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Affective Interaction Enabled by Fabric-Based Social Robots: Reducing Anxiety Through Haptic Engagement*

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I. Introduction

With the rapid advancement of technological devices, research in the field of digital mental health has grown substantially, with increasing evidence supporting its efficacy [1]. This area of research has gained heightened attention particularly in the context of the COVID-19 pandemic [2]. The present study focuses on the issues of anxiety and psychological tension, which are prevalent across various populations. Heightened sensitivity to such emotional states can, in severe cases, culminate in panic episodes, clinically classified as panic disorder, a subtype of anxiety disorders [3]. Although the etiology of anxiety and tension is highly individualized, the inability to effectively regulate these emotions can significantly impair social functioning and daily life.

In response to this challenge, a growing body of research has explored the development and implementation of technological interventions aimed at monitoring emotional states and alleviating psychological distress. Among the diverse technological interventions explored, textile-based interactive devices have emerged as a notable modality for promoting emotional stability. Wakita et al. proposed a smart textile that dynamically alters its shape using wool and conductive threads [4]. This textile mimics biological movements to express emotions and facilitates a novel form of animacy interaction, allowing users to experience emotional stability through their engagement with the fabric. Similarly, Emanuela Corti and her design team, "Caravan," developed a garment called "Sensewear" [5]. This wearable device employs an inflation mechanism within its structure to create a hugging sensation, thereby promoting psychological comfort. These prior studies suggest the potential of textiles and wearable devices in eliciting emotional stability through sensory stimulation. However, existing research has primarily focused on the design and implementation of emotion-relieving mechanisms, with limited comprehensive investigation into user experience and effectiveness validation. Haptic interaction, particularly through soft and textile-based media, has shown promise in eliciting emotional responses and promoting psychological comfort. Therefore, this study aims to explore the design of a fabric-based social robot that provides a sense of stability and examines the potential for new forms of interaction utilizing such a device.

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II. Methods

Previous studies have focused on the use of smart textiles for tactile stimulation [6]. The prototypes used in these experiments, which focused on the concept of comfort upon touch, comprised changes in weight, size, texture, and form as well as modifications to textile properties according to interaction styles. In this study, we extended previous studies to create Tangible-E-Motion, a novel textile-based system that combines fabric with sensors, an air-based pressure mechanism, and color emergence upon touch. Its primary goal was to identify an individual's emotions by employing the textile that encourages movement and touch around the body, allowing color and pressure to affect a person's calm mental state. More specifically, an accelerometer was used to detect the user's posture, which served as the basis for distinguishing different light emission patterns. Additionally, a pressure sensor embedded on the back of the textile triggered an air-based inflation system, which inflated a polybag beneath the rayon layer and caused the textile to expand accordingly. This inflatable textile was designed to provide a calming haptic pressure sensation akin to being hugged, while also functioning as a playful object that could be tapped, reflecting its multifunctional purpose.

Arousal levels were measured as part of the experiment to evaluate participants' psychological states. Arousal was assessed using electrodermal activity (EDA), a physiological indicator of sympathetic nervous system activity. User participation took place at Chubu University's HRI lab in Japan. Six male university students, with an average age of 21, took part in the research. As part of the experimental protocol, participants wore an E4 wristband to monitor EDA and waited until their arousal levels stabilized. After that, they were exposed to a series of chosen images from the International Affective Picture System (IAPS) [7] for a maximum of 20 minutes to arouse them. Image presentation ceased as soon as heightened arousal was confirmed. Participants then spent around 20 minutes interacting with a fabric-based robot. For future behavioral analysis, the entire session was recorded on video. Following the interaction, participants completed the Godspeed questionnaire [8], a standardized instrument used to assess perceptions and attitudes toward robots across multiple dimensions. EDA data were analyzed using Ledalab, where Continuous Decomposition Analysis (CDA) was applied to extract tonic components indicative of increased physiological arousal in response to cognitive or emotional stimulation.

III. Results

The results of the EDA data, video analysis, and Godspeed questionnaire responses are summarized below. The tonic component of EDA reflects slow and long-term changes and is considered an indicator of tension, stress, emotional stability, and anxiety. In general, higher tonic values indicate heightened arousal, while lower values suggest a more relaxed state. Among the six participants, one in particular exhibited a clear and representative pattern, as shown in Fig. 1. The EDA values began to rise just before the onset of IAPS viewing (indicated by the first red dashed line) and continued to increase sharply. This pattern suggests an intensification of psychological tension or emotional stimulation. As intended in the experimental design, the IAPS images successfully elicited heightened arousal.

Following this, when the participant began interacting with the fabric-based social robot, tonic EDA values gradually declined and stabilized at a moderate level. This pattern may reflect post-stimulation relaxation or signs of physiological adaptation, supporting our hypothesis that interaction with a fabric-based social robot contributes to the reduction of psychological tension. A Wilcoxon signed-rank test was conducted to compare tonic EDA levels before and after the second event. The results showed no statistical significance for Event 1 ($p = 1.0$), although the rank-biserial correlation was $r = 1.0$, indicating a strong and consistent elevation in arousal levels following IAPS onset. After using the fabric-based social robot (Event 2), statistical significance was observed ($p < .001$), with a rank-biserial correlation of $r = -0.94$, suggesting a strong and consistent decrease in tonic EDA values.

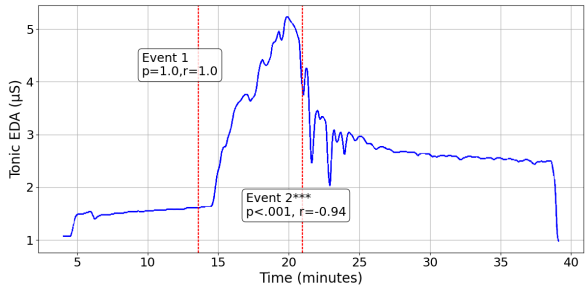

Fig. 1. Tonic features of EDA data results (blue line). Event 1 (red dashed line): IAPS onset; Event 2 (red dashed line): Fabric-based social robot usage onset.

To assess users' perceptions of the robot, the Godspeed questionnaire was administered to measure five key attributes: Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety. Each attribute score was compared to a neutral baseline value of 3.0 using the Wilcoxon signed-rank test. This non-parametric method was chosen due to the small sample size ($n = 6$) and the lack of assumption of normality. The results indicated that among the five attributes, only Likeability (γ) was significantly higher than the baseline ($p < .05$), suggesting that participants perceived the robot as likable. While the other

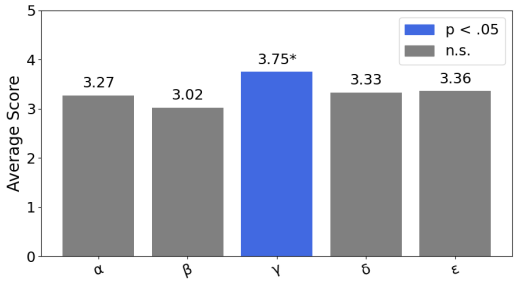

Fig. 2. Godspeed questionnaire results. α (Anthropomorphism), β (Animacy), γ (Likeability), δ (Perceived Intelligence), and ϵ (Perceived Safety).

attributes showed mean scores above 3.0, none demonstrated statistically significant differences from the baseline. As the analysis focused on central tendency and significance relative to the neutral value, standard deviations were omitted from the visual representation. These findings align with the study's objectives. In particular, the significantly high Likeability scores ($p < .05$) suggest that the fabric-based social robot was perceived as pleasant and approachable, offering participants a sense of comfort and a favorable impression.

IV. Conclusion

The objective of this study is to develop a fabric-based social robot designed to promote emotional stability. Experimental results indicate that the system may contribute to emotional regulation, demonstrating its practical potential for reducing anxiety through haptic stimulation. By enabling tactile interaction with textile-based components, the system facilitates haptic engagement that supports both emotional regulation and anxiety relief.

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