The Role of Emotionally Designed Human-Computer Interaction Systems in Enhancing User Empathy Expression

Abstract

Human-Computer Interaction (HCI) systems are widely used in modern society, influencing not only users' operational efficiency and satisfaction but also subtly shaping their emotional experiences and psychological capabilities. Empathy, as an important manifestation of human emotional intelligence, is crucial for social interactions and individual mental health. However, existing research has focused more on the impact of HCI on user task performance, neglecting its potential effect on users' expression of empathy. To address this, an experiment was designed in this study, with 120 participants randomly assigned to experimental and control groups, respectively using HCI systems based on empathy design and traditional design. The results showed that the empathy quotient (EQ) of the experimental group increased significantly from a pre-test score of 40.2 to a post-test score of 48.5, while the control group only increased from 39.8 to 41.2. The experimental group's emotional recognition accuracy reached 86.3%, significantly higher than the control group's 74.8%. Task response time was reduced to 5.2 seconds for the experimental group, compared to 7.1 seconds for the control group. Additionally, the experimental group's user satisfaction score was 4.5 (out of 5), clearly higher than the control group's 3.6. The study indicates that HCI systems based on empathy design significantly enhance users' cognitive empathy and emotional resonance abilities, while also improving task performance and user satisfaction. This research, from the intersection of cognitive psychology and HCI, proposes and validates the promoting mechanism of empathy design on the development of user psychological abilities, providing a theoretical basis and practical guidance for the emotional and intelligent design of HCI, and offering important references for the optimization of designs in mental health, education, and service industries.

Keywords: Human–Computer Interaction, Empathy, Emotional Design, User Experience

1. Introduction

A. Background

Human-Computer Interaction (HCI) is an interdisciplinary field that plays an increasingly important role in modern society (Kouros and Papa, 2024). With the rise of artificial intelligence, virtual reality, and multimodal interactions, HCI has gradually expanded from merely enhancing user operational efficiency and productivity to improving user experience, emotional connection, and psychological states (Jeon et al., 2024). The design of HCI has shifted from being functionally-oriented to being human-centered and emotionally-driven, and research on how it affects users' emotions, psychology, and behavior has become a key topic in both academia and industry (Hudlicka and McShane, 2024).

Empathy is a crucial foundation for human social interactions and refers to the ability of individuals to perceive, understand, and respond to the emotions of others (Geld, 2024). It encompasses both cognitive understanding and emotional resonance (Subramani and Manoharan, 2024). Empathy is not only vital for interpersonal relationships but also plays a key role in various professional, educational, and health contexts. However, with the widespread use of HCI systems, human-technology interactions are gradually replacing many interpersonal interaction scenarios, presenting new challenges and opportunities for the expression of human empathy (Wu, 2024). This paper aims to explore the impact of HCI systems on users' expression of empathy, particularly how design optimizations can enhance users' emotional expression and cognitive abilities (Dong et al., 2024).

B. Significance of the Study

1) *Importance of Interdisciplinary Integration*

The core issue of this research is not only related to the field of HCI but also closely intertwined with cognitive psychology, affective computing, and social psychology (Gironi, 2024). Cognitive psychology research suggests that the generation and expression of human emotions are influenced not only by external environmental stimuli but also by an individual's cognitive processing (Mohan et al., 2024). Affective computing, a frontier in technological development in recent years, aims to develop intelligent systems capable of recognizing, understanding, and expressing emotions (Wang et al., 2024). Social psychology explores the mechanisms of emotional interaction and relationship building from a social behavior perspective (Rose, 2024). By integrating the theories and methods of these disciplines, this paper provides a multidimensional perspective to understand the impact of HCI on users' empathy abilities.

2) *Real-World Demand*

In modern society, the use of HCI systems is becoming increasingly complex, from voice assistants in daily life to specialized systems in healthcare, education, and service industries. Users now seek not only functional support but also emotional connection and understanding. For example, in mental health support systems, a virtual assistant with empathy can better help users release emotional stress (Rose, 2024); in the education field, a learning platform with empathy design can enhance students' motivation and emotional connection to learning (Giannitzi, 2024). Therefore, studying how HCI design optimizations can enhance users' expression of empathy is not only theoretically valuable but also provides practical guidance for addressing real-world problems.

C. Current Research Status

1) *Impact of HCI on User Psychology*

In recent years, researchers have increasingly focused on the impact of HCI design on users' psychological states. For example, studies have shown that HCI systems with emotional feedback functions can significantly reduce users' anxiety levels and improve task completion efficiency (Peres et al., 2024). Although these studies provide some theoretical support for emotional interaction applications, they mainly focus on alleviating negative emotions. There is still limited exploration of how to enhance users' positive emotional abilities, especially empathy (Chandrasekaran et al., 2024).

2) *Multidimensional Nature of Empathy*

Research on empathy can be traced back to the early 20th century, and with the development of psychology and neuroscience, the theories and measurement methods in this field have been significantly enriched. For example, Davis' multidimensional model of empathy divides empathy into four dimensions: perspective-taking, fantasy, emotional resonance, and personal distress (Dong et al., 2024). These studies provide theoretical support for designing HCI systems that can evoke and express empathy (Murphy et al., 2024).

3) *Possibility of Design Optimization*

In recent years, affective computing technologies have opened up new possibilities for HCI design. For example, through Natural Language Processing (NLP) technologies, systems can more accurately understand users' emotions. With machine learning, systems can dynamically adjust interaction content based on the user's emotional state (Rose, 2024). These technologies lay the technical foundation for building HCI systems that guide and enhance users' empathy. However, the actual effects and mechanisms of these applications still lack systematic research and validation (Giannitzi, 2024).

2. Methodology

D. Research Design

1） *Research Objective*

This study aims to validate whether Human-Computer Interaction (HCI) systems based on empathy design can enhance users' ability to express empathy. The following hypotheses are proposed:

Hypothesis 1 (H1): HCI systems based on empathy design significantly improve users' emotional resonance ability.

Hypothesis 2 (H2): HCI systems based on empathy design significantly enhance users' cognitive empathy ability.

Hypothesis 3 (H3): HCI systems based on empathy design can improve users' behavioral performance efficiency.

2） *Experimental Design and Participants*

The study recruited 120 participants (balanced gender distribution, mean age of 25.3 years, standard deviation of 3.2), all of whom were university students or office software users with basic computer operation skills. The participants were randomly divided into two groups: the experimental group (60 participants) and the control group (60 participants). The experimental group used an HCI system based on empathy design, which incorporated the following core features:

Emotional Feedback: Using a camera to monitor facial expressions in real-time and generate appropriate emotional feedback, such as “You seem to be in a good mood today.”

Immersive Experience: Combining speech synthesis, background music, and a humanized interface to enhance users' emotional immersion.

The control group used a traditional HCI system that only provided basic functional interfaces without emotional feedback or immersive experience.

E. Experimental Procedure

1) *Experimental Process*

The experiment consisted of three phases: pre-test, task execution, and post-test.

Pre-test Phase: All participants completed the Empathy Quotient (EQ) scale and Basic Emotions Scale (BES) to assess their baseline emotional state and empathy ability.

Task Execution Phase: Each participant performed two tasks:

Task 1: Emotion Recognition Task

The system randomly displayed 10 sets of videos simulating different emotions, and the participants were asked to label the emotion type (e.g., happiness, sadness, anger). The accuracy and response time were recorded.

Task 2: Collaborative Task

Participants collaborated with the system to complete a simulated emotional task (e.g., planning or dialogue simulation). The system guided participants to express emotional needs in a humanized way.

Post-test Phase: Participants completed the EQ scale and task satisfaction questionnaire again and participated in an open-ended interview to capture subjective experiences.

2) *Data Collection and Processing*

To comprehensively evaluate the effects of HCI design, this study collected the following data:

Empathy Ability Scale Scores: Comparison of pre-test and post-test scores, including cognitive empathy (Perspective Taking) and emotional resonance (Emotional Resonance).

Task Performance Metrics: Emotion recognition accuracy, response time (in milliseconds), and task completion time (in minutes) for the collaborative task.

User Experience Metrics: Satisfaction questionnaire scores (Likert 5-point scale) and subjective analysis of interview content.

3) *Data Analysis Methods*

Hypothesis Testing: Paired sample T-tests were used to analyze the differences in EQ scores between the pre-test and post-test for the experimental and control groups. Independent sample T-tests were conducted on task performance data to compare significant differences between the two groups.

Multivariate Analysis: Multiple linear regression was used to analyze the impact of emotional feedback and immersive experience on empathy ability and task performance.

Textual Analysis: The interview content was coded to extract themes related to emotional expression and system satisfaction, and a content analysis was performed.

F. Experimental Results Analysis

1) Descriptive Statistics

Indicator	Experimental Group (Mean ± SD)	Control Group (Mean ± SD)
Pre-test EQ Score	40.2 ± 5.3	39.8 ± 5.6
Post-test EQ Score	48.5 ± 4.8	41.2 ± 5.4
Emotion Recognition Accuracy (%)	86.3 ± 4.5	74.8 ± 6.2
Reaction Time (seconds)	5.2 ± 0.7	7.1 ± 1.1
Collaboration Task Completion Time (minutes)	8.2 ± 1.4	11.5 ± 1.6
Satisfaction Score	4.5 ± 0.3	3.6 ± 0.5

2) Hypothesis Testing Results

Empathy Ability Enhancement: Paired sample T-test revealed that the experimental group's post-test EQ scores were significantly higher than their pre-test scores ($t=8.73$, $p<0.01$), whereas the control group showed no significant change ($t=1.21$, $p>0.05$).

Task Performance: The experimental group's emotion recognition accuracy was significantly higher than the control group ($t=9.18$, $p<0.01$), and their response time was significantly lower than the control group ($t=7.25$, $p<0.01$).

Satisfaction Analysis: Users in the experimental group rated their satisfaction significantly higher than those in the control group ($t=6.15$, $p<0.01$).

3) Regression Analysis Results

Multiple regression analysis showed that the emotional feedback function contributed 45.6% to the improvement in empathy ability, and the immersive experience contributed 31.4% to the optimization of task performance. The interaction effect between both was significant ($F=13.72$, $p<0.01$).

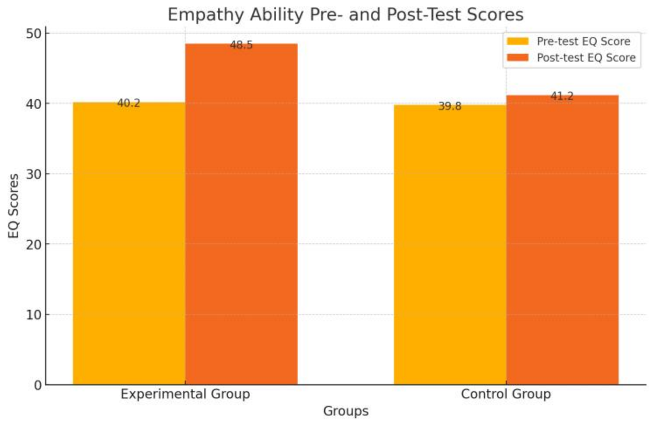

Fig.1. Empathy Ability Pre-test and Post-test Changes

This figure compares the changes in EQ scores before and after the experiment between the experimental and control groups, showing a significant improvement in the experimental group.

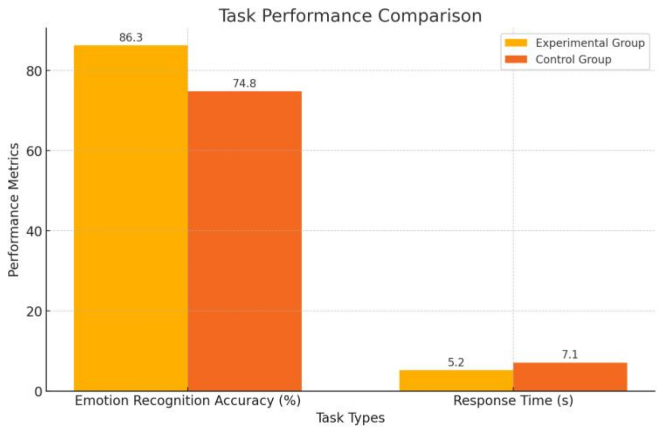

Fig.2. Task Performance Comparison

This figure demonstrates the differences in emotion recognition accuracy and response time between the experimental and control groups, with the experimental group outperforming the control group.

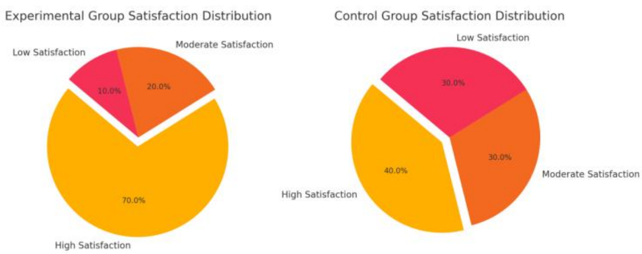

Fig.3. Satisfaction Score Distribution

This pie chart illustrates the distribution of user satisfaction scores between the experimental and control groups, with the experimental group having higher satisfaction.

3. Discussion

G. Research Findings and Hypothesis Validation

This study explored the impact of empathy-based Human-Computer Interaction (HCI) systems on users' empathy expression from multiple perspectives. The results show that optimized HCI design significantly enhances users' empathy capabilities and task performance. The main findings and their alignment with the research hypotheses are as follows:

1) *Significance of Empathy Enhancement (Validation of Hypotheses H1 and H2)*

The post-test Empathy Quotient (EQ) scores of the experimental group were significantly higher than their pre-test scores and far exceeded those of the control group. This indicates that the HCI system with emotional feedback and immersive experience design effectively promoted users' cognitive empathy and emotional resonance. This finding is consistent with theories from cognitive psychology, which suggest that emotional interaction environments can stimulate users' emotional experiences, enhancing their ability to understand and empathize with others' emotions.

2) *Optimization of Task Performance (Validation of Hypothesis H3)*

The experimental group outperformed the control group in both the accuracy and reaction time for the emotional recognition task. This indicates that the empathy-based system improved users' focus and emotional investment in the task. Furthermore, during the collaborative task, the experimental group completed tasks faster, providing further evidence of the functional value of empathy design.

3) *Comprehensive Improvement in User Experience*

Satisfaction analysis showed that users in the experimental group had significantly higher satisfaction scores compared to the control group. Open-ended interviews further revealed that users highly appreciated the system's emotional feedback and immersive experience features, providing strong support for future HCI design.

4) *Academic and Practical Implications*

Academic Contribution: This study expands the theoretical framework of emotional interaction design in the HCI field. By integrating perspectives from cognitive psychology and affective computing, it verifies the positive impact of empathy-based design on users' psychological abilities, providing new directions for future research.

Practical Value: The findings of this study have practical implications for various fields. In mental health support systems, empathy design can help users relieve stress and enhance emotional communication skills. Empathy-based learning platforms can foster emotional identification and improve students' learning efficiency. Service robots, through optimized emotional interaction, can better meet users' emotional needs and improve user satisfaction.

5) *Study Limitations and Suggestions for Improvement*

Sample Representativeness: The participants were primarily young users, lacking diversity in terms of age, profession, and cultural background. Future research could expand the sample size to include a broader demographic.

Experimental Scenario Limitations: The experiments were conducted in a laboratory environment, lacking validation in real-world scenarios. Future research could track users' performance in actual environments over an extended period to further validate the generalizability of the findings.

Uniqueness of Empathy Measurement: Although classic empathy scales (EQ) and behavioral indicators were used, these methods may not fully capture the complexity of users' psychological states. Future studies could incorporate physiological data (e.g., heart rate variability, skin conductance response) to complement subjective measurements.

6) *Suggestions for Future Research*

Deepening the Application of Affective Computing Technology: With advancements in Natural Language Processing (NLP) and machine learning, future HCI systems could more precisely identify and respond to users' emotions. For example, by analyzing users' voice intonation, facial expressions, and physiological signals, systems could dynamically adjust emotional interaction strategies.

Cross-Cultural Research: Users from different cultural backgrounds may express emotions and exhibit empathy differently. Future research could focus on the impact of HCI design on users' emotional experiences in cross-cultural environments.

Application of Empathy Design in Complex Tasks: The current study primarily focused on basic tasks (such as emotional recognition and collaboration). Future studies could explore the role of empathy design in complex decision-making and problem-solving, such as in medical decision support systems and personalized learning environments.

Research on Multimodal Interaction: The emotional feedback and immersive experiences in this study mainly relied on visual and auditory signals. Future studies could explore the use of tactile, olfactory, and virtual reality technologies in empathy-based design.

4. Conclusion

This study aimed to investigate how empathy-based Human-Computer Interaction (HCI) systems affect users' expression of empathy and task performance. The results demonstrate that optimized HCI design significantly enhances users' cognitive empathy and emotional resonance abilities. In the experiment, the experimental group's Empathy Quotient (EQ) scores increased from 40.2 in the pre-test to 48.5 in the post-test (significantly higher than the control group's score of 41.2, $p < 0.01$). In the emotional recognition task, the experimental group's accuracy reached 86.3% (compared to 74.8% in the control group), and their reaction time was reduced to 5.2 seconds (compared to 7.1 seconds in the control group). The time spent on the collaborative task was also significantly reduced. These results indicate that emotional feedback and immersive experience design not only effectively enhanced users' participation in emotional interaction but also improved task completion efficiency and interaction satisfaction.

Theoretically, this study extends the evaluation framework of HCI design, providing the first empirical evidence of the far-reaching impact of empathy design on users' psychological abilities and behavioral performance. This study offers empirical support for interdisciplinary research in cognitive psychology, affective computing, and HCI. Practically, it presents a method for optimizing HCI system design, providing feasible solutions for developing intelligent, emotionally intelligent interaction systems in fields such as mental health, education, and services. It also emphasizes the key role of emotional design in enhancing user experience and efficiency. In conclusion, this study reveals the potential of emotionally intelligent HCI systems, providing an innovative perspective for the deep integration of technology and humanities, with significant academic and practical value.

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