Facial Expressions of Pain Among Patients in the Emergency Department

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Research article

Abstract

Objective: The use of facial expression tracking to measure pain in patients in an emergency clinical setting has not been used before. This study examined facial expressions via an action unit (AU)-based model to determine the pain levels of emergency department (ED) patients.

Methods: Adult patients admitted to the ED due to complaints of headache, chest pain, abdominal pain, backache, or painful limbs at triage were included. Two assessments, each lasting at least 30 s, were performed for each participant. A basic description of the pain was acquired, including pain intensity, using a self-report numerical rating scale (NRS). To identify the characteristics of facial expressions of pain, 18 facial AUs were assessed. The model was developed according to analyses of the significantly correlated facial AUs. Area under the receiver operating characteristic curves (AUC) of the AU-based model for different pain severities was calculated.

Results: 429 video recording sessions were enrolled for analysis. 57.7% were male and the mean age was 51.3 years. Abdominal pain (49.4%) was the most common complaint, followed by back/limb pain (12.3%). The initial and follow-up mean NRS scores were 6.4 and 3.7, respectively. Several AUs showed significant correlations with NRS scores, including AU 1 (brow raising, $p=0.024$), AU 4 (brow lowering, $p<0.001$), and AU 26 (jaw dropping, $p=0.038$). A model to predict pain severity that included AUs 1, 4, 5, 9, 26, and 45 was created. The AUC of the prediction model to identify severe pain and no pain from others showed a value of 0.633 and 0.645, respectively.

Conclusions: Although this study identified several facial AUs correlated with patient self-report NRS pain scores, analysis of facial expressions alone failed to accurately predict pain among patients in the ED. Further studies should aim to develop a more comprehensive means of measuring pain via multiple behavioral measurements.

Introduction

Pain, which can be defined as an unpleasant sensation experienced after a harmful event (1), represents a major reason for engaging with medical services (1–3). The type of pain experienced varies according to the nociceptors involved (5, 6) Pain involves the detection, transmission, and modulation of signals by receptors (7, 8). In addition to sensory-discriminative factors, motivational-affective and cognitive variables are also involved in the experience of pain (9). Furthermore, the interpretation of painful stimuli can be affected by cultural, personality-related, experiential, environmental, and emotional factors (7–9).

Previous studies have tended to measure pain via behavioral assessments, for example of facial expressions. Neural control of the facial musculature in response to pain involves both voluntary and involuntary actions (10). Ekman developed the Facial Action Coding System (FACS), which divides the face into 44 action unit (AUs) involved in the production of different facial expressions (11). The prototypic facial expression of pain engages the AUs responsible for brow lowering, orbital tightening, levator contraction, and eye closure (12). Training in the recognition of specific cues, such as brow

lowering, eye closing, nose wrinkling, and mouth opening, improves the ability to discriminate 'deceptive' pain expressions (13, 14). Painful facial expressions involve a combination of emotions, including anger, fear, and disgust (13–15). Previous studies have demonstrated the utility of the automated FACS for monitoring pain (16, 17). However, the use of facial expression tracking to measure pain in patients in an emergency clinical setting has been limited. To facilitate pain measurement in the emergency department (ED), analyses of the facial expressions of patients in pain should be performed. This study examined facial expressions via an AU-based model to determine the pain levels of ED patients. We also evaluated whether the model is suitable for future use as a tool for pain measurement in ED patients.

Methods

Study design

This study used a cross-sectional design. Convenience sampling of patients admitted to the ED of a university-affiliated hospital over a 1-year period was performed.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Chang Gung Medical Foundation, Taipei, Taiwan (approval no. 104–3625B). Informed consent was obtained from all participants.

Patients

Adult patients (≥ 18 years old) admitted to the ED due to complaints of headache, chest pain, abdominal pain, backache, or painful limbs at triage were included. Patients who had undergone trauma, received prior treatment, were lost to follow-up, were unwilling to participate, or had been referred from another center were excluded.

Study protocol

The primary investigators and research assistants identified adult patients who met the inclusion criteria at ED triage. Then informed consents was obtained from the patients. Two assessments, each lasting at least 30 s, were performed for each participant (i.e., at initial triage and approximately 1 h after the administration of treatment, if any). A basic description of the pain was acquired, including its location, duration, and intensity, using a numerical rating scale (NRS) ranging from 0 (no pain) to 10 (worst pain imaginable) (18, 19). NRS scores of 1–4, 5–7, and 8–10 were considered to indicate mild, moderate, and severe pain, respectively (18, 19). In order to standardize patients' attention, the primary investigators or research assistants sits behind an HDR Handycam® (Sony, Tokyo, Japan), which is mounted on a tripod, to acquire pain description and the video record in a designated assessment room. The patients received

indication to look at the camera and answer the questions. The camera was positioned to allow consistent capture of facial expressions between sessions.

Data collection

Facial feature extraction

The open-access OpenFace (ver. 0.4.0), facial behavior analysis software, was used to extract facial features from the videos and generate AUs. In a pre-processing step using a facial feature-detecting algorithm, constrained local neural fields (CLNFs) were employed to detect facial landmarks in all video recordings using a point-distribution model. A layered, unidirectional graphical model was also applied by local neural field patch experts, together with an optimization-fitting procedure (non-uniform regularized landmark mean-shift) (20). In total, 68 facial landmarks (located at the eyes and nose contour, for example) were tracked based on the active orientation model generated for each patient (Fig. 1) (21). To identify the characteristics of facial expressions of pain, 18 facial AUs were assessed (Table 1). Each video was divided into several 0.03 s frames for facial AU coding and analyses. The mean amplitude of the AUs was calculated as the sum of the individual frames.

Table 1
Background characteristics of participants

	All
	N = 241*
Age, years; mean (SD)	51.3 (17.0)
Male, N (%)	139 (57.7)
Painful body parts, N (%)	
Head	25(10.4)
Chest	25 (10.4)
Abdomen	119 (49.4)
Back	38 (15.8)
Limbs	34 (14.1)
Initial Pain level by NRS, mean (SD)*	6.3 (2.5)
Follow-up Pain level by NRS, mean (SD)*	3.7 (2.6)
Initial vital signs	
Body temperature; C, mean (SD)	36.5 (0.8)
HR; bpm, mean (SD)	87.4 (16.3)
SBP; mmHg, mean (SD)	141.5 (23.3)
DBP; mmHg, mean (SD)	88.5 (48.4)
RR; per min, mean (SD)	18.2 (1.5)
Analgesics provision, N (%)	140 (58.1)
Admission to hospital, N (%)	63 (26.1)

*Total 241 participants with 241 and 188 video recordings at initial presentation and during follow-up, respectively. Total 429 videos were abstracted for face action coding and analysis.

Abbreviations: SD, standard deviation; NRS, numeric rating scale; HR, heart rate; bpm, beats per minute; SBP, systolic blood pressure; DBP, diastolic blood pressure; RR, respiratory rate.

Model covariates

Covariates were entered into the models, including patient age (years), sex, chief complaint, body part affected, NRS pain score at the initial and follow-up sessions, duration of video recordings, vital signs at

ED triage (i.e., body temperature, heart rate, blood pressure, and respiration rate) and analgesia provision and hospital admission status.

Outcome measures

The main outcome measure was the area under the receiver operating characteristic (ROC) curves of the AU-based model for different pain severities; the model was developed according to analyses of the significantly correlated facial AUs.

Statistical analyses

The demographic characteristics of the participants are presented as numbers (%) and means (standard deviation [SD]) for categorical and continuous variables, respectively. The correlations between AUs and NRS scores were examined using a Pearson correlation test. The AU-based pain prediction model was established according to significantly correlated ($p < 0.1$) facial AUs. Then the results of the prediction model were plotted as ROC curves by NRS pain severity score (no pain, 0; mild pain, 1–4; moderate pain, 5–7; severe pain, 8–10) in area under the curve (AUC) analyses. Subgroup analyses according to pain site were also performed. The data were analyzed using SPSS for Windows software (ver. 13.0; SPSS Inc., Chicago, IL, USA). A p-value < 0.05 was considered significant.

Results

In total, 241 participants (429 video recording sessions) were enrolled. Table 1 shows the basic characteristics of the participants; 57.7% were male and the mean age was 51.3 years. None had beards nor nasal cannula/oxygen facial mask use. All participants were Asians. Abdominal pain (49.4%) was the most common complaint at ED triage, followed by back/limb pain (12.3%). The initial and follow-up mean NRS scores were 6.4 and 3.7, respectively. In total, 140 participants (58.1%) had taken medications to alleviate pain and 26.1% were admitted to the hospital. Table 2 shows the correlations between NRS scores and facial AUs. Several AUs showed significant correlations with NRS scores, including AU 1 (brow raising, $p = 0.024$), AU 4 (brow lowering, $p < 0.001$), and AU 26 (jaw dropping, $p = 0.038$). A model to predict pain severity that included AUs 1, 4, 5, 9, 26, 45 was created using the following equation:

$$y = AU\ 1 + (2 \times AU\ 4) - AU\ 5 + AU\ 9 + AU\ 26 + AU\ 45$$

Table 2
AUs correlated with NRS scores

AU	r	P*
1	0.109	0.024
2	0.058	0.234
4	0.215	< 0.001
5	-0.080	0.096
6	0.049	0.313
7	0.071	0.140
9	0.092	0.057
10	0.052	0.284
12	-0.030	0.538
14	-0.026	0.585
15	0.078	0.105
17	-0.044	0.361
20	0.066	0.175
23	-0.074	0.124
25	0.001	0.983
26	0.100	0.038
28	0.026	0.595
45	0.082	0.089
*Pearson correlation test		
Abbreviations: AU, action unit; NRS, numeric rating scale.		

Then the performance of the prediction model was examined by calculating the AUC after plotting the ROC curves of the different pain severities (Table 3). The AUC of the prediction model showed a minimum value of 0.528 (moderate pain group) and a maximum value of 0.645 (no pain group). In analyses of pain location by severity, the lowest AUC was 0.532 (abdomen, moderate pain) and the highest was 0.770 (abdomen, no pain).

Table 3
Face AU model poorly predicts pain level by the area under ROC curve*

	No pain (NRS = 0)	Mild (NRS = 1−4)	Moderate (NRS = 5−7)	Severe (NRS = 8−10)
AUC (95%CI)				
Total	0.645	0.600	0.528	0.633
N = 429	(0.528−0.761)	(0.545−0.655)	(0.471−0.585)	(0.571−0.694)
Head	-	0.678	0.601	0.655
N = 39		(0.510−0.846)	(0.415−0.786)	(0.439−0.871)
Chest	0.612	0.540	0.738	0.710
N = 42	(0.369−0.855)	(0.336−0.743)	(0.466−0.811)	(0.534−0.885)
Abdomen	0.770	0.578	0.532	0.652
N = 219	(0.654−0.886)	(0.501−0.655)	(0.453−0.611)	(0.564−0.739)
Back	0.591	0.700	0.545	0.614
N = 69	(0.184−0.998)	(0.572−0.828)	(0.399−0.692)	(0.473−0.754)
Limbs	0.679	0.594	0.578	0.557
N = 60	(0.447−0.910)	(0.446−0.741)	(0.421−0.729)	(0.378−0.736)

Abbreviations: AU, action unit; ROC, receiver operating characteristic; NRS, numeric rating scale; AUC, area under curve; CI, confidence interval

* The area under curve and 95% confidence interval were calculated for total patients and different painful body parts

Discussion

Several facial AUs were correlated with NRS pain scores, including AU 1 (inner brow raising), AU 4 (brow lowering), AU 26 (jaw dropping), AU 5 (upper lid raising), AU 9 (nose wrinkling), and AU 45 (blinking). These findings echo previous results with respect to the AUs most associated with pain expression, namely, AUs 4 and 9 (12, 22, 23). Various other AUs related to pain expression have been reported, such as AU 6 (cheek raising), AU 7 (eyelid tightening), AU 10 (upper lip raising), AU 12 (lip pursing), AU 16 (lower lip depression), AU 25 (lip parting), and AU 43 (eye closing) (12, 22, 23). The majority of previous studies have recorded facial pain expressions induced by specific stimuli or exercises (12, 14, 24−27). The method used in this study was different, being based largely on observation without application of painful stimuli. Furthermore, the characteristics of patient populations are likely to differ among studies, for example in terms of the intensity and causes of pain. Finally, the clinical setting and purpose of pain measurements can differ among studies, where in this study the data were obtained in an ED setting. In

summary, although universal AUs underlying painful facial expression might exist, differences remain among studies that could influence their identification.

This study created a prediction model based on the correlations among facial AUs. However, the predictive power of the model was only fair to poor, in terms of both identifying those experiencing no pain (AUC, 0.645; 95% CI: 0.528−0.761), and those suffering from severe pain (AUC, 0.633; 95%CI: 0.571−0.694). Subgroup analyses of different pain sites again revealed only fair to poor predictive ability of the model. Several aspects should be discussed when interpreting our results. First, Hadjistvropoulos et al. indicated that the overall facial activity (total frequency and average intensity), not individual one, differentiate painful from non-painful periods in hospitalized elders (28). Further research also confirmed the similar findings by induced pain among older adults (29). However, the authors noticed that AU 43(eye closing) and 45(blinking) showed high frequency during the pain segments. These findings consist with our results. The face action coding system identified actions of facial muscles involved for recognition of the basic emotions. Examples of emotion-related facial actions are sadness: AU 1, 4, 5; fear: AU 1, 2, 4, 5, 7, 20, 26; anger: 4, 5, 7, 23; disgust AU 9, 15, 16 (30). Patients in pain, who visit ED, may present with mixed emotions in varying degree, such as sadness, fear, anger, and disgust. Therefore, a prediction model, which made up of specific AUs, limited its performance.

Second, there might be a difference between short- and long-lasting emotional facial expressions. Different facial expressions were associated with particular types of pain stimuli at different timing (31). Unlike laboratory experiments, in which facial expressions are recorded right after pain stimuli, the timing of recordings obtained in our study varied, which might result in reduced performance of the model in terms of predicting pain.

Third, this study used baseline-corrected amplitudes derived from the mean AUs of all 0.03 s video frames. For those participants who came without emotional change during ED visit will potentially loss capture of the signal. This process might compromise the sensitivity of AUs, which could have reduced the effectiveness of the model.

Fourth, the experience of pain differs according to the nociceptors that are stimulated; pain types include superficial and deep somatic pain, as well as visceral pain (5, 6). Whether different types of pain are reflected in the same facial expressions remains unclear. In this study, pain was categorized by body part. Determining the type of pain experienced by an individual relies on the clinical judgment of ED physicians, who may be operating according to different principals and personal experiences. To avoid any bias arising from subjective judgments, the type of pain was not acquired. However, our results appear to suggest that facial pain expressions differ according to the body part.

According to our results, there are barriers to replacing current pain assessment methods with facial expression analyses performed in the ED. Pain is subjective, involving sensory-discriminative, motivational-affective, and cognitive factors (9). Furthermore, pain experience is also affected by the culture, personality, experiences, environment, and emotional state of a patient (7−9). To date, self-report NRS scores have served as the primary means of measuring pain. Instead of replacing these self-reported

pain scores, using additional behavioral and physiological measurement techniques as an adjunct might facilitate more accurate pain assessment (32). Comprehensive behavioral assessments encompassing several methods, including facial expression analyses, are warranted. Improving the care of patients in pain by integrating such methods should be the ultimate goal.

Limitations

There were several limitations to the present study. First, sampling and selection biases were present, as we applied a convenience sampling method. Furthermore, several patients declined to be videoed and no patients who required resuscitation or emergent procedures were included. Therefore, the study population comprised mainly patients of triage level 3–5 who were willing to have their facial expressions recorded. The triage level 1 and 2 patients were in critical condition and were triaged according to variables other than NRS pain scores (e.g., unconsciousness, respiratory distress, or circulatory collapse status). Thus, our study population may not be representative of all patients in pain. Second, unmeasured confounders may have been in play, where facial expressions might be affected by the type, cause, and intensity of pain, as well as by the emotional state, personality, experiences, environment, and culture of the patient. Most of these variables are difficult to measure and thus were not assessed in this study. Third, the study included only a limited number of participants, all of whom drawn from a single university-affiliated hospital in northern Taiwan; this may limit the generalizability of our findings. Further studies conducted in different settings would therefore be of value.

Conclusion

Although this study identified several facial AUs correlated with NRS pain scores, analyses of facial expressions alone failed to accurately predict pain among patients in the ED. Further studies should aim to develop a more comprehensive means of measuring pain via multiple behavioral measurements. In addition, to facilitate pain assessment and ultimately improve the care of patients in pain, drawing on relevant results pertaining to pain experience would be a valid approach.

Abbreviations

AU, action unit

AUC, action unit curves

CI, confidence interval

CLNF, constrained local neural field

ED, emergency department

NRS, numerical rating scale

ROC, receiver operating characteristic

SD, stander deviation

Declarations

Availability of Data and Materials

Not applicable

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

LCC and WYM conceived the study. NCJ and TFS supervised the data collection. WKC, TFS and WYM undertook recruitment of participating patients and managed the data, including quality control. CCY, CJS and LCC provided statistical advice and analyzed the data; TFS and LCC chaired the data oversight committee. WKC, CJS, WBC and WYM drafted the manuscript, and all authors contributed substantially to its revision. WYM takes responsibility for the paper as a whole.

Conflict of interest disclosure

No thing to declare.

Consent for Publication

Not applicable

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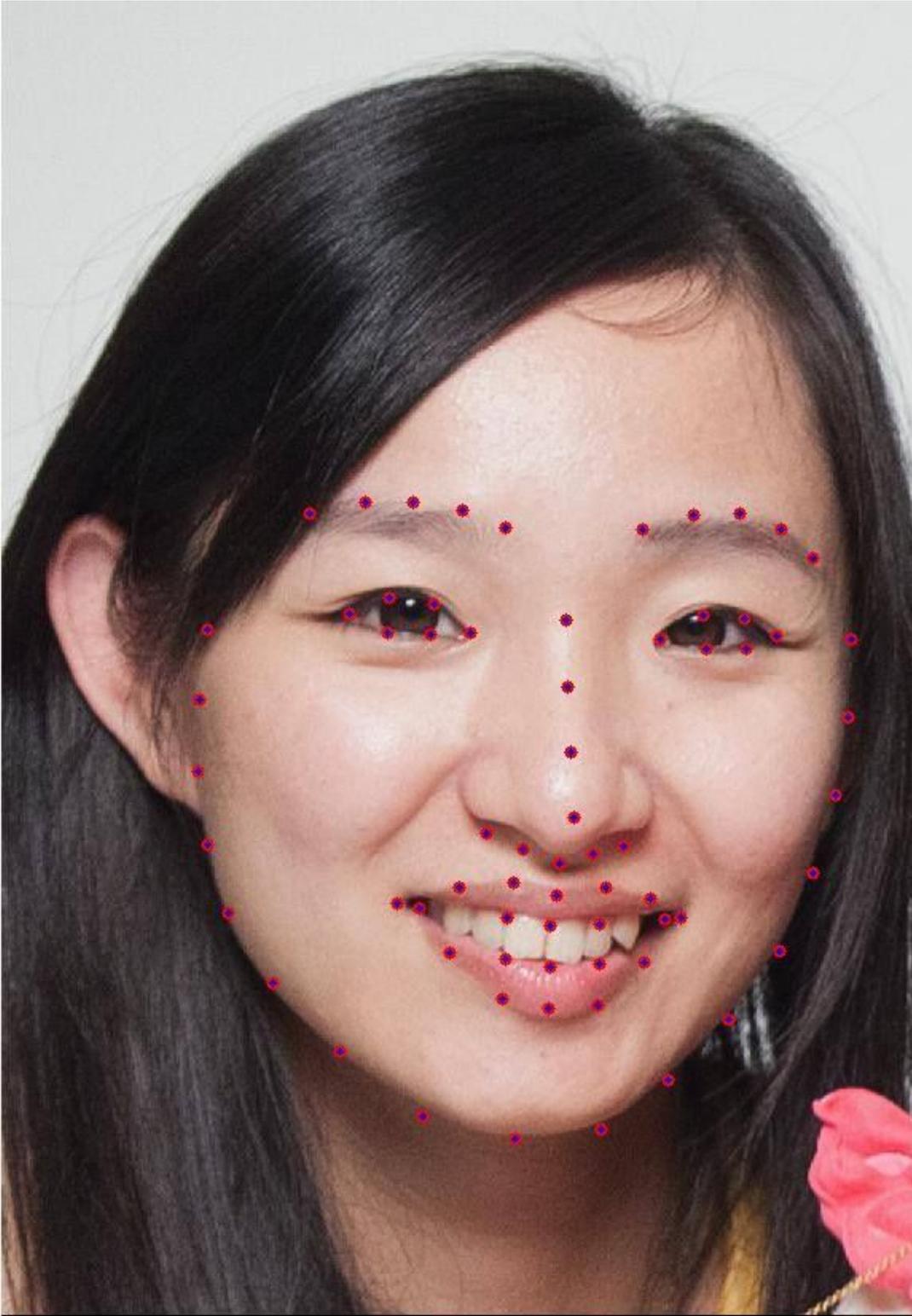
Figures

Figure 1

In total, 68 facial landmarks (located at the eyes and nose contour, for example) were tracked based on the active orientation model generated for each patient

AU	Description
1	Inner brow raiser
2	Outer brow raiser (unilateral, right)
4	Brow lower
5	Upper lid raiser
6	Cheek raiser
7	Lid tightener
9	Nose wrinkler
10	Upper lip raiser
12	Lip corner puller
14	Dimpler
15	Lip corner depressor
17	Chin raiser
20	Lip stretcher
23	Lip tightener
25	Lip part
26	Jaw drop
28	Lip suck
45	Blink

Figure 2

Face action unit (AU) tracked in this study