[3]Hwang, Ing-Shiou, et al. Electomyographic Analysis of Locomotion for Healthy and Hemiparetic Subjects. Gait and Posture 18. (2003): 1-12