INVESTIGATING THE UNIVERSALITY OF OPTICAL MYOGRAPHY

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ABSTRACT

Optical myography, a lesser-known approach for monitoring muscle activity, may be influenced by factors such as skin tone, blood oxygenation, and the composition of the surrounding tissue. This study presents a preliminary investigation of optical myography across 20 limb-intact individuals with varying skin tones and one individual with limb difference. The findings underscore the approach's potential applicability across diverse populations, advancing its viability as a muscle monitoring technique.

INTRODUCTION

The vast majority of wearable systems designed to monitor muscle activity use electromyography, forcemyography or phonomyography [1]. Relatively little research has explored wearable photonic systems for monitoring muscles [1, 2]. As such, optical approaches are poorly understood [1]. Explanations for exact phenomenon measured are contradictory, ranging from changes in skeletal muscle oxygenation to movement of deep blood vessels [1, 3]. Additionally, the COVID-19 pandemic highlighted that optical biomedical sensors can have inherent ethnic biases; the accuracy of pulse oximetry having recently been found to depend on skin colour [4]. Furthermore, research in upper-limb prosthetics has stressed the importance of testing on end users, as conclusions drawn from studies using limb-intact individuals are not guaranteed to hold for individuals with limb-difference [5].

This research investigated the application of a novel photonic sensor to detect muscular movement in a residual limb and examined the impact of skin pigmentation on the recorded optical signal.

METHODS

Participants

One limb-different and twenty limb-intact participants took part in this study. Before participating in the study all participants provided written informed consent. Ethical approval was granted by the local committee at Newcastle University (ref: 21-029-FRA).

Recordings

Finger position: Finger position data were recorded using an Etee (TG0, UK) virtual reality (VR) controller at 100 Hz. For the participant with limb difference, finger position was recorded from the contralateral hand, and they were instructed to mirror finger movements with contractions in the residual limb.

Optical: Optical myography data were sampled at a rate of 500 Hz with a custom-made sensor [6]. For limb intact participants, the placement of the optical sensor targeted the flexor digitorum superficialis muscle which was located via palpation. For the limb different participant, the sensor was placed on, or close to, their EMG electrode site used for prosthesis control.

Electromyography: EMG data were sampled at 2000 Hz using a Trigno Quattro (Delsys, USA) sensor. Only recordings with the limb-different participant used EMG sensors. Two electrodes were placed on the muscle targeted by the optical sensor.

Protocol

Participants began at rest with their arm supported by a table. After a period of rest, the experimenter played a series of audible beeps for a total of 10 seconds at a time. The beeps played at a rate of 2.5 Hz and acted as a digital metronome. Participants were instructed to move their finger(s) in concert with the metronome, tapping the VR controller with the specified finger on each beep, and fully extending the finger between beeps. After the metronome had played for 10 seconds the beeps stopped, signalling the participant to relax. Participants were first given a practice run with the metronome before data collection began. A real-time plot of all sensor data was visible to the experimenter.

Analyses

Skin tone mapping: Skin tone data were collected using a digital camera (Canon EOS 1200D). Participants stood in a light-controlled room beside a colour correction palette commonly used in photography. Skin tone data were sampled from colour corrected images of the anterior forearm. Colour data were recorded using the CIELAB colour-space.

SNR calculation: The signal-to-noise ratio was calculated using the ratio of the signal power attributed to desired frequencies vs the power attributed to all other frequencies. The desired signal frequencies were taken to be below 5 Hz. Calculations were performed on optical data that had been filtered by a 4th order high-pass Butterworth filter at 1 Hz. Where statistical comparisons were used, SNR data across participants were assumed to be non-parametric.

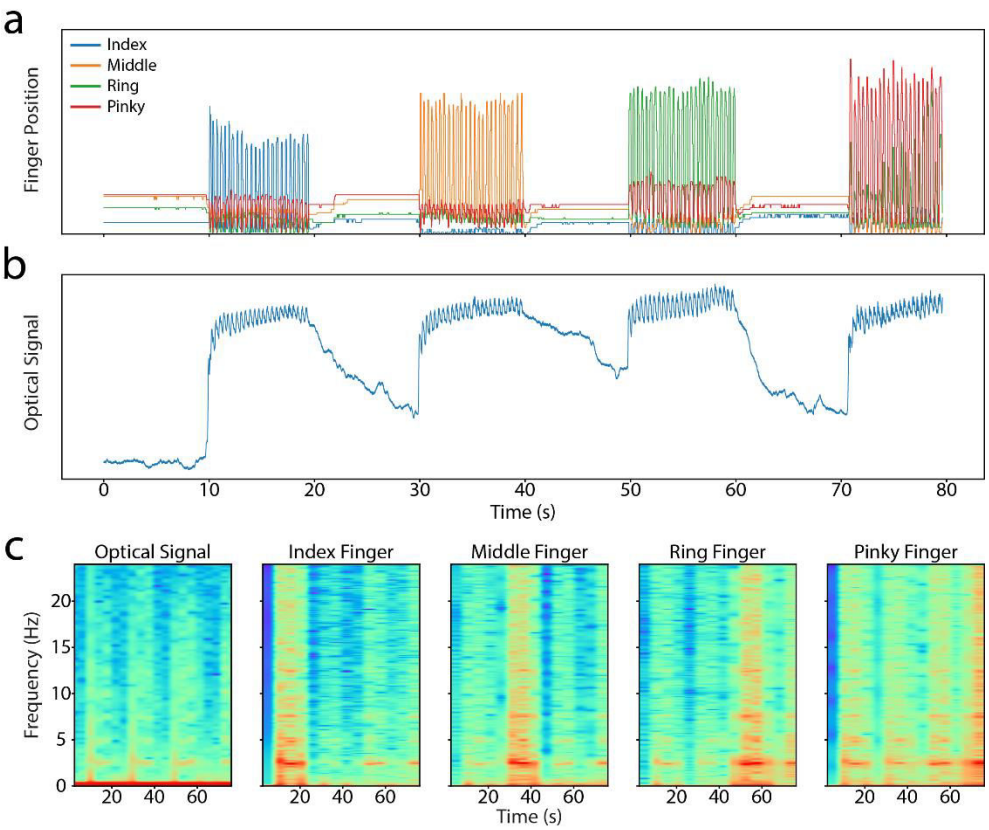

Figure 1: Finger movement detection using optical myography. The plots correspond to data collected from a single limb-intact participant. (a) Finger positions recorded from the VR controller. (b) Optical signal response. (a) & (b) are aligned on the time axis. (c) Time-frequency plots illustrating the detection of the 2.5 Hz finger movements across the optical sensor and VR controller.

RESULTS

Figure 1 shows the response of the optical signal during finger movement. Figure 1a shows that during the initial 12 seconds when the hand was at rest, the optical signal in Figure 1b is relatively stable. Once finger movement commences, an equally varying response is observed in the optical signal. When finger movement ceases, so do the rapid fluctuations of the optical signal. Then, the amplitude of the optical signal slowly decays, until the movement of the next finger, where the pattern repeats again. Figure 1c shows the time-frequency plots of the optical and the finger position data. For the optical signal, an increase in 2.5 Hz signal power can be seen repeating in concert with each finger's movement which is also confirmed to be approximately 2.5 Hz.

Figure 2 shows the effect of skin tone on the optical signal. No correlation was found between the skin tone and optical signal SNR (r = 0.06, p = 0.79), depicted in Figure 2a. Whereas, a strong positive correlation was found between skin tone and the baseline value of the optical signal when the participant is at rest (r = 0.63, p < 0.01).

Figure 3 shows an overview of the data collected from the residual limb of a single participant. Figure 3a & 3b shows a similar pattern, previously seen in Figure 1, between finger movement (on the intact limb) with the optical signal. In addition, a comparable pattern between the optical signal and EMG data can be seen in Figure 3b & 3d, with peaks of the EMG signal appearing to occur at similar points in time to the peaks of the optical signal. Finally, time-frequency plots of optical and EMG data are shown in Figure 3d & 3e. Increased optical signal power is evident around 2.5 Hz, and repeats in accordance with the metronome and finger movement. Likewise, the envelope of the EMG signal also has increased signal power at around 2.5 Hz. Both time-frequency plots show increased signal power occurring at the same moment in time, both aligning with the start and end of the metronome sound (and hence contralateral finger movement).

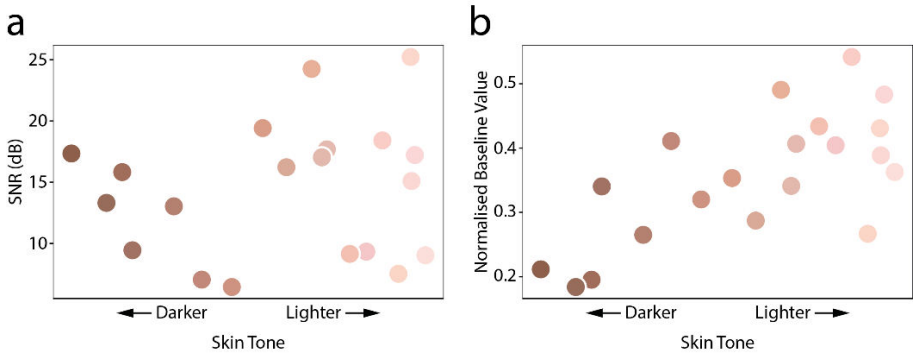

Figure 2: Effect of skin tone on optical signal properties. (a) Differences in signal-to-noise ratio across skin tones. (b) Differences in signal baselines across skin tones. Points correspond to individual participants. Point hues visually reflect the participants' measured skin tone.

DISCUSSION

Several theories have been proposed to explain the physiological source of optical myography signals, such as skeletal muscle oxygenation or blood vessel movement [1, 3]. This study showed that the optical sensor not only detected the onset and offset of movements with relatively little latency, but the frequency of the resultant optical signal also mirrored the physical rate of movement. This tight coupling between movement and signal response suggests that the optical signal reflects biomechanical changes associated with physical movement.

It has been shown that skin tone can affect properties of optical signals [4]. Furthermore, research in prosthetics has highlighted the importance of testing on individuals with limb-difference [5]. In order to assess the efficacy of the approach for a range of individuals, we tested participants with different skin tones or limb-difference. While a strong relationship was found between skin tone and the baseline optical signal, no relationship was found between skin tone and the SNR during finger movement. Testing on a limb different participant yielded similar results to limb-intact participants. Anecdotally, locating the ideal sensor placement on the residual limb was more challenging. This could be due to increased fatty tissue around the residual limb which may affect the SNR. However, to increase the certainty of our findings, we remain committed to expanding the sample size with the goal of enhancing diversity and inclusivity.

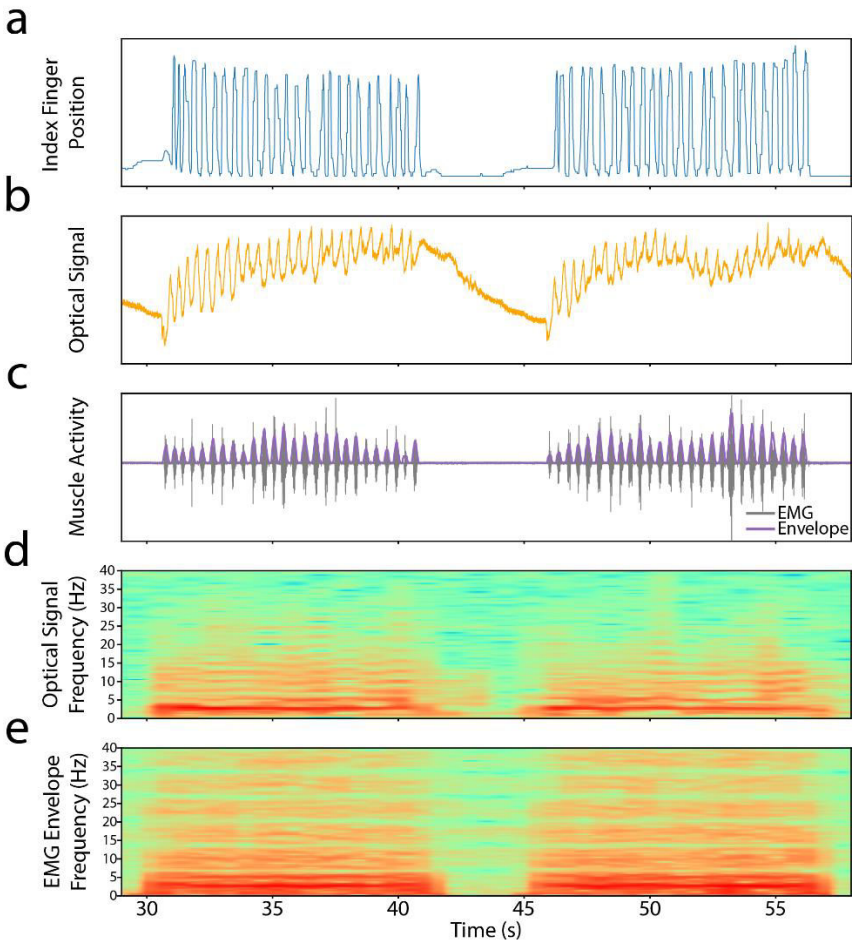

Figure 3: Overview of data collected from a residual limb. (a) Index finger position from the contralateral hand. (b – e) Recordings from residual limb. (b) & (c) Optical and muscle activity data, respectively. (d) & (e) Time-frequency plots of the optical signal and EMG envelope, respectively. Figures are temporally aligned on the x-axis.

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