FIGUR8

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Detection of Biceps Brachii Muscle Activity via sMMG Sensors Compared to a Dynamometer

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Introduction

The FIGUR8 Lower Body Movement Assessment quantifies human body movement in a unique way. Using the surface Mechanomyograghy (sMMG) sensor part of the sensor system, the FIGUR8 movement platform can evaluate muscle activation. sMMG sensors are applied across the largest portion of a muscle bulk and record linear displacement in millimeters from the resulting change in muscle bulk shape during contraction.

The main objective of this study was to determine the relationship of sMMG sensor measurement of muscle displacement to muscle force output. A secondary goal of this study was to verify that the sMMG sensors successfully measured a muscle contraction by visually comparing timing of muscle activation and deactivation with corresponding EMG data. A handheld dynamometer (HHD) was used to compare the sMMG signal to a more recognizable output; Force. Specifically, a Lafayette Manual Muscle Test System was used to record force output by using the HHD to resist motion during maximum volitional contraction of the Biceps Brachii.

Methods

sMMG sensors were applied to the subject's right and left biceps brachii. The biceps musculature was chosen due to its ease of muscle belly identification and ability to collect force output across male and female participants. Care was taken to ensure the sMMG sensor was placed over the bulk of the muscle during contraction. For a comparison of muscular activation, EMG (Trigno Wireless System, Delsys, Inc.) sensors were simultaneously placed on the right and left bicep for some of the trials.

After device application was complete, testing was conducted beginning with a calibration trial. For this trial, subjects were instructed to hold their arms at 90 degrees elbow flexion with their palms supinated. This provided a reference baseline value for muscle displacement and, when applicable, EMG activity.

Subjects then performed maximal volitional isometric contractions (MVICs) for each bicep. The subject began in a seated posture with 90 degrees of elbow flexion. Each subject was requested to push the distal portion of their supinated forearm up into a sturdy table for 3 seconds with as much applied force as possible.

With baseline and maximum contraction values recorded, the strength testing trials were then performed. Subjects performed 3 trials of a maximal bicep curl on each arm following the standard 'make' manual muscle test.[1] The distal portion of the supinated forearm was used as a contact point, but this time the dynamometer (Lafayette Instruments) was used to counteract and record the force output. The dynamometer began recording once a 5 lbf threshold was passed and ended when the force returned to 0 lbf.

Figure 1. *Demonstration of subject position during calibration trials.*

Figure 2. *Demonstration of an MVIC (maximum volitional isometric contraction) for the right biceps brachii.*

Figure 3. *Demonstration of the maximum biceps contraction testing activity using the HHD to resist the motion and record muscle force output over time.*

Subjects

Healthy subjects (n=10, mean age: 26.7 ± 9.67 y) completed three maximal bicep contractions for both the right and left arms. sMMG sensors and wireless EMG sensors were simultaneously applied to each biceps brachii while the dynamometer resisted motion at the distal portion of the forearm.

Equipment Set-up

sMMG sensors recorded using an iOS app at 75 Hz streamed via Bluetooth Low Energy to the mobile device, while the dynamometer recorded standalone at 40 Hz. For trials that included EMG sensors, the EMG sensors recorded wirelessly at 120 Hz. EMG data was filtered using a 6th order Butterworth low pass filter at 3 Hz to rectify and smooth the signal for analysis.

Results: Force vs Muscle Displacement

Data for all three devices was recorded simultaneously for each maximal bicep contraction. Maximum values that included muscle displacement, muscle force, and muscle electrical activity were tabulated for further analysis. The sMMG data was overlaid on the force data and time shifted to account for a difference in sampling rate.

An obvious relationship can be seen between both modalities simply by observing graph shape. However, in order to take this one step further, a statistical analysis was performed to determine the significance of the maximum muscle displacement compared to the maximum force generated. This analysis was broken down into subgroups to investigate relationships based on writing hand dominance. More specifically, a two tailed T-test was performed to determine the significance of the datasets to 95% confidence (α = 0.05).

Table 1: *Overall Stats (62 trials)*

Force (lbf) vs Displacement (mm_D)	
Pearson Correlation	0.794**
p-value	<0.001

Table 2: *Dominant Arm (37 trials)*

Force (lbf) vs Displacement (mm_D)	
Pearson Correlation	0.792**
p-value	<0.001

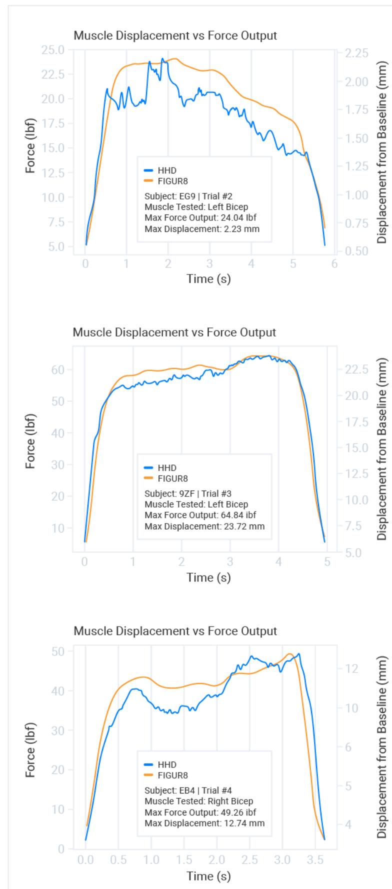

Figure 4. *Force (orange) and muscle displacement (blue) plots over time of activity for 3 different subjects. Maximum values are shown for reference.*

Table 3: *Non-Dominant Arm (28 trials)*

Force (lbf) vs Displacement (mm_D)	
Pearson Correlation	0.782**
p-value	<0.001

*** statistical significance reached with p value set at < 0.05*

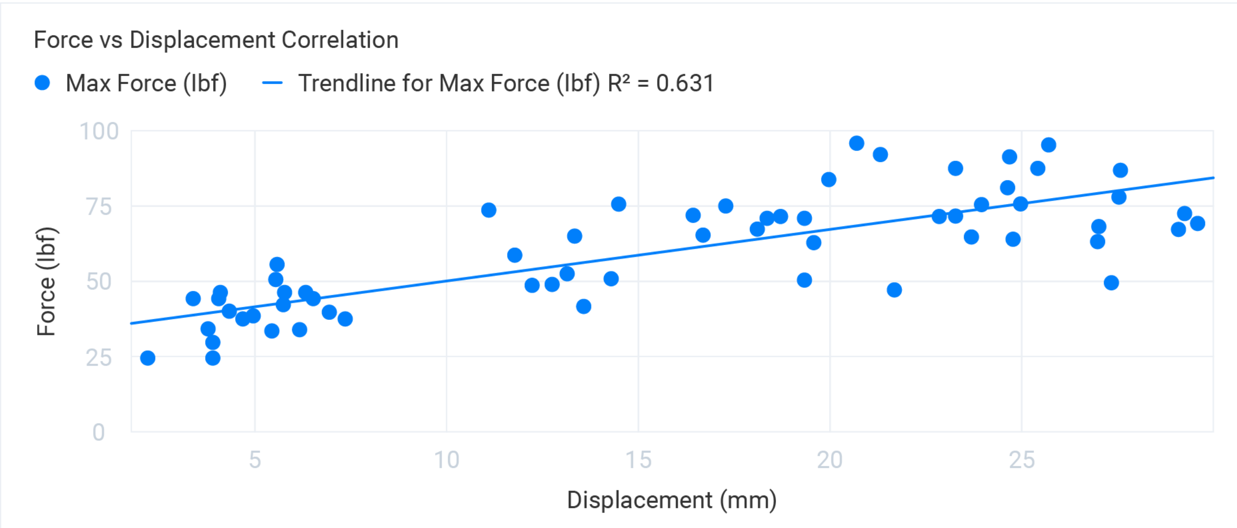

Figure 5. *Maximum force vs maximum muscle displacement for all trials (n=62) with a linear trendline overlaid (R2 = 0.631).*

The results show a significant correlation between force and muscle displacement. This relationship is displayed for both the dominant and non-dominant arm. However, the non-dominant muscle output demonstrates a slightly lower correlation, which could be explained by less muscle memory for the non-dominant bicep curl movement resulting in increased variation.

Data was also categorized into male and female subgroups to observe how sex affects the force-displacement relationship (Table 4-5).

Table 4: *Male (n=5, 24.2 ± 3.12y)*

Average Force (lbf)	**Average Displacement (mm_D)**	**Average Ratio (lbf/mm_D) (Force/Displacement)**
74.51 ± 11.30	21.89 ± 5.27	3.58 ± 0.94

Table 5: *Female (n=5, 28.4 ± 13.87y)*

Average Force (lbf)	**Average Displacement (mm_D)**	**Average Ratio (lbf/mm_D) (Force/Displacement)**
42.86 ± 10.84	8.47 ± 6.34	6.82 ± 2.95

While it is expected that males would, on average, produce larger force and and exhibit larger muscle displacement than females, it is interesting to observe the difference in force/displacement ratio between sexes. Results show that males produce a force that is roughly 3.5 times the size of their corresponding displacement, whereas females produce a force nearly 7 times their displacement. This trend may be explained by physiological differences or differences in the overall shape of the biceps brachii muscle bulk between sexes. For example, it is well documented that men naturally have a larger amount of lean muscle mass. These findings suggest that sex must be taken into account if surface Mechanomyography is to be used to predict force production.

EMG Validation

EMG data was used to confirm the accuracy of the sMMG detection of a muscle contraction compared to a dynamometer. Raw EMG data was recorded using Delsys EMG sensors. The signal was then filtered using a 6th order Butterworth low pass filter at 3 Hz. A Teager–Kaiser energy operator (TKEO) was applied to further smooth the signal and aid in determining accurate muscle activation points.[2] Plots were generated for a visual comparison of muscle activation and deactivation. Due to the nature of the signal filtering process, EMG data was plotted separately.

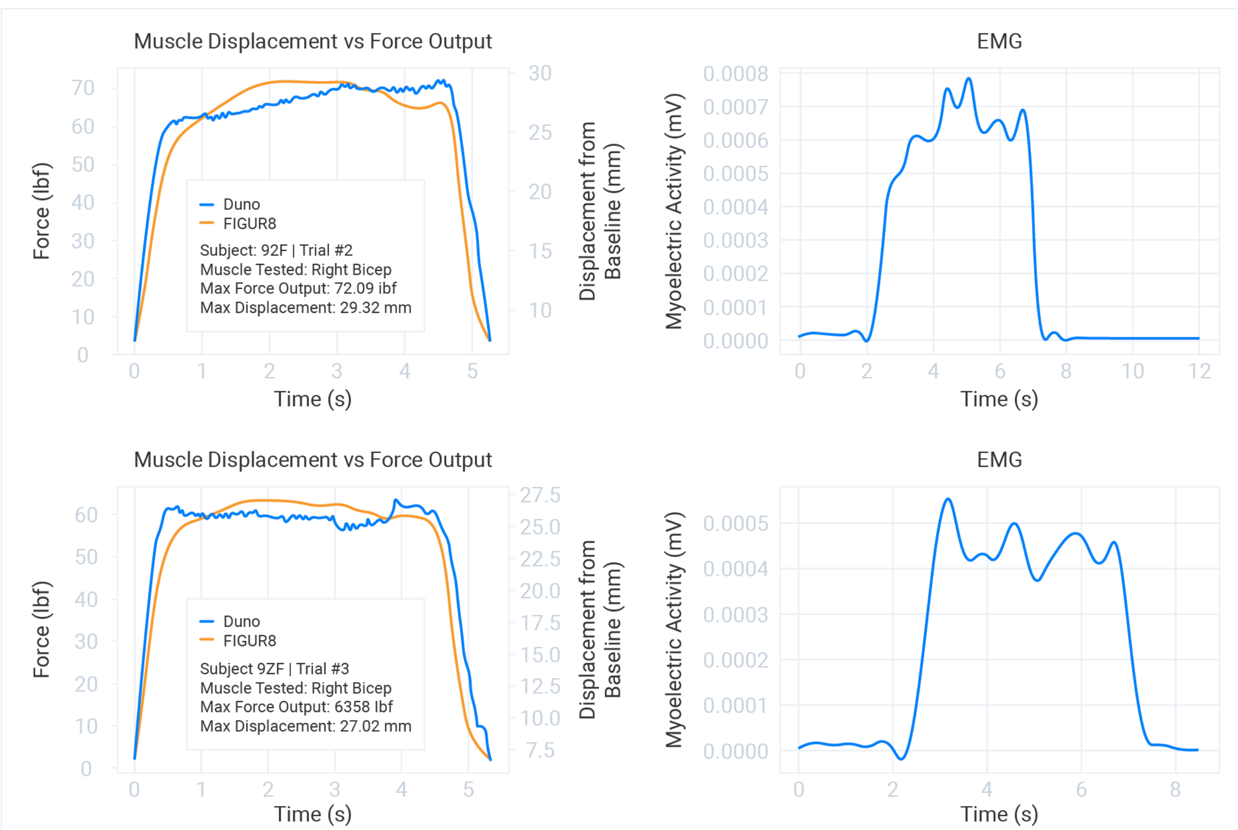

Figure 6. *Comparison of muscle activation and deactivation using sMMG sensors and a dynamometer (left) and EMG sensors (right).*

Similar contraction duration timing between all 3 modalities helps to verify the accuracy of sMMG sensor detection of a muscle contraction. Additionally, when compared to the sMMG and dynamometer signals, the filtered EMG signal exhibits a similarly shaped, although slightly noisier curve. Visual comparison reveals good alignment of muscle displacement and force values for the duration of the biceps contraction, not just at the time of peak force or peak muscle displacement output.

Conclusion

The results of the statistical analysis show that muscle displacement is significantly correlated to the force generated for a maximal biceps muscle contraction. This significant finding was upheld for dominant and non-dominant arm subgroups, although dominant arm displacement and force were slightly more correlated than non-dominant values. The visual trend in force and muscle displacement plots suggests the relationship exists across the duration of a biceps brachii contraction, not only at the time point of peak contraction. Finally, the force to displacement ratio for females was almost twice as large as it was for males, suggesting that sex could have a strong impact on the relationship of biceps brachii strength generation and the amount of displacement during contraction.

References

1. Stratford PW, Balsor BE. A comparison of make and break tests using a hand-held 462 dynamometer and the Kin-Com. J Orthop Sports Phys Ther. 1994;19(1):28-32.

2. Solnik S, Rider P, Steinweg K, DeVita P, Hortobagyi T. Teager-Kaiser energy operator signal conditioning improves EMG onset detection. Eur J Appl Physiol. 2010;110:489-498.

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