Real-time muscle fascicle length measurement via machine learning

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Summary
To develop assistive devices that can account for muscle dynamics, we developed a machine learning algorithm that measures muscle fascicle lengths in real-time from live ultrasound imaging. Our algorithm’s predictions yielded up to 95% correlation and $R^2 = 0.89$ with respect to hand-tracked images, opening the door towards real-time feedback for device control with muscle dynamics in-the-loop.

Introduction
Muscles drive human movement, yet injuries, aging and inherent musculoskeletal constraints often limit performance. State of the art wearable devices have begun to improve locomotion performance but are still limited because they fail to directly account for underlying muscle dynamics. Making direct measurements of muscle force, length, and velocity in vivo would require invasive instrumentation techniques. Dynamic ultrasound imaging is a viable alternative, but currently requires time-intensive offline image tracking that hinders real-time implementation [1]. Here, we aim to develop machine learning (ML) techniques that extract muscle length changes from live ultrasound images in real-time.

Methods
We collected ultrasound images from the tibialis anterior muscle of a single subject (Fig. 1[A]). Next, we hand-tracked 500 frames to obtain a training length set [B] and 100 frames to be used as a ground truth set for verifying performance of the live feed [F]. Then we trained a ML regressor which mapped together two inputs [C]: images processed as matrices of pixel brightness values [A], and the previously measured training length set [B]. Lastly, the algorithm looked at changes in pixel brightness and gradient flow from live ultrasound images [D] to yield real-time fascicle length predictions [E]. Since hand-tracking is time intensive, we also processed the training images with UltraTrack, a semi-automated muscle fascicle length measurement software [2]. We calculated the processing times of manual and semi-automated tracking and used both data sets for training, yet the ML algorithm predictions were done in real-time from the live feed. After data collection, we plotted obtained lengths to understand how closely the algorithm predictions followed ground truth fascicle lengths [F] and quantified the correlation and coefficient of determinations ($R^2$).

Results
The ML algorithm predictions well-correlated to the hand-tracked ground truth fascicle lengths when trained with hand-tracked training lengths (95% correlation, and $R^2 = 0.89$). The ML algorithm predictions had lower correlation to hand-tracked fascicle lengths when trained with UltraTrack training lengths (76% correlation, and $R^2 = 0.58$). Obtaining the muscle fascicle length changes via hand-tracking and UltraTrack took 4 hours and 0.5 hours, respectively (Table 1).

Table 1: ML trained with training lengths from HT vs UT.

<table>
<thead>
<tr>
<th>Training Set Comparison</th>
<th>Hand-Tracked</th>
<th>UltraTrack</th>
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<tbody>
<tr>
<td>Correlation</td>
<td>94.6%</td>
<td>76.2%</td>
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<tr>
<td>$R^2$</td>
<td>0.89</td>
<td>0.58</td>
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<tr>
<td>Processing Time (500 frames)</td>
<td>4 hours</td>
<td>0.5 hours</td>
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</tbody>
</table>

Discussion and Conclusions
ML predictions closely matched ground truth length changes under both training conditions. Depending on the intended application, scientists can choose either greater accuracy (hand-tracked) or faster training speeds (UltraTrack) while still obtaining real-time muscle fascicle lengths through both training methods. Having access to muscle fascicle length change data in real-time will enable novel assistive device controllers and biofeedback training protocols that place muscle physiology in the loop in order to augment human locomotion performance.

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References