Integrative Analysis of Multimodal Interaction Data: Predicting Communication Dynamics and Willingness to Communicate (WtC) in Human-Agent Interaction

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ABSTRACT: This research delves into the intricate relationship between physiological and behavioral indicators and the Willingness to Communicate (WtC) in the context of human-agent interactions. Specifically, it examines how heart rate, eye movement, facial expressions, and conversational dynamics influence individuals' engagement and willingness to engage in dialogue with agents. Set to take place in March 2024, the study employs a combination of ANCOVA and SVM machine learning techniques to analyze multimodal interaction data collected from participants engaging with conversational Agent. The aim is to identify patterns and correlations that can predict and subsequently enhance WtC, thereby improving the design and effectiveness of conversational agents. This research stands at the intersection of emotional intelligence, communication studies, and AI technology, offering a novel perspective on enhancing human-agent communication. Through its integrative approach, it seeks to contribute to the development of AI agents that can better understand and respond to human emotional and communicational cues, paving the way for more natural and meaningful digital interactions.

Keywords: Human-Agent Interaction, Conversational AI, Biometric Indicators, Machine Learning, and Communication Dynamics.

1 INTRODUCTION

1.1 Background

The quest to enhance Willingness to Communicate (WtC) in language learning and the realms of human-computer interaction has led to groundbreaking research endeavors. A pivotal component of language acquisition, WtC, denotes an individual's propensity to engage in communication using a second language (L2) across various contexts (MacIntyre, Clément, Dörnyei, & Noels, 1998). Despite extensive studies on pedagogical strategies and technological interventions to foster WtC (Cassell, Sullivan, Prevost, & Churchill, 2000), a significant gap remains in understanding and integrating biometric feedback within conversational agents. This research pivots on the premise that non-verbal cues, such as heart rate, eye movements, and facial expressions, significantly influence WtC, offering a nuanced perspective on human-agent interactions (Cowie, Douglas-Cowie, Tsapatsoulis, Votsis, Kollias, Fellenz, & Taylor, 2001).

1.2 Main Research Question (MRQ)

How can the integration of biometric indicators reflecting emotional states, eye-tracking metrics, and emotional facial cues, combined with conversational strategies (Affective Backchannel - AB, Conversational Strategies - CS, and their combination AB+CS) implemented by a dialogue agent, predict and enhance the Willingness to Communicate (WtC) gain in human-agent interactions while taking into account the nuanced

interpretations of these emotional and attentional cues? (MacIntyre, Clément, Dörnyei, & Noels, 1998; Cassell, Sullivan, Prevost, & Churchill, 2000).

1.3 Main Hypothesis

The integration of biometric indicators (heart rate, eye tracking, emotional facial cues) alongside conversational strategies (AB, CS, and AB+CS) by a dialogue agent plays a crucial role in predicting and enhancing Willingness to Communicate (WtC) gain in human-agent interactions. This complex interplay can be effectively deciphered and modeled through advanced analytical methods, promising not just to accurately forecast WtC gains but also to provide strategic insights for refining interaction dynamics with dialogue agents. (Cowie, Douglas-Cowie, Tsapatsoulis, Votsis, Kollias, Fellenz, & Taylor, 2001; Ayedoun, Hayashi, & Seta, 2016).

Research Questions	Hypothesis
RQ1: How do biometric indicators, eye tracking, and emotional facial cues individually contribute to predicting Willingness to Communicate (WtC) gain in interactions with dialogue agents?	**H1:** The individual analysis of biometric indicators, eye tracking, and emotional facial cues significantly boosts the predictive accuracy of WtC gain, highlighting distinct impacts and patterns each of these factors contributes to interaction outcomes with dialogue agents.
RQ2: How do biometric indicators, eye tracking, emotional facial cues, and dialogue content integrated with strategies (AB, CS, AB+CS) by dialogue agents interact to influence and enhance WtC gain?	**H2:** The synergistic effect of integrating biometric indicators, eye tracking, emotional facial cues, and dialogue strategies (AB, CS, AB+CS) through dialogue agents offers a deeper insight and significantly enhances the ability to predict and improve WtC gain in human-agent communications.

1.4 Objectives

The primary objectives of this study are twofold: Firstly, to develop a sophisticated system capable of collecting and analyzing biometric data in real-time to adapt conversational strategies dynamically. This system, leveraging the nuanced interplay between biometric indicators and conversational dynamics, aims to provide insights into the underlying mechanisms of WtC enhancement (Picard, 1997; Vinciarelli, Pantic, & Bourlard, 2009). Secondly, to evaluate the efficacy of this integrative approach in real-time human-agent interactions, thereby contributing to the development of more responsive and empathetic conversational agents (Cassell, Sullivan, Prevost, & Churchill, 2000).

This research encompasses a multidisciplinary approach, integrating insights from linguistics, psychology, and computer science to create a holistic understanding of communication dynamics (Baron-Cohen, Tager-Flusberg, & Lombardo, 2013; Pennebaker, Boyd, Jordan, & Blackburn, 2015). By focusing on the analysis of biometric and behavioral signals during interactions with conversational agents, this study endeavors to uncover patterns that could predict and enhance WtC. Through the lens of sophisticated machine learning techniques and predictive modeling, the research aims to offer strategic insights for refining interaction dynamics, thus pushing the boundaries of conventional human-agent

communication studies (Vinciarelli, Pantic, & Bourlard, 2009; Baltrušaitis, Robinson, & Morency, 2016).

2 LITERATURE REVIEW

2.1 Willingness to Communicate in Language Learning

Willingness to Communicate (WtC) is a fundamental aspect influencing the frequency and quality of second language use. MacIntyre, Clément, Dörnyei, and Noels (1998) describe WtC as stemming from a dynamic interplay of linguistic self-confidence and the desire to communicate, underscored by personality traits and situational variables. Their heuristic model forms the foundation for understanding WtC within the L2 acquisition landscape.

2.2 Human-Agent Interactions

The advent of conversational agents has significantly altered human-computer interaction, notably in educational realms. Cassell, Sullivan, Prevost, and Churchill (2000) emphasize the potential of embodied conversational agents (ECAs) to mimic human-like interactions, thus offering an immersive learning experience. These agents utilize verbal and non-verbal cues to facilitate natural and engaging interactions that could significantly enhance the learning process, especially in language education.

2.3 Biometric Feedback and Communication Dynamics

Advancements in sensor technology have allowed for the integration of biometric feedback into interactive systems, opening new pathways to assess and enhance communication dynamics. Cowie, Douglas-Cowie, Tsapatsoulis, Votsis, Kollias, Fellenz, and Taylor (2001) discuss the potential of leveraging emotional states, inferred from physiological signals, to dynamically adapt conversational agents' responses. This approach indicates that a deeper understanding of the emotional underpinnings of communication can lead to more effective and personalized educational experiences.

2.4 Embodied Conversational Agents in Educational Contexts

The use of ECAs in education, particularly for language learning, has garnered considerable interest. Johnson, Rickel, and Lester (2000) showed that ECAs could act as effective tutors, offering personalized feedback and fostering an encouraging learning environment. In language learning, ECAs' potential to simulate conversational contexts and provide immediate, context-relevant feedback presents a promising avenue for enhancing WtC. Ayedoun, Hayashi, and Seta (2016) propose a web-services based conversational agent designed to encourage WtC in the EFL context. By providing a dynamic and adaptable system that combines various web services, their study emphasizes the potential of conversational agents to simulate natural conversations and enhance learners' WtC in specific social contexts.

In a subsequent study, Ayedoun, Hayashi, and Seta (2018) further explore the addition of communicative and affective strategies to an embodied conversational agent, aiming to increase second language learners' WtC. Their research focuses on dialogue management models based on communication strategies (CS) and affective backchannels (AB) to foster natural and WTC-friendly conversations with learners. Their findings suggest that incorporating both CS and AB into conversational agents can significantly improve learners'

WtC, marking a crucial step towards creating more interactive and supportive language learning environments.

3 METHODOLOGY

3.1 System Architecture

The system architecture for this research integrates a comprehensive setup designed to analyze human-agent interactions, focusing on language learning scenarios. The system encompasses various data collection methods to gather biometric and behavioral data, including heart rate monitoring, eye tracking, and facial emotion recognition. Additionally, the Peter Conversational Agent plays a central role in interacting with participants, simulating realistic conversational experiences. Here's a breakdown of the system setup:

- **Heart Rate Monitoring**: Utilizes the RookMotion Device, a wearable technology, to continuously monitor the participant's heart rate, providing insights into their physiological responses during interactions with the conversational agent.
- **Eye Tracking**: Employs the Tobii Nano Pro Device, which captures the participant's gaze patterns, including fixation duration and saccades, to infer attention and engagement levels.
- **Facial Emotion Recognition**: A built-in camera integrated with OpenFace software analyzes facial expressions in real-time, identifying emotional states such as happiness, confusion, or frustration.
- **Peter Conversational Agent**: An advanced AI-driven agent designed to simulate naturalistic dialogues with participants. The agent adapts its conversational strategies based on the analyzed biometric and behavioral data, aiming to enhance the Willingness to Communicate (WtC) in a second language.

3.2 Data Analysis

The analysis of the collected biometric and behavioral data leverages machine learning techniques to infer user states and adapt the conversational agent's responses. The methodology encompasses several key categories and techniques:

- **Preprocessing**: Initial data cleaning and normalization processes prepare the biometric data (heart rate, eye tracking, facial expressions) for analysis.
- **Feature Extraction**: Identifies key features from the raw data that are indicative of the participant's engagement level, emotional state, and interaction patterns.
- **Classification and Regression Models**: Utilize supervised learning algorithms to classify emotional states and predict engagement levels. Techniques may include Support Vector Machines (SVM), Random Forests, and Neural Networks.
- **Time-Series Analysis**: Analyzes the sequential nature of biometric data to understand the dynamics of participant responses over time.
- **Adaptive Response Mechanism**: Based on the analysis, the system dynamically adapts the Peter Conversational Agent's dialogue strategies. This could involve changing the complexity of language, introducing supportive feedback, or modifying the emotional tone of responses.

- **Evaluation Metrics**: Includes accuracy, precision, recall, and F1 score for classification models, as well as mean squared error (MSE) for regression predictions. User experience and language learning outcomes are also assessed through task completion time, number of errors, and participant feedback.

4 SYSTEM DESCRIPTION

Overview of Conversational Agent Web Application Requirements

4.1 Input Variables:

- **Heart Rate**: Collected via Bluetooth from the RookMotion device, providing real-time physiological data indicative of the participant's stress or relaxation levels.
- **Eye Movement**: Recorded through a direct cable connection to the Tobii Pro Nano, tracking where and how long a participant looks at specific elements on the screen.
- **Facial Emotions**: Monitored using 1 camera integrated with OpenFace software, which analyzes facial muscle movements to identify emotions.

4.2 Output Objectives:

- **Causality between Status and WtC Improvement**: The primary goal is to understand how changes in the input variables relate to and can predict improvements in Willingness to Communicate (WtC).
- **Adaptation of Conversational Strategies**: The agent, powered by Dialogflow's database, dynamically adjusts its conversational tactics based on the input variables to foster a supportive and effective communication learning environment.

4.3 Agent Conversational Strategies:

- Utilizes a cloud-based Dialogflow database to access an extensive repertoire of dialogue scenarios and responses.

- Employs strategies such as mirroring participant emotions, offering encouragement, simplifying language when needed, and providing context-relevant backchannel feedback.

4.4 System's User Interface

The user interface for the conversational agent features a visually intuitive and responsive design, which facilitates seamless interaction between the user and the agent. The UI also displays real-time biometric feedback, if necessary, to enhance the user's self-awareness and engagement.

Figure 1 : The user interface of Peter - Conversational Agent

4.5 Data Storage

- **Local Storage**: Aguida dashboard locally saves all biometric data streams in CSV format, which can be used for in-depth offline analysis.
- **Text and CSV Outputs**: Conversational data from the agent are saved in both txt and CSV formats, allowing for easy parsing and analysis.

4.6 Privacy Considerations

- **Data Anonymization**: Personally identifiable information is stripped from the datasets to maintain participant confidentiality.
- **Secure Data Transfer**: Bluetooth and cable connections ensure that sensitive biometric data is not transmitted over the internet, reducing exposure to potential breaches.
- **Compliance with Regulations**: The system adheres to privacy regulations by informing users about the data collected and its use.

4.7 Scalability

- **Dialogflow Integration**: Leveraging cloud databases like Dialogflow allows for scalable conversation management that can grow with the user base.
- **Modular Data Collection**: The use of standard data formats like CSV for biometric data and txt/CSV for conversational data supports scalability in data processing and analysis.
- **Expandable Software**: OpenFace and the Tobii system can support additional cameras and trackers as needed, allowing the system to accommodate a larger number of participants or more complex experiments.

5 EVALUATION

5.1 Evaluation Methods

To assess the system's impact on users' Willingness to Communicate (WtC) and their overall interaction experience, a mixed-methods approach will be adopted, encompassing both qualitative and quantitative evaluation strategies:

5.1.1 Quantitative Analysis:

- Pre- and post-interaction surveys to measure changes in WtC.
- Analysis of interaction logs to determine usage patterns and frequency of engagement with the conversational agent.
- Performance metrics, including task completion times and error rates during interactions with the agent.
- Statistical analysis to correlate biometric data (heart rate, eye movement, facial expressions) with levels of engagement and WtC improvement.

5.1.2 Qualitative Analysis:

- Structured interviews to gather in-depth feedback on the user experience.
- Observational studies to note non-verbal cues such as body language and signs of emotions during interactions.
- Content analysis of verbal responses for indications of confidence, hesitation, and willingness to communicate.

5.1.3 Usability Testing:

- Heuristic evaluation by experts to assess the user interface and interaction flow.
- User task analysis to observe how participants interact with the system and identify potential points of friction.

5.1.4 Longitudinal Study:

- Follow-up sessions to determine the long-term impact of the system on WtC.
- Repeated measures over time to track progression and any sustained effects on language learning and communication willingness.

5.2 Preliminary Results and Feedback

The initial user interactions with the system involved six participants engaged in sessions utilizing strategies (AB, CS, AB+CS) for 45 minutes. Preliminary findings suggest:

- **Positive User Engagement**: Early observations indicate an increased willingness among participants to interact with the agent, potentially due to the dynamic conversational strategies and the personalized feedback based on biometric cues.
- **Feedback on System Features**: Users have highlighted aspects of the system they found most helpful and engaging, as well as features they liked least, which will be crucial for iterative design improvements.

- **Technical Performance**: The system has shown reliability in integrating biometric data with conversational strategies, although there may be areas to improve in terms of system response times and data synchronization.

Table 1: Evaluation Methods and Results

Evaluation Type	Methods	Preliminary Results
Quantitative Analysis	- Pre/post-surveys for WtC - Interaction log analysis - Performance metrics (task times, error rates) - Biometric data correlation	- Improved WtC scores post-interaction - Data on user engagement and system interaction frequency
Qualitative Analysis	- Structured interviews - Observational studies - Content analysis of verbal responses	- Insight into user confidence and communication willingness - Notes on body language and emotional responses
Usability Testing	- Heuristic evaluation - User task analysis	- Expert feedback on UI/UX - Identification of friction points
Longitudinal Study	- Follow-up sessions - Repeated measures over time	- Data on long-term impact on WtC - Tracking of learning progression

Table 2: User Feedback on System Features

Feature	Positive Feedback	Suggestions for Improvement	Technical Performance
User Engagement	- Increased willingness to interact	- N/A	- Reliable integration of biometric data
System Features	- Helpful and engaging aspects noted	- Features to improve or add	- System response time - Data synchronization

Note: The information contained within the tables is based on the preliminary findings, first expermentation and is subject to change as more data are collected and analyzed.

6 DISCUSSION

6.1 Analysis of Findings

Once the evaluation is complete, the analysis will focus on the relationship between the system's input variables and the improvement of users' Willingness to Communicate (WtC). This will involve:

- Comparing the pre- and post-interaction WtC scores to assess the direct impact of the system.
- Examining the correlation between biometric data and engagement levels to understand how physiological and emotional cues influence WtC.
- Assessing the efficacy of different conversational strategies (AB, CS, AB+CS) in promoting user engagement and language practice.

The findings will be contextualized within the broader framework of human-agent interaction and language learning, providing insights into how such systems can be optimized to facilitate communication in a second language.

6.2 Implications for Future Research

The initial results and user feedback will set the stage for future research, potentially exploring:

- **Longitudinal Impact**: Extending the study over a longer period to evaluate the sustained impact on WtC and language proficiency.
- **Diverse User Groups**: Broadening the participant pool to include diverse language backgrounds and proficiency levels to validate the system's adaptability and effectiveness across different learner profiles.
- **Advanced AI Integration**: Investigating the potential of incorporating more advanced AI features, such as natural language understanding and generation, to further personalize interactions and learning experiences.
- **Cross-Cultural Communication**: Exploring the system’s effectiveness in diverse cultural contexts, which might influence communication styles and WtC.

6.3 Potential Enhancements to the System

Based on the initial feedback, several enhancements to the system may be considered, such as:

- **Improved Responsiveness**: Enhancing the system’s ability to process and respond to biometric data in real-time to create a more fluid interaction.
- **User Interface Customization**: Developing a more customizable UI that can adjust to user preferences and learning styles.
- **Data Integration**: Streamlining the integration of conversational data and biometric feedback to provide more coherent and contextually relevant responses from the agent.
- **Expansion of Conversational Domains**: Including a wider array of conversational topics and scenarios to cater to different interests and needs of language learners.

7 CONCLUSION

The initial exploration of integrating biometric feedback into conversational agents within the realm of language learning has embarked on an innovative journey, marking a significant step forward in educational technology. While this research is ongoing and the work remains unfinished, the preliminary phase has already illuminated promising avenues for enhancing human-agent interactions and, by extension, language learning experiences.

Research Findings Summary:

- The use of pre-selected conversational strategies (Affective Backchannels - AB, and Conversational Strategies - CS) has been instrumental in assessing their impact on learners' Willingness to Communicate (WtC).

- Early observations from experiments involving six participants indicate a positive influence on participant engagement and interaction, suggesting that specific conversational tactics significantly affect learners' WtC.

Significance of Biometric Feedback:

- Although the current system design does not include dynamic strategy adaptation during interactions, the structured implementation of conversational strategies showcases the potential of conversational agents to foster user engagement.
- These insights highlight the critical role of biometric feedback in personalizing the learning experience, providing a foundation for future research aimed at integrating these elements more seamlessly.

Potential for Real-Time Adaptation:

- The findings underscore the promise of real-time adaptation of conversational strategies based on biometric feedback to enhance educational outcomes and user engagement.
- Future extensions of this research could explore more sophisticated AI capabilities, enabling conversational agents to adapt strategies dynamically, offering a more personalized and responsive educational tool.

As this research continues, it aims to delve deeper into the nuances of conversational agent design, particularly concerning real-time adaptation and the integration of biometric feedback. The goal is to create conversational agents that not only improve language learning outcomes but also enrich the overall educational experience by making digital interactions more intuitive, engaging, and tailored to individual learner needs and preferences.

This ongoing work is poised to contribute significantly to the fields of educational technology, applied linguistics, and human-computer interaction, promising to refine the use of conversational agents in educational settings and ultimately enhance both the experience and outcomes for language learners globally.

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Additional Information

In this research, we explore the integration of biometric feedback into human-agent interactions, specifically focusing on enhancing Willingness to Communicate (WtC) in language learning. This study sits at the intersection of learning analytics and conversational AI, aiming to leverage physiological and behavioral indicators like heart rate, eye movement, and facial expressions to predict and improve engagement in educational settings. The relevance of this work extends to the development of AI agents that can adapt dynamically to users' emotional states, offering personalized learning experiences and insights into effective human-computer interaction strategies.

Research Challenges:

Our project navigates through multifaceted challenges: technically, integrating diverse biometric data streams in real-time to ensure responsive agent interactions; theoretically, establishing a robust framework to understand and predict WtC leveraging biometric signals; and methodologically, selecting and applying advanced machine learning techniques to analyze multimodal data. These hurdles underscore the complexity of creating adaptive, responsive educational technologies that cater to individual learner needs while ensuring privacy and ethical considerations are meticulously addressed.

Seeking Expert Feedback:

I'm seeking expert feedback on several fronts: Firstly, on the selection and application of machine learning techniques suitable for analyzing multimodal biometric data in learning contexts. Secondly, advice on effectively integrating diverse biometric indicators to predict learner engagement and WtC. Lastly, guidance on navigating ethical considerations, particularly in terms of data privacy and informed consent in research involving biometric data collection and analysis.

Collaboration Interests:

I am keen on exploring potential collaborations with fellow researchers and experts at the consortium, particularly those working in fields overlapping with learning analytics, AI, and human-computer interaction. Collaborative opportunities that could enhance the theoretical underpinnings of our research, provide insights into advanced data analysis techniques, or offer novel perspectives on ethical practices in biometric data use are of great interest.

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Additional Information

Impact and Contribution:

This research has the potential to significantly impact the field of learning analytics by introducing innovative methods for integrating biometric feedback into educational technologies. By enhancing the understanding and prediction of Willingness to Communicate (WtC), this study could lead to the development of more responsive and effective AI-driven educational tools, contributing to personalized learning experiences. These advancements promise to enrich the educational landscape, offering insights into student engagement and facilitating more effective learning strategies.

Questions for the Committee:

I would like to inquire about the best practices for ensuring data privacy, algorithms, and ethical considerations in projects involving sensitive biometric data. Additionally, I seek advice on optimizing the scalability of AI-driven educational tools developed from this research. How can we ensure these tools are adaptable to diverse educational settings and learner needs?

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March 25, 2024

Doctoral Consortium Co-Chairs:

- Yannis Dimitriadis, Universidad de Valladolid, Spain
- Rebeca Cerezo Meléndez, Universidad de Oviedo, Spain
- Rebecca Ferguson, Institute of Educational Technology, Open University, UK

Dear Doctoral Consortium Co-Chairs,

I am writing to wholeheartedly recommend Mr. Aboul Hassane CISSE, a dedicated Ph.D. candidate under my supervision at Osaka Metropolitan University, for participation in the Doctoral Consortium at LASI Europe 2024. Mr. CISSE's ongoing doctoral research, titled "Integrative Analysis of Multimodal Interaction Data: Predicting Communication Dynamics and Willingness to Communicate (WtC) in Human-Agent Interaction," represents a pioneering effort to enhance human-agent communication through the analysis of multimodal interaction data.

Mr. CISSE's project ambitiously seeks to bridge the gap between artificial intelligence and human-computer interaction by leveraging physiological and behavioral indicators to predict and improve the Willingness to Communicate in human-agent interactions. His innovative approach, which combines advanced computational models with practical applications, stands to make a significant contribution to the field of learning analytics. This research not only highlights his technical acumen but also underscores his commitment to addressing real-world problems through the lens of educational technology.

Participation in the LASI Europe 2024 Doctoral Consortium would afford Mr. CISSE a platform to further refine his research through engagement with leading experts and peers in the field. I am confident that the feedback and collaborative opportunities provided at the consortium will be invaluable to him as he advances his doctoral work. Furthermore, Mr. CISSE's participation will undoubtedly enrich the consortium itself, as he brings fresh insights and a passionate commitment to the role of analytics in enhancing educational experiences.

In addition to his academic qualifications, Mr. CISSE has demonstrated a remarkable ability to communicate his research findings to diverse audiences, a skill that will serve him well in the consortium's collaborative and multidisciplinary setting. His enthusiasm for learning and sharing knowledge aligns perfectly with the consortium's objectives to foster a spirit of collaborative research and develop a supportive community of learning analytics scholars.

I am fully supportive of Mr. CISSE's application to the Doctoral Consortium and believe that his participation will significantly benefit his doctoral research and contribute to the broader learning analytics community. I look forward to the opportunities that the consortium will offer him and am happy to provide any further information you may require.

Thank you for considering Mr. Aboul Hassane CISSE for this prestigious opportunity.

Sincerely,

Prof Kazuhisa Seta

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