Pharmacology & Pharmacy, 2026, 17(4), 169-181
https://www.scirp.org/journal/pp
ISSN Online: 2157-9431
ISSN Print: 2157-9423

Predicting the Effects of Pharmacists' Communication on Patients: A Medical Communication Analysis Using Biological Signals

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How to cite this paper: Miyagi, Y., Yamagiwa, H., Gocho, S., Miyachi, Y., Nakayama, C. and Oshima, T. (2026) Predicting the Effects of Pharmacists' Communication on Patients: A Medical Communication Analysis Using Biological Signals. *Pharmacology & Pharmacy*, **17**, 169-181.
https://doi.org/10.4236/pp.2026.174009

Received: March 25, 2026
Accepted: April 17, 2026
Published: April 20, 2026

Abstract

Introduction: Understanding patients' emotional responses during clinical communication is essential for patient-centered care. This study examined the psychological impact of pharmacists' communication using objective physiological measures. **Methods:** Four simulated patients (SPs) and five pharmacists participated in medication counseling sessions. Electroencephalography (EEG) and heart rate variability (RMSSD) were recorded during the sessions. Emotions were classified into 10 categories based on verbatim transcripts and SPs' feedback. Objective emotions identified by researchers and subjective emotions reported by patients were aligned with physiological indices and analyzed within a four-quadrant emotional model. **Results:** Significant associations were observed between objective and subjective emotions, particularly for fear, disgust, calm, and surprise. Pharmacists' empathic communication and clear explanations were associated with positive emotion (e.g., calm and surprise), whereas inappropriate or unexpected expressions were linked to negative emotion (e.g., fear and disgust). **Discussion:** These findings suggest that EEG and RMSSD may serve as complementary physiological indicators of emotional responses during medical communication.

Keywords

Electroencephalography, Heart Rate Variability, Emotional Response, Clinical Communication, Patient Satisfaction

1. Introduction

A survey on European physicians reported patient-centered care and the doctor-patient relationship as the most frequently cited core values in medical practice [1]. To effectively provide patient-centered care, healthcare professionals need to evaluate the quality of their communication and identify areas that require improvement.

In communication education, simulation training using simulated patients (SPs) and communication skills training programs are commonly employed [2] [3]. By learning through simulations and communication training that reflect real clinical situations, learners can improve their communication skills.

In simulation training, two major approaches are commonly used for assessing the relationship between healthcare professionals and patients. The first is behavioral observation, in which a third party evaluates audio- or video-recorded clinical interactions through structured frameworks or coding systems [4]. The second approach relies on patient-reported questionnaires that assess their experiences in medical communication [4]. However, the behavioral observation method exhibits considerable variation in the quantification of communication behaviors, which is dependent on the rating scale used, and they frequently need to undergo extensive training to ensure evaluator reliability [4] [5]. Although easier to implement, the questionnaire-based method may place an additional burden on patients and is influenced by subjective perception. These limitations indicate the need for a convenient and low-burden method for quantifying communication between healthcare professionals and patients.

In the research on psychological states, experienced emotions and intentionally expressed emotions may be observed; however, capturing genuine emotional responses requires the exclusion of intentionally expressed emotions [6]. For this reason, physiological measures have attracted increased scholarly attention because they are less influenced by individual subjectivity. Similarly, in the medical field, there is growing interest in using various physiological signals—such as facial expressions, eye movements, and EEG results—to assess a subject's emotions and stress levels [7]. Emotional states can be assessed using psychological measures (e.g., questionnaires), behavioral measures (e.g., verbal and facial expressions), and physiological measures [8]. Specifically, physiological measures include autonomic nervous system-based responses (e.g., blood pressure, skin temperature, and electrocardiograms [ECG]) and central nervous system-based responses (respiration and electroencephalograms [EEG]). Among these approaches, EEG and ECG are considered relatively robust against arbitrary emotional expression.

EEG reflects electrical activity in the cerebral cortex and is commonly classified into delta (0.5 - 3 Hz), theta (4 - 7 Hz), alpha (8 - 13 Hz), and beta (14 - 30 Hz) frequency bands [9]. Beta activity is associated with heightened arousal, while theta activity is related to low levels of alertness (e.g., drowsiness) [10]. Accordingly, the beta-to-theta (β/θ) ratio is typically used as an indicator of brain arousal. In ECG,

heart rate variability (HRV) reflects cardiac autonomic regulation by measuring fluctuations in successive RR intervals [11]. HRV can be analyzed using frequency-domain measures, including low- and high-frequency components, as well as time-domain measures (e.g., the root mean square successive difference [RMSSD]) [12].

The present study aimed to determine whether the psychological impact of healthcare professionals' communication skills on patients can be objectively assessed using EEG and ECG, which change in response to emotional states. Among healthcare professionals, this study focused on pharmacists and examined pharmacist-patient communication during medication counseling.

2. Methods

2.1. Apparatus

EEG and ECG data were collected using a Micro DAQ Terminal (intercross-413, Intercross Corp.), electrode connectors (intercross-415-03, Intercross Corp.), and real-time acquisition software (DAQ Master intercross-311, Intercross Corp.) to assess changes in EEG and HRV associated with emotional responses. For ECG recording, two electrodes were placed across the chest (**Figure 1(A)**). For EEG recording, electrodes were positioned at C3 (left parietal region), Cz (parietal midline), and C4 (right parietal region) in accordance with the international 10 - 20 system (**Figure 1(B)**).

Physiological data were analyzed using real-time emotion analysis software (intercross-340, Intercross Inc.), which visualizes emotional states based on Russell's circumplex model of affect. This model represents emotions captured within a two-dimensional space defined by valence (pleasant-unpleasant) and arousal (awake-drowsy) [13]-[15]. In the present system, arousal was estimated using the beta-to-theta (β/θ) ratio derived from EEG frequency analysis, while comfort level was estimated using the RMSSD derived from ECG data. Variations in β/θ and RMSSD were plotted within the valence-arousal space (**Figure 2(A)**).

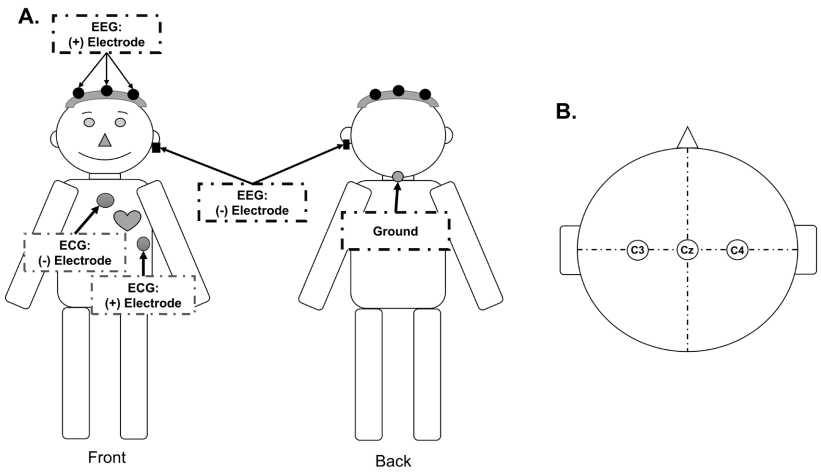

Figure 1. (A) Electrode placement for ECG and EEG; (B) EEG electrode locations.

2.2. Procedure

EEG and ECG recordings were collected from the simulated patients during medication counseling sessions to assess the psychological impact of pharmacists' communication. The counseling scenario simulated medication instruction for a patient with stage-IV lung cancer at the initiation of opioid therapy. The patient was assumed to be receiving opioid medication for the first time and experiencing anxiety related to its use.

The SPs received scenario materials that described prescription details, patient background, and internal emotional states; they were then instructed to express these emotions via role playing. Meanwhile, the pharmacists received materials on prescription information, patient background, and basic guidance on medication counseling. Each session began with the pharmacist greeting the patient and providing medication instructions.

To ensure reliable physiological recordings, the SPs were instructed to obtain sufficient sleep one day before measurement, refrain from alcohol consumption and smoking, and avoid caffeine intake for at least 2 h prior to the session. On the measurement day, EEG and ECG electrodes were attached, followed by a 15 min adaptation period to allow participants to familiarize themselves with the environment and equipment. Each counseling session lasted approximately 10 min. A facilitator was present throughout the session, and each SP received counseling consecutively by four of the five pharmacists who participated in the study.

On the following day, the SPs reviewed video recordings of the counseling sessions and were encouraged to verbally report any emotions or concerns experienced during the interaction. The facilitator remained present throughout this process.

2.3. Participants

The study recruited four SPs (all women; mean age: 69.0 ± 11.5 years) with 1 - 10 years of SP experience through the help of the Simulated Patient Association of Kinjo Gakuin University and five pharmacists (one man and four women; mean age: 30.4 ± 3.6 years) with 1 - 12 years of professional experience. To assess patients' psychological states, only physiological data from the SPs were recorded and analyzed.

2.4. Data Analysis

Each counseling session was segmented into 20 s intervals to examine the relationship between emotional responses and physiological signals. A 20 s interval was selected in accordance with the specifications of the real-time emotion analysis software, which performs analysis in 20 s units. This interval length was also considered appropriate for RMSSD analysis based on previous reports supporting reliable ultra-short-term HRV assessment within 10 - 30 s [16].

For each simulated patient, a 20 s artifact-free segment from the same time interval of the baseline EEG and ECG recordings obtained 10 min before the session

was used as the baseline for normalization. The β/θ ratio and RMSSD values during the counseling session were normalized relative to this baseline.

Physiological data were visualized at one-second intervals using the real-time emotion analysis software and plotted within the valence-arousal space.

Based on previous research, the valence-arousal space was divided into four quadrants, namely, high arousal/high valence (HAHV), high arousal/low valence (HALV), low arousal/low valence (LALV), and low arousal/high valence (LAHV; **Figure 2(B)**) [17]. For each 20 s interval, the quadrant with the highest frequency of data points was set as the representative quadrant. When data points were evenly distributed across quadrants, each quadrant was counted once.

Emotions were identified using verbatim transcripts and SP feedback and classified into 10 categories (*i.e.*, joy, anger, sadness, fear, shame, liking, disgust, pleasure, calm, and surprise) based on the Emotion Expression Dictionary [18]. To ensure inter-analyst reliability, two independent analysts confirmed the classification.

Objective emotions were defined as emotions identified by the analysts from a third-party perspective based on the transcripts. Subjective emotions were defined as emotions reported by the SPs in the video review the following day. For each interval, emotions were matched with corresponding physiological quadrants.

Each 20 s interval obtained from the counseling sessions was treated as the statistical unit for analysis. First, Spearman's rank correlation coefficient was used to examine the correspondence between physiological quadrants associated with objective and subjective emotions.

Additional statistical analyses were conducted only for emotions in which correlations were observed across multiple EEG recording sites or quadrants. The Kruskal-Wallis test was used to compare three groups, whereas the Mann-Whitney U test was used for pairwise comparisons.

Because multiple comparisons were conducted across emotions, recording sites, and quadrants, these analyses were considered exploratory in nature.

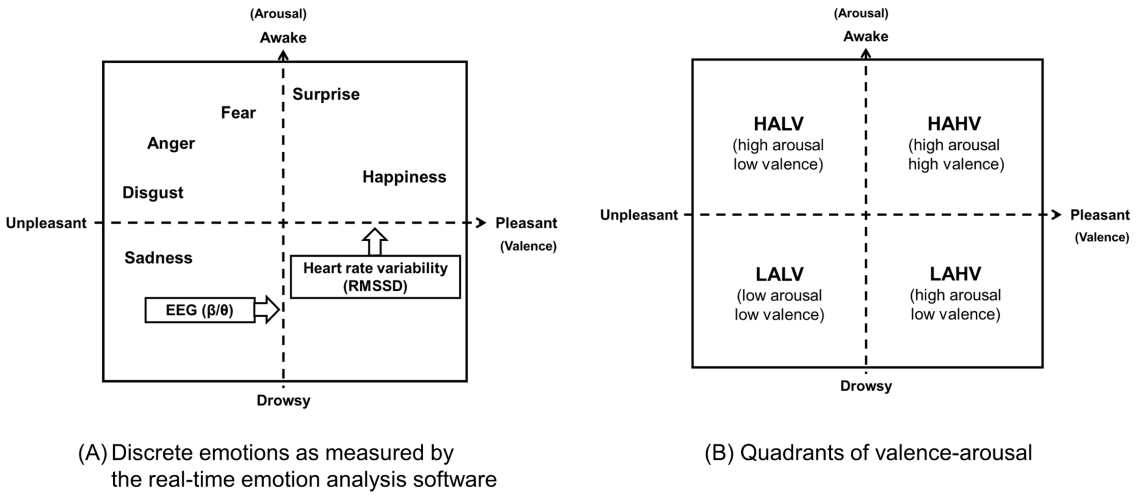

Figure 2. Valence-arousal space: (A) Emotional states visualized by the real-time analysis software; (B) Quadrant classification.

2.5. Ethical Considerations

The participants received written information regarding the study procedures and provided written informed consent prior to participation. The Ethics Review Committee of Kinjo Gakuin University approved the study (approval date: February 25, 2020; approval number: R19015).

3. Results

3.1. Correspondence between Biological Signal Quadrants and Objective and Subjective Emotions

This study examined the correspondence between biological signal quadrants derived from EEG data and RMSSD and objective and subjective emotions. Analyses were conducted using medication counseling sessions segmented into 20 s intervals. Table 1 summarizes the major findings.

The number of 20 s intervals included in each emotion-specific analysis was as follows: joy, 12; anger, 4; sadness, 34; fear, 173; disgust, 52; calm, 62; and surprise, 34. No intervals were identified for shame, liking, or pleasure.

For fear, strong positive correlations between objective and subjective emotions were observed in the LAHV quadrant at EEG sites C4 ($r = 0.782$, $p < 0.05$) and Cz ($r = 0.766$, $p < 0.05$). At site C3, the study noted a significantly positive correlation in the LAHV quadrant ($r = 0.647$, $p < 0.05$). A positive correlation was also observed in the LALV quadrant at C3 ($r = 0.507$), although it was not statistically significant.

For disgust, a strong positive correlation between objective and subjective emotions was identified in the LAHV quadrant at site C4 ($r = 0.782$, $p < 0.05$). With regard to calm, moderate positive correlations were observed at site C3 in the LAHV quadrant ($r = 0.671$, $p < 0.05$) and in the HAHV quadrant ($r = 0.533$), although the latter was not statistically significant. In addition, a significant positive correlation for calm was found in the HAHV quadrant at site C4 ($r = 0.688$, $p < 0.05$). For surprise, a positive but non-significant correlation was observed in the HAHV quadrant at site C3 ($r = 0.577$). No strong or statistically significant correlations were found at other EEG sites or in other quadrants.

In summary, these results indicate that when specific emotions were elicited, corresponding physiological signals tended to appear in particular quadrants of the valence-arousal space. Fear and disgust were mainly associated with low-arousal quadrants (*i.e.*, LAHV and LALV), whereas calm and surprise were more frequently observed in high-valence quadrants (*i.e.*, HAHV and LAHV). However, not all observed correlations reached statistical significance.

This study further examined whether the same emotion differed in its occurrence across EEG recording sites (*i.e.*, C3, Cz, and C4) or across quadrants (*i.e.*, HAHV, HALV, LALV, and LAHV). Only emotions for which correlations were observed across multiple sites or quadrants were included in the comparison.

The Kruskal-Wallis test showed no significant differences among C3, Cz, and C4 for fear in the LAHV quadrant. Pairwise comparisons using the Mann-Whitney

U test showed no significant differences between C3 and C4 for calm, between the LAHV and LALV quadrants for fear at C3, or between the HAHV and LAHV quadrants for calm at C3.

Table 1. Correlation between biological signal quadrants corresponding to objective and subjective emotions.

Emotion	EEG Site	Quadrant	Correlation Coefficient (r)
Fear	C4	LAHV	0.782*
	Cz	LAHV	0.766*
	C3	LAHV	0.647*
	C3	LALV	0.507
Disgust	C4	LAHV	0.782*
Calm	C3	LAHV	0.671*
	C3	HAHV	0.533
	C4	HAHV	0.688*
Surprise	C3	HAHV	0.577

Using Spearman's rank correlation coefficient (*$p < 0.05$).

3.2. Pharmacists' Communication Skills

Pharmacists' communication characteristics were examined in counseling scenarios in which fear, disgust, calm, and surprise were observed and corresponded with the biological signal quadrants and EEG sites. Table 2 provides an example of a conversation in which surprise was observed.

Table 2. Narratives in which surprise appeared in the HAHV quadrant (example).

Summary of Conversation	Feedback	10 Emotion
The pharmacist explains that just because you start using narcotics doesn't mean you become dependent or anything like that at all.	-	surprise (positive content)
The pharmacist explained that the dosage of the medication would be adjusted according to the level of pain. The patient asked if the dosage of narcotics could be reduced to suit the individual.	I was surprised to hear that it is better to start narcotics early. It also leads to treatment.	surprise (positive content)
The pharmacist explained that narcotics are a medicine that can be reduced because each person has their own dosage, and it is also a medicine that is said to be more successful in future treatment if started early.		surprise (positive content)
These days, narcotics are used from the beginning of treatment.	-	surprise (positive content)
Pharmacists explain that many people have the impression that narcotics are scary, but medical narcotics are different from what the public is used to.	-	surprise (positive content)
The pharmacist explains that the government recognizes narcotics as a medicinal product and that if it is used as the doctor instructs, no dependence is said to occur.	-	surprise (positive content)

Continued

The pharmacist explains that if the pain is controlled with narcotics, there is no problem, and that narcotics are not medicines that you must take all the time once you start taking them.	I was relieved to hear that I could stop using narcotics. These words made me the happiest.	calm, surprise (positive content)
The pharmacist explained that the drug cannot be reduced at one's discretion, but can be reduced depending on the level of pain and the doctor's judgment.		calm, surprise (positive content)
The pharmacist explains that if used as directed by the doctor, narcotic dependence is not a problem and is safe. Patients ask whether the dosage will be increased if the medication is ineffective.	-	surprise (negative content)
The pharmacist explained that narcotics are medicines that may be gradually reduced.	I was happy and surprised to hear that narcotics could be stopped because I thought it would be impossible to stop and that there would be an increase.	joy, surprise (positive content)
The pharmacist stated that pain can affect the patient's work and other aspects of their life.	The pharmacist also told me about my job. I am happy that I can do my job.	joy, surprise (positive content)
The pharmacist explained that enduring the pain would affect the patient mentally and physically, as well as the anticancer treatment.	The pharmacist's explanation is easy to understand. I found out that taking away the pain is good for my mental health.	joy, surprise (positive content)
The pharmacist explained that early pain control helps the patient fight the cancer. Patients are convinced that pain control is necessary for their feelings as well.		joy, surprise (positive content)
The pharmacist explained that the pain makes daily life difficult and depresses the patient's mood.		joy, surprise (positive content)
The pharmacist explains to the patient that the pain is better controlled, allowing them to continue focusing on their treatment. The patient says, "I understand".	-	calm, surprise (positive content)

Fear and disgust were most frequently observed during discussions related to narcotic medications. In several scenes related to fear, the patients reported that they understood the pharmacist's explanation, although they continued to feel fear internally. In contrast, in other scenes involving fear, pharmacists' explanations decreased patients' anxiety and led to a shift toward reassurance. Disgust was observed when pharmacists did not demonstrate empathy as patients described unpleasant or distressing experiences.

By contrast, calm was frequently observed when pharmacists provided careful explanations, supportive responses, or gentle verbal and nonverbal expressions that reassured patients. Surprise was mainly observed during positive interactions, such as when pharmacists informed patients that narcotic medication could be discontinued if necessary (Table 2). Surprise was also elicited when explanations were clear and reassuring.

4. Discussion

In this study, we conducted communication training for pharmacists using simulation sessions with SPs, an approach that is effective in improving pharmacists'

communication skills [2] [3].

Furthermore, given the growing recognition of the value of objective physiological signals for assessing emotional responses in healthcare communication research [7], we investigated the impact of pharmacists' communication during medication counseling on patients' psychological states using indicators derived from EEG and ECG data.

The results demonstrated correspondences between subjective emotions reported by the SPs during next-day video review and objective emotions identified by the analysts for several emotion categories, as reflected in EEG activity and HRV.

For fear, strong positive correlations between objective and subjective emotions were observed in the LAHV quadrant at EEG sites C4 and Cz. Additional correlations were found at site C3 in the LAHV and LALV quadrants (**Table 1**). Previous studies reported that fear is commonly associated with the HALV quadrant [19]. In contrast, fear in the present study mainly appeared in low-arousal quadrants. This difference indicates that physiological expressions of fear may be dependent on situational contexts, individual differences, and EEG recording locations.

The EEG signals were recorded at parietal sites (*i.e.*, C3, Cz, and C4). EEG activity at these sites may reflect neural activity in other regions, including the frontal lobe and cingulate cortex, due to volume conduction in the brain [20]. Previous studies have reported increased theta activity near C3 and in the cingulate cortex during fear-related processing [21]. The present study observed a decrease in the β/θ ratio during fear, which may indicate neural activity related to fear processing [22]. These findings are consistent with those of earlier neurophysiological research.

Regarding HRV, fear is known to yield different cardiovascular responses depending on contexts. While general fear has been associated with increased heart rate [23] and decreased RMSSD [24], heart rate may decrease when a threat is imminent [25]-[27]. This study did not identify a consistent pattern for fear via RMSSD. This variability may reflect differences in the type of fear experienced, such as anxiety about death, concerns about treatment side effects, or uncertainty about the future.

Although the patients frequently reported that they understood the pharmacist's explanations in fear-related situations, the physiological responses indicated that they continued to feel fear internally. This finding indicates that EEG and HRV may capture emotional states that are not fully expressed through subjective self-report.

For disgust, a significant positive correlation between objective and subjective emotions was observed in the LAHV quadrant at site C4 (**Table 1**). Previous studies mainly positioned disgust in the HALV quadrant [19]; however, the present results indicate that disgust may also appear in different physiological patterns according to contexts.

HRV responses during disgust pointed to increased RMSSD, indicating parasympathetic involvement. Previous EEG studies reported decreased beta activity in the right parieto-temporal region during disgust [28]. Consistent with these findings, a reduction in the β/θ ratio was observed at site C4 in this study.

Disgust was classified using the valence-arousal model; however, the patterns observed did not always match expectations. As disgust is influenced by social norms and cultural background, using a two-dimensional model based only on valence and arousal may fail to fully capture this emotion, thus requiring a more complex model that accounts for social and contextual factors.

When subjective and objective disgust were aligned, disgust tended to occur when pharmacists' responses did not meet patients' expectations. The patients expected empathy and professional reassurance, and explanations that were perceived as impersonal or insufficient were likely to lead to negative emotional reactions.

For calm, positive correlations between subjective and objective emotions were observed in high-valence quadrants, along with increased RMSSD (**Table 1**). These findings signify a relaxed physiological state. Calm was frequently observed when pharmacists used a gentle tone, empathetic language, and supportive nonverbal behavior. This aspect highlights the importance of communication style in clinical practice.

Surprise was mainly observed in the HAHV quadrant (**Table 1**), which is consistent with prior research reporting that emotion terms such as "aroused", "excited", and "astonished" are likewise located in this quadrant [13]. Although surprise may include positive and negative aspects, the majority of surprise-related scenes involved positive information. For example, patients expressed surprise when informed that opioid medication could be discontinued, or early pain control could improve quality of life (**Table 2**). In these cases, surprise was followed by relief or reassurance.

In summary, pharmacists' word choice, tone of voice, facial expressions, and clarity of explanation influenced patients' emotional responses. When subjective and objective emotions were consistent, pharmacists' communication behaviors played a key role in the formation of patients' emotional states.

The observation that a number of emotions appeared in physiological quadrants is different from those reported in previous studies, which indicates that emotional responses are strongly influenced by context and interpersonal interaction. Thus, future studies should consider individual differences and communication styles in detail.

5. Limitations

This study included a small number of participants (*i.e.*, four SPs and five pharmacists). All SPs were women, and potential gender effects cannot be overlooked. In addition, the use of a single scenario may have limited the emergence of emotions such as joy, anger, sadness, shame, affection, and pleasure. Future studies

should include larger and more diverse samples and multiple scenarios.

In addition, the number of 20 s intervals differed substantially across emotion categories, with some emotions being represented by only a small number of segments. Therefore, the results for these emotions should be interpreted cautiously, and future studies with larger datasets are needed to confirm these findings.

The present data did not enable the identification of specific EEG sites or quadrants uniquely associated with each emotion. To address this concern, increasing the sample size may enable a more precise analysis.

The EEG recordings exhibited relatively high noise levels at site Cz, which indicates the need for improved electrode attachment. Movement-related artifacts were also observed, particularly among SPs, which implies that better monitoring of body movement is necessary in future studies.

Because the subjective emotion data were obtained from SPs during next-day video review in a controlled experimental setting, the generalizability of these findings to real patients in live clinical practice may be limited.

6. Conclusions

This study examined the physiological effects of pharmacists' communication on patients' emotions using EEG and HRV. Clear correspondences between subjective and objective emotions were identified for fear, disgust, calm, and surprise. The verbal and nonverbal communication of pharmacists strongly influences patients' emotional states. Specifically, empathetic explanations were associated with positive emotions, whereas unmet expectations were linked to negative emotions.

The variability observed in the physiological patterns of fear and disgust underscores that emotional responses are dependent on individual and situational contexts. These findings emphasize that emotional states cannot always be explained by a single physiological pattern.

Future studies should aim to develop objective methods for assessing patient emotions using physiological signals. These approaches may foster a real-time evaluation of healthcare communication and contribute to improved patient-centered care.

Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Yukina Miyagi, Haruno Yamagiwa, Saori Gocho, Yuka Miyachi, Chika Nakayama, and Taeyuki Oshima. The first draft of the manuscript was written by Yukina Miyagi, and all authors commented on previous versions of the manuscript. All authors read and approved of the final manuscript.

Funding

The authors did not receive support from any organization for the submitted work.

Data Availability Statement

The datasets generated and analyzed during the current study are not publicly available due to ethical and privacy restrictions, but are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors have no relevant financial or non-financial interests to disclose.

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