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Noncontact Sensing of Facial Muscle Activity Using Laser Doppler Vibrometry: Time Domain Data Analysis

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Abstract. Movements of the facial muscles offer a promising avenue for assessing stress, fatigue and emotion, and appear useful for a number of applied and clinical purposes. This paper describes a novel application of laser Doppler vibrometry (LDV) as a noncontact method for assessing facial myographic activity. The principle of the LDV method involves detection of the minute vibrations of contracting muscles, associated with the activation of individual motor units. Data were obtained from 11 participants who received 15-20 min of training before the measurement acquisitions. Participants produced several standardized facial expressions involving activation of the upper face (lowering and raising the eyebrows) and the lower face (raising the upper lip, stretching the lip corners, and clenching the jaw). The associated muscle vibratory activity was assessed using the LDV method, within context of the simultaneous electromyogram (EMG). A separate condition entailed study of the jaw muscle signals during repetitive chewing. The temporal, spatial and measurement sensitivity aspects were studied in separate tests; the present report focuses on the temporal aspects of the response, in comparison to the onsets and offsets of the simultaneous EMG and gross facial surface displacement. The LDV signals were obtained from a site overlying the principal involved muscle for the various movements. Results showed that LDV myographic signals (LDV-MMG) could be recorded from all facial muscles studied, although they were relatively small from the muscles of the upper face. LDV-MMG signals were especially prominent at times of contraction onset and offset, indicating that the method may be particularly useful for the study of dynamic activity as would be associated with brief changes in facial expression. The LDV-MMG signals generally were found to lead the onset of the EMG signal by about 100 ms, and to lag the offset of the EMG signal by about 200 ms. The LDV-MMG response associated with chewing was associated in time with the EMG and displacement signs of chewing, but were generally more polyphasic in form. The findings generally support the potential use of the LDV method as a non-contact and non-obtrusive method for assessing activity of the facial muscles.

1. Introduction

Considerable attention is given to the assessment of facial muscle activity, which is important in multiple domains. These include basic studies aimed at expression and coding of affect, applied issues such as affective computing and detection of fatigue and stress, the study of psychiatric and communication disorders, and clinical evaluation of disorders of the facial nerves and mastication. There are two primary modes of assessment: 1) coding of the visible deformations of the face, and 2) direct electromyographic (EMG) measurement of muscle activity. These assessment modes each has well-recognized strengths and weakness, in terms of application issues and measurement properties.

In the present report, we describe a non-contact method for direct measurement of muscle activity, which may offer the basis for yet another assessment opportunity. We present some preliminary data bearing on the effectiveness of the non-contact method—in terms of timing and amplitude characteristics, for multiple facial muscles. The non-contact nature of the method offers several potential advantages, insofar as there is no strict requirement for preparation of the skin, or encumbrance with electrodes or other attached transducers.

Laser Doppler vibrometry (LDV) as a physiological assessment method. The non-contact technique described here is an extension of the method of laser Doppler vibrometry (LDV). LDV is a technically mature method for non-destructive testing of mechanical vibrations, usually in industrial and engineering applications [1].

The application of LDV to the study of human physiology is based on the premise that many relevant physiological functions at the system level (including tremor, muscle contraction, and cardiorespiratory activities) are accompanied by mechanical activities which are reflected (however minutely) at the surface of the body. This uncontroversial premise underlies a number of techniques that are routinely used in clinical and laboratory investigations, including auscultatory and palpatory methods; microphone-based methods for recording muscle activity as well as cardiovascular, respiratory and gut sounds; and accelerometry as a technique for characterizing precordial, vascular and ballistocardiac movements, as well as tremor, hyperkinesias and gross body movements. A now substantial body of evidence attests to the effectiveness of the LDV method for evaluating mechanophysiological activity, particularly cardiorespiratory signals [2-7].

LDV recording of muscle activity: The mechanical myogram (MMG). The present application is based on observations that muscle contraction is accompanied by mechanical vibration activity, which can be detected at the skin surface. Following recommendations of Orizio et al. [8], we adopt here the nomenclature “mechanical myogram (MMG)” to describe these muscle vibrations. Prior evidence from our group has demonstrated the effectiveness of LDV in detecting and quantifying these vibrations, in somatic muscles including a small hand muscle [9], and bilateral muscles in the arms and legs [10-11]. The LDV-MMG signals were shown to vary systematically as a function of force under elastic tension, and to be roughly coextensive with the simultaneous EMG signals (as considered in greater detail below).

Overview of experiment. The principal goals of this experiment were to describe the basic aspects of facial myographic activity measured using the LDV method, emphasizing the temporal domain properties. There appear to have been only limited prior studies of the facial MMG signal (using conventional mechanical sensors), focusing on the muscles involved in mastication [12-17] and brow lifting [18-19]. The LDV signals were obtained here under posed facial expressions, guided by the Facial Action Coding System (FACS), which identifies 46 elemental action units (AUs) [20-21]. Although the AUs are formally described in terms of deformations of the facial surface, involvement of the underlying facial musculature is fairly well understood. Conditions were also included that

supported comparison with more conventional methods based on the EMG as well as FACs coding of the video images.

Participants were tested in several sequences involving posed expressions (defined in terms of standardized AUs) involving the upper and lower face. In the conditions described here, LDV data were obtained from individual skin sites overlying the principal engaged muscles, for comparison with the simultaneous EMG as well as an LDV-obtained measure of gross surface displacement during contraction. Particular attention was paid to the transitional aspects of the LDV and EMG signals at the times of contraction onset and offset.

2. Materials and Methods

Participants. Data were obtained from 15 participants within the age range of 20-28 years (9 female). The majority of analyses described here were based on a subset of 11 participants (6 female) for whom complete sets of data were available. Comparison of data from these 11 participants with the full data set, where possible, did not show any appreciable qualitative or quantitative differences. Exclusionary criteria included body mass index > 25; facial hair, piercing or severe acne that would interfere with any of the recording procedures; history of psychiatric illness; and any illness, use of medication or cosmetic procedure that would interfere with normal neuromuscular function. Participation entailed a single session, approximately 2½ hrs in length. Following a detailed explanation of the purpose and experimental procedures, informed consent (including specific consent to reproduce images containing the face) was obtained using a protocol approved by the Washington University School of Medicine.

Facial posing. Five facial actions involving the upper and lower face were studied, selected in large part on the basis of prior reports regarding their utility signs of emotion and stress. The gestures, which were standardized and labeled according to the Facial Action Coding System [20-21], included:

- AU1, which consists of raising the inner brows, and involves contraction of the medial frontalis muscles.
- AU4, which consists of lowering and pulling together the brows, and includes involvement of the corrugator supercilii muscles.
- AU10, which consists of raising the upper lip and involves contraction of the levator labii superioris muscles.
- AU20, which consists of pulling the corners of the lips backward, and involves contraction of the risorius muscles.
- AU31, which consists of clenching the teeth and includes involvement of the masseter muscles.

Participants received 15 to 20 min of training in producing the target facial expressions. Training followed the methods and guidelines described in the Facial Action Coding System (FACS) manuals [20-21]. Training included detailed instruction and supervised production, assisted by videos and still photos drawn from the FACS manuals, and with an opportunity to practice in front of a mirror. Participants were encouraged to produce the facial actions symmetrically with an emphasis on avoiding co-contraction of other muscles—especially the common linkages cited in the FACS manuals. Participants were instructed to produce the facial actions with a force level that would be readily detectable by an observer. In general, the instructions refrained from any attempt to link the facial actions to specific emotions. In the case of AU31, the teeth were clenched against a dental cotton roll placed between the left molars, with a force level described as “3—neither weak nor strong” on a scale of 1 to 5 [22]. The instructions and video examples were repeated, with opportunity for additional practice, immediately prior to the production of individual facial actions during the course of the experiment. Review of the physiological and video records indicated that the participants were generally successful in producing the target gestures, although with a fairly high incidence of co-contraction as might be expected given the limited training received.

Procedure. The experiment involved two series of facial action production, given in the same sequence for all participants. For the single point measurements described here, two productions of

each target gesture were obtained for 5 s each. The productions were cued by pre-recorded speech signals to "tense" and "relax". The two productions were separated by a 5 s rest period, and preceded and followed by 10 s resting periods. The delivery of the speech signals was under computer control. Training emphasized the importance of making the two productions equivalent, and constant during the 5 s periods. EMG and LDV data were obtained during this series, and video data were obtained throughout. A test involving masseter activity while chewing, which focused on rapid transitional aspects of the LDV-MMG signals, was also conducted as described below.

Physiological recording methods. Physiological data were acquired using a Biopac MP150 system, with the EMG and LDV data integrated into a common file with a 1 kHz sampling rate. Data were obtained from the left side of the face.

EMG recording. EMG was recorded using shielded 4 mm Ag/AgCl electrodes affixed with double-sided tape collars, from bipolar pairs with inter-electrode spacing of 2 cm. Sites were prepared by cleaning with alcohol and abrading with a sterile lancet. Signals were amplified with a gain of 5k over the band of 0.5 to 500 Hz. The four electrodes across the forehead were originally recorded referentially to the left earlobe (A1), and subsequently recombined to produce differential signals. (A horizontal configuration was adopted, to permit evaluation of the course of the frontalis EMG signal over the nasion and eye-brows [23]). For AU1 (brow raise), the electrode pair was centered above the pupil, over the frontalis muscle 1-2 cm above the upper margin of the eyebrow. For AU4 (brow lower), the pair was horizontal and centered on the midline, 1 cm above the brow (at a site intended to overlie the conjunction of the corrugator supercilii, procerus and orbicularis oculii muscles). For AU10 (upper lip raise), the electrode pair was oriented vertically, approximately 1 cm lateral to the wing of the nose, over the course of the levator labii superioris muscle. For AU20 (lip stretch), the electrode pair was oriented horizontally over the course of the risorius muscle, with the anterior electrode located 2 cm lateral to the angle of the lips. For AU31 (teeth clench), the electrode pair was oriented vertically along the palpated superficial bulge of the masseter muscle. A ground electrode was affixed to the mid-forehead.

Laser Doppler vibrometry (LDV) recording. LDV data were obtained using a Polytec PSV-300 scanning vibrometer system (with a OFV-505 sensor head and OFV 3001 controller). This instrument utilizes a 633 nm laser beam, which at an output power < 1 mW classifies it as an "eye safe" laser (Class 2 by ANSI standards, "Standard, A. N. S. I. (2000). Z136. 1-2000, for Safe Use of Lasers. Published by the Laser."). Data were obtained with the beam direction approximately radial to the target skin site (with the laser head repositioned as necessary), from an offset of 826 mm (corresponding with a laser beam coherence node), with a sensitivity of 5 mm/s/V and an anti-aliasing filter at 500 Hz. The beam was targeted at a site midway between the EMG electrodes overlying the principally engaged muscle. (Prior to recording, the reflectivity of the skin was enhanced by treating it with a compound of 80 □m glass retroreflective beads mixed in suspension with mineral oil, with additional beads applied to the surface using a cosmetics brush. (The retroreflective bead treatment was applied to decrease the incidence of speckle-related artifact, while avoiding any appreciable surface loading or areal summation of the signal that might be associated with use of retroreflective tape. Subsequent improvements in equipment and signal processing methods indicate that this skin treatment is not necessary.)

Preprocessing of LDV signal. Prior to specific analyses described below, the LDV signal was processed to suppress speckle dropout artifacts. Speckle effects are inherent with highly coherent and monochromatic light sources as are used by the LDV method [24], particularly when recording from non-cooperative surfaces such as the skin that have high micro-roughness (with associated areas of destructive interference in the reflected signal), as well as a relatively low reflectivity and lack of translational stationarity. The speckle artifact is manifest in the LDV signal in the form of aperiodic large amplitude high frequency events in the waveform. The artifact was suppressed using a non-linear method that was designed to minimize the suppression of genuine higher frequency aspects of the signal. Speckle-affected data points were defined in terms of the abrupt (and aphysiological) transition points in the waveform, as identified in the thresholded second derivative of the original velocity

signal. These points were then removed from the waveform, and the missing points were resampled using linear interpolation. In general, the speckle artifact affected less than 1% of all points.

3. Results

Basic character of response. Figure 1 illustrates a typical LDV response obtained during a single-point measurement condition—in this case from the skin overlying the masseter during AU31. Shown in the bottom trace (e.) is the accompanying EMG. The intent of this figure is to depict the overall frequency composition of a typical signal and the rationale for selecting a narrow band-pass filtered signal for analyses. The original velocity signal in the top trace (a.) contains activity related to multiple sources, including gross surface deformation during contraction, physiological tremor, a readily visible ballistocardiac signal, and nonspecific, adventitious movement of the body and face. As described below, the ratio of activity generated intramuscularly to these other signals is generally improved at the higher frequencies, even though the absolute amplitude there is small. In the second trace (b.) the velocity signal has been converted by differentiation to an acceleration signal, to facilitate comparison with other MMG findings in the literature which are generally based on accelerometry recordings. The non-contraction related activities are evident in the acceleration signal as well. The third panel (c.) depicts a time-frequency spectrogram for the acceleration signal, produced by the Welch technique using 512 points, with 50% overlap.

The results reported here are based principally on activity within a narrow band of 30-50 Hz (or 32-48 Hz in some analyses). A band-bass filter of finite impulse design (999 taps) was used. In addition to providing a favorable signal to noise ratio, this band supported a high temporal resolution with respect to identifying signal onset and offset during transitional periods. It should be noted in this context that many of the findings described below are correspondingly restricted to this band. This is a potentially important caveat in view of indications that the MMG (at least as recorded from muscles of the limbs and hand) appears to incorporate activities in at least 3 functionally distinct frequency ranges [27]. The 32-48 Hz band encompasses the range that is often referred to as the “Piper rhythm” [28]

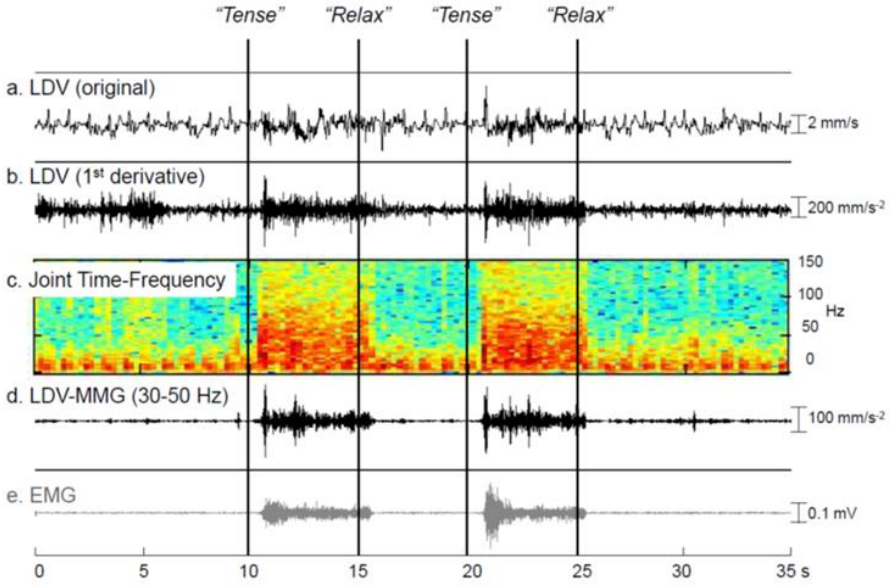

Figure 1. Illustration of an original LDV signal during two repetitions of AU31 (a.), acceleration signal derived by differentiation of the native velocity signal (b.), joint time-frequency depiction of the acceleration signal (c.), plus the narrow band filtered LDV-MMG signal (middle) and the accompanying EMG (bottom).

It should also be noted that the absolute magnitude of the LDV-MMG at higher frequencies is small. If converted to a displacement signal, the high frequency MMG shown in Figure 1 (d.) is on the order of 6 μm peak to peak, indicating that a high level of measurement sensitivity is required. This small vibratory component compares with the much larger gross surface displacements (associated with gross surface deformation including lateral expansion of the underlying muscle masseter bundle during contraction) in the mm range (see below).

The amplitude characteristics of the LDV and EMG signals associated with the five facial action units were investigated in detail from the records obtained during the single point conditions. Four segments, each 4 s in duration, were selected from each condition for more detailed analysis. Data associated with active expression were extracted during 2.048 s segments beginning 2 s after the commands to begin contraction. Two resting segments (also of 2.048 s) were also extracted, one from the first 9 s of the baseline period, and one from the final 9 s of the post-contraction period. The precise resting segments were selected as those periods in which the root-mean square (RMS) of the LDV-MMG signal was lowest (attesting to quiescence). Power spectral density functions were computed for each of the four segments (Hanning windowed), and individual spectra were normalized with respect to the total power of a mean spectrum computed across all four segments.

In Figure 2 (left), the normalized LDV-MMG power specifically within the 30-50 Hz band for each AU is depicted, for both resting and contraction conditions.

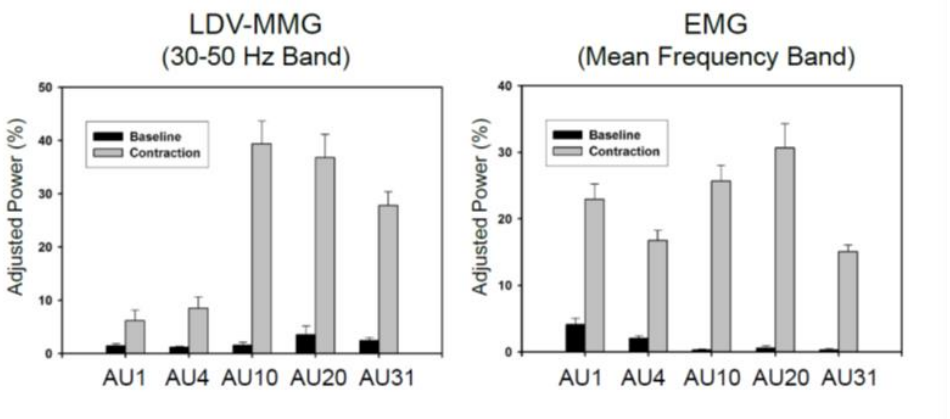

Figure 2. Adjusted LDV-MMG spectral power within the 30-50 Hz band, under baseline and contraction conditions for each of the five AUs (left), and corresponding EMG values (right).

The increase in contraction values (in comparison to resting values) there is evident and was observed without exception—for all participants, for all AUs, and for all replications. The greatest LDV-MMG activation was seen in the lower face AUs. Shown at the right of Figure 2 are the corresponding EMG values, for a 20 Hz band centered on the mean EMG frequency (which was generally in the range of 21 Hz (AU1) to 34 Hz (AU31). The EMG signal amplitudes were more uniformly distributed among the various AUs than were the LDV-MMG effects, although the resting-activation differences were readily apparent for both measurement methods, for all AUs.

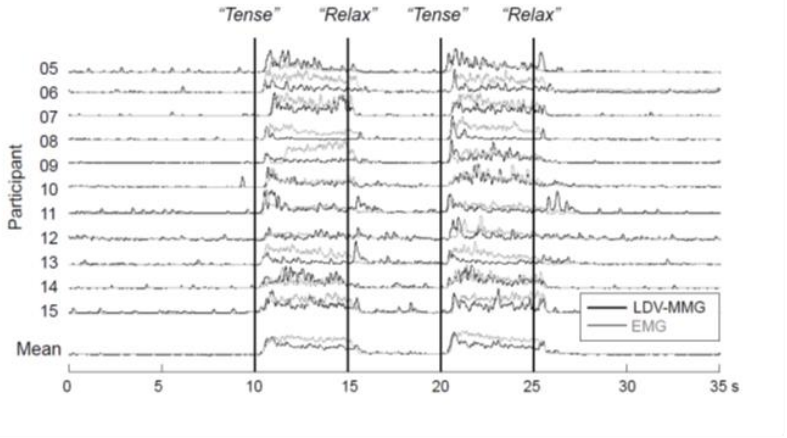

Figure 3. Overlaid integrated LDV-MMG and EMG activity for eleven participants (05 through 15), for two 5 s expressions of AU10. Vertical scaling is arbitrary.

Time domain characteristics. Temporal aspects of the LDV-MMG signals were analyzed in detail, with particular emphasis on the onsets and offsets. The following presentation focuses on the AU10 movement, which produced a large amplitude signal from all participants. Figure 3 illustrates the overlaid processed LDV-MMG and EMG signals obtained during the AU10 posing sequence. The LDV-MMG signal was filtered with a pass band of 32-48 Hz, as described above, and the EMG signal was high pass filtered with a filter of IIR design at 10 Hz. The signals were full wave rectified, and integrated using a 100 point moving window. For purposes of this illustration, the waveforms have been individually scaled so that all waveforms have identical peak to peak scale values.
Figure 3 illustrates several key aspects of the LDV and EMG signals. Both were reliably produced during the AU10 productions. Both types of signal showed substantial variability, both between consecutive productions, and over the course of individual contractions. For some participants (05, 07, 11, 12, 14) the temporal coherence between the two types of signals was high, whereas for other participants there was less agreement. A major difference appears to be that the LDV-MMG signal contained large bursts of activity at the times of contraction onset and, to lesser extent, offset, which were not reliably seen in the EMG signal.

The onset and offset segments of the integrated LDV-MMG and EMG signals associated with AU10 are illustrated in greater detail in Figure 4. The record of surface position (dotted trace) is the integrated representation of the original (unfiltered) velocity signal, and can be interpreted in terms of the gross in plane displacement toward and away from the laser sensor head—reflecting lateral expansion of the skin overlying the levator labii superioris muscle during contraction and subsequent relaxation. The position waveform has been formed by averaging across the two repetitions for each of the eleven participants (total number of records = 22). Each of the individual records was synchronized before averaging to the moment of peak expansion velocity (for the onset), and separately for peak retraction velocity (for the offset). These peaks were clearly evident in the unprocessed velocity waveforms. The total displacement amplitude for this averaged record is approximately 1.75 mm.

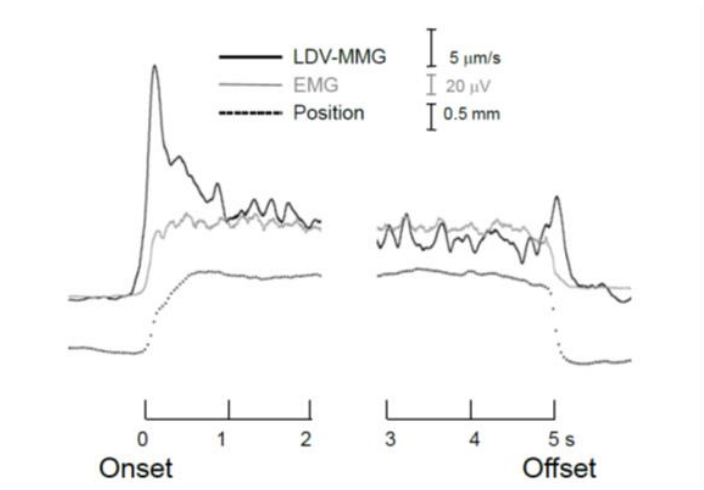

Figure 4. Averaged displacement, and integrated LDV-MMG and EMG signals associated with AU10 onset and offset. These records are averaged over the 11 participants (two replications for each participant).

The associated integrated LDV-MMG (black trace) and EMG (grey trace) signals were similarly time locked to the peak velocities in the displacement records and averaged over repetitions and participants. These records disclose two major differences between the EMG and LDV records. One is that the LDV velocity record shows prominent peaks at the times of the gross dimensional changes associated with the onset and, to lesser extent, offset of muscle contraction. This property would suggest that the LDV-MMG would be well suited for identifying rapidly transient events, such as facial micro expressions. The second property is that there are appreciable differences in timing of the LDV-MMG and EMG signals, with the LDV signal leading the onset of the EMG signal by about 100 ms, and lagging the offset of the EMG signal by about 200 ms. Although the integration process would tend to shift the peaks of these waveforms toward later values and thereby affect the apparent relationship with the position signal, both the LDV-MMG and EMG signals were processed using the same procedures so the relationships between them would be unaffected. The physiological interpretation of these latency differences remains unclear.

Time domain characteristics: Masseter muscle signals during chewing. Temporal relationships among LDV-MMG signals, EMG and surface movement associated with muscle contraction were examined in detail from the masseter muscle while chewing. Participants chewed a single standard 3g piece of gum of their desired flavor. Participants were given 3 min preliminary chewing, then a 30 s standard chewing period during which they were instructed to chew between their left molars at an approximate rate of 1 chew per s (approximating a natural rate observed for gum chewing [29]) and to avoid swallowing to the extent possible. The actual rate varied from 0.7 chews per s (participant 14) to 1.5 chews per s (participant 10) (mean = 0.9 chews per s). The chewing period was preceded and followed by 5 s recording periods of rest.
The raw EMG signals and band pass filtered LDV-MMG signals (32-48 Hz) from 11 participants are illustrated in Figure 5. Consistent with prior observations [30] there were substantial individual differences in the kinematic and myographic signals. The EMG signal generally consisted of a monophasic burst associated with each chew, whereas the LDV myographic signal was less consistent across chews and also more complex, with indications of additional bursts within the chewing cycle.

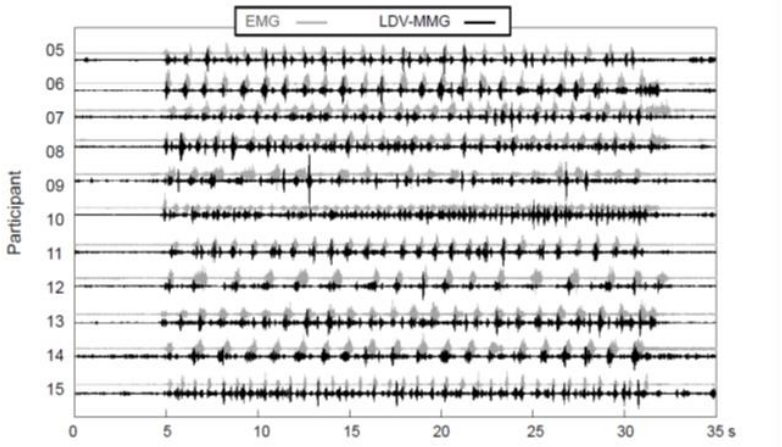

Figure 5. EMG and LDV-MMG signals from the masseter while chewing, for 11 participants. Vertical scaling is arbitrary.

Processed signals are illustrated in Figure 6. The signals were transformed by full wave rectification, followed by smoothing using a 100 point symmetric average. Symmetric smoothing was used, rather than integration, to preserve the absolute timing of peaks in the waveform with respect to gross dimensional changes. The dimensional changes were analyzed in terms of the original (unfiltered) LDV waveform, which included low frequency surface movements related to lateral expansion of the masseter during contraction. A position (displacement) waveform was generated by integrating the original velocity signal. The peak velocity of the expansion movement was used as a synchronization point, for purposes of averaging the waveforms across all available chews. The overlaid records in Figure 6 include the position, smoothed EMG, and smoothed LDV-MMG within the 32-48 Hz band. Vertical scaling is arbitrary.

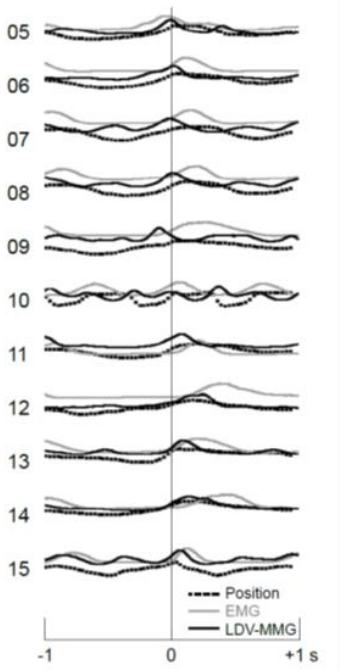

Figure 6. Masseter muscle surface position (displacement), smoothed EMG and smoothed LDV-MMG signals during chewing for 11 participants. Records are synchronized to a point corresponding to the peak velocity of the displacement signal (not illustrated).

Consistent with the known complexity of mastication movements [31], the gross displacement signals, which reflect the visible superficial bulge of the masseter muscle during chewing, were typically polyphasic with multiple inflection points during the opening and closing phases. The peak to peak amplitude of the gross displacement movements averaged 1.89 mm (range 0.44 to 3.26 mm), and the displacement peaked on average 182 ms following the velocity peak (see Table 1). The smoothed EMG waveforms were generally simpler, with a single monomorphic inflection that peaked in most participants later than the peak velocity (mean = 196 ms) and nearly coincided with the time of peak displacement. (The exception was participant 05, whose EMG waveform showed a peak that slightly preceded the velocity peak, and a second, smaller peak about 350 ms later; see Figure 6 top.)

Table 1. Peak latencies (in ms) of key features in chewing-related EMG and LDV signals. Times are measured with respect to the peak of the gross LDV velocity peak.

	Mean	Range
Latency of displacement peak	182	45 to 512
Latency of EMG peak	196	-19 to 440
Latency of LDV-MMG1 (peak 1)	46	-97 to 174
Latency of LDV-MMG2 (peak 2)	523	262 to 807
Interpeak latency: LDV-MMG1 to EMG	150	-15 to 318
Interpeak latency: LDV-MMG1 to LDV-MMG2	477	178 to 706

In contrast, the smoothed LDV-MMG in all participants contained two peaks. The first peak was close to the time of the gross velocity peak (following it on average by 46 ms). The first LDV-MMG peak was significantly earlier than the EMG peak (mean difference = 150 ms, $t[10] = 5.022$, $p < .001$). The latencies of the first LDV-MMG and EMG peaks were significantly but modestly correlated ($r = 0.64$, $p < .05$). The second LDV-MMG peak followed the first by a mean of 477 ms. In general, none of the latency variables was significantly correlated to chew rate ($p > .05$).

The functional significance of the second LDV-MMG peak is not clear. Although it is difficult to appreciate from the records in Figure 6, which have been smeared temporally by the smoothing process, there was no consistent overlap between this peak and the EMG burst. The EMG burst peaked on average 327 prior to the second LDV-MMG peak, and inspection of the records indicated that in many records the EMG burst was terminated prior to the onset of the second LDV burst. This would suggest that the second LDV-MMG component was not a simple product of masseter muscle relaxation during the jaw opening phase of the chewing cycle.

Considerable latency differences between the LDV-MMG and EMG signals were thus evident in the chewing condition, in which the two were separated in time but not to a consistent degree across individuals. Neither the LDV-MMG onset nor offset was consistently related to the timing of the EMG onset and offset. The LDV-MMG signal was again biphasic, with a distinct chewing-related component appearing mid-cycle. The physiological origins of this are, again, uncertain, since it did not appear to be reliably associated in time with either the offset of the EMG burst or the mechanical signs of masseter relaxation as evidenced in the retraction of the gross surface displacement. Chewing is a complex movement involving many muscles in addition to the masseter (including the anterior

temporalis, lateral pterygoid, digastric and sternocleidomastoid muscles [32-33], several of which are active during the jaw opening phase of mastication. It is not clear, however, that the LDV recording site used would pick up the associated mid-cycle activities, unless they were transmitted through bone or were referred from distant sites.

4. Discussion and Conclusions

The results described here indicate that the LDV method can be used to provide a sensitive measure of facial muscle activity:

1) The LDV-MMG signal was reliably obtained from all participants, from all muscle groups studied. The variations in amplitude from different muscle groups corresponded with similar variations in the amplitude of the simultaneous EMG signals.

2) The LDV signals corresponded in time with the durations of muscle contraction, but were especially prominent at the times of contraction onset and offset indicating that they would be particularly well suited for the study of dynamic aspects of facial expression including micro-expressions.

Temporal aspects of the facial LDV-MMG. The LDV-MMG signal generally agreed well with that of the simultaneous EMG. The principal difference was that the LDV signal showed bursts of activity coinciding with contraction onset and, to lesser extent, offset. Careful examination of the temporal relationships for the AU10 signals showed that there were also appreciable latency differences in comparison to the EMG signal, with the LDV-MMG onset preceding the EMG onset by about 100 ms, and the LDV-MMG offset lagging the EMG offset by about 200 ms. The physiological origins of these effects are uncertain. The large LDV myographic burst at contraction onset could be ascribed to the additional effort required at onset to produce the gross dimensional muscle change [34-35], although the terminal burst is more difficult to explain on this basis. It may be that it is associated with some active eccentric process during cessation of the posed expression, although the latency differences in comparison to the EMG remain anomalous. Collectively, the differences between the LDV-MMG and EMG signals are consistent with suggestions that the two types of measures are to some extent non-redundant, and that the LDV-MMG signal may harbor unique information regarding muscle function.

General considerations. Several limitations, and possible directions for future research and development, can be identified. A major limitation in the procedures used here likely lies in the need to maintain the gesture at a constant level over the course of the measurement period lasting several seconds. Facial gestures are normally fluid in nature, and the requirement here to sustain a static pose likely placed unrealistic and artificial demands—ones not properly served by the limited training regimen.

A limitation of the technology used here lies in the use of a visible laser beam (at 633 nm) in the Polytec PSV-300 instrument. Although the instrument is rated “eye safe” (Class 2), concerns for eye safety nevertheless prompted us generally to avoid potentially informative periorbital facial sites including the belly of the corrugator supercilii and the orbicularis oculii muscles. Fortunately, this is no longer an issue in future studies, given the recent availability of commercial Class 1 vibrometers (i.e., no concerns with eye or skin exposure) based on infrared lasers [36]. It also is worth noting that there are options for increasing the simultaneous spatial sampling among multiple facial sites, including rapid dithering or continuous scan of the beam among selected sites, multi-point systems, and the technical feasibility of full-field methods. Computer vision-based dynamic tracking

capabilities are now available, to accommodate the natural range of movement during interviews and other assessment situations.

The non-contact basis of the LDV method is an inherent strength that presents unique assessment opportunities. A major disadvantage of the EMG method in this context, as noted by Ekman et al. [20] is that applied surface electrodes and the accompanying leads are inherently obtrusive. The constant awareness of the recording sensors almost certainly interferes with the natural production of facial expressions. An additional problem is that the surface EMG signals are rather poorly focalized, because of the conduction by volume of bioelectric signals. High resolution methods utilizing dense sensor arrays have been described [37-39] but the sensor apparatus is cumbersome and would be incompatible with the study of naturally produced facial displays. Further research will be needed to establish the spatial discreteness of the LDV-MMG signal.

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