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RESEARCH ARTICLE

# Breathing-Cycle Haptic Cues Reduce Perceived Mental Workload and Enhance Engagement in Remote Collaborative Learning

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**ABSTRACT** Since the COVID-19 pandemic, synchronous online classes using video conferencing systems have become an established lecture format in higher education institutions. However, the overuse of remote communication via video conferencing systems has been reported to impose stress, including cognitive and psychological exhaustion. This study investigates the effectiveness of a cushion-shaped device designed to induce respiratory rhythm and depth within collaborative learning contexts. We conducted a between-subjects experiment with 54 university students, comparing three conditions: no device, an inactive cushion, and a cushion delivering continuous breathing-cycle guidance. Pairs of participants completed two consecutive discussion-based collaborative learning tasks. Perceived mental workload, measured once after both tasks, was significantly lower with breathing-cycle guidance than without a device. In the first task, ratings of engagement and satisfaction were also higher, whereas no such differences emerged in the second task. Physiological and behavioral measures showed no significant differences among conditions. These findings suggest that breathing-cycle haptic cues can shape learners' subjective appraisal of task demands during remote collaborative learning, even in the absence of measurable physiological change.

**INDEX TERMS** Online collaborative learning, synchronous online learning, video conferencing, cognitive load, student engagement, stress reduction.

## I. INTRODUCTION

The COVID-19 pandemic accelerated the adoption of synchronous video conferencing systems in education, such as Zoom and Microsoft Teams [1], [2]. While these systems enable real-time audiovisual interaction [3], [4], they impose significant cognitive and psychological burdens on students, commonly referred to as "Zoom fatigue" [5]. The causes of Zoom fatigue are manifold, but it has been noted that the unique environment of video conferencing, where one's own image and that of one's partner are constantly visible, can heighten self-consciousness and concerns about others' evaluations [6]. This heightened self-awareness differs from the cumulative fatigue resulting from prolonged use; it can arise even in short periods during situations involving social evaluation, such as collaborative learning activities with first-time students.

Research aimed at improving remote communication has been conducted for some time, with hugging-oriented devices demonstrating the ability to enhance intimacy and promote relaxation [7], [8], [9], [10]. However, much of this research has focused on informal interpersonal contexts, such as interactions between family members or romantic partners. The effects of such interventions on

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student communication in formal classroom settings remain unclear. Regarding stress reduction, slow and deep breathing activates the parasympathetic nervous system [11], [12], and several breathing-guidance systems have been developed using visual feedback [13] or tactile stimulation [14], [15]. Recent work has proposed a method that integrates hugging-oriented devices with respiratory rhythm guidance as a promising approach to reducing stress and improving task performance [16]. However, its effectiveness in task-oriented collaborative learning in video-conferencing environments remains unexplored.

This study investigates the effectiveness of a breathing-guidance method using a cushion-type device to support communication during collaborative learning via video conferencing. We conducted a between-subjects experiment with 54 university students to examine whether the device reduces stress and enhances communication, as well as whether its effects differ according to levels of social anxiety. Participants were assigned to three conditions: No Feedback (NF), Cushion Only (CO), and Cushion with Breathing Feedback (CF). Pairs completed two 10-minute consensus-building discussions via Zoom while we measured physiological responses (respiratory patterns, cardiac autonomic indices), behavioral patterns (speech ratio, turn-taking), and subjective experiences (mental workload, satisfaction, engagement, tension). This design enabled us to isolate the effects of breathing guidance from the mere presence of a held object.

Specifically, we examined the following three research questions.

RQ1. Does the breathing guidance method using a cushion-shaped device reduce student stress in synchronous remote communication via video conferencing?

RQ2. Does the use of the breathing guidance method with a cushion-shaped device promote engagement compared to its non-use?

RQ3. Does the effectiveness of the breathing guidance method using a cushion-shaped device differ depending on students' levels of social anxiety?

In summary, the contributions of this study are as follows:

- This study provides empirical evidence that a hugging-oriented device with breathing-based haptic support can influence participants' subjective experiences during pair-based collaborative discussions, including perceived mental workload, engagement, and satisfaction with the final answer.
- The results further suggest that breathing-based haptic support may benefit individuals across varying levels of social anxiety, indicating that engagement-related support can emerge even in the absence of measurable reductions in physiological or subjective tension.

## II. RELATED WORK

### A. THE CHALLENGES OF SYNCHRONOUS ONLINE LEARNING

The flexibility, accessibility, and inclusivity of online learning, including e-learning and distance education, have revolutionized education [17]. Since the global outbreak of COVID-19, digital technologies and remote communication infrastructures, such as Zoom and Microsoft Teams, have become prevalent in educational settings [1], [2], enabling synchronous online learning to become well established. Even in the post-COVID-19 era, synchronous online learning has continued to be utilized for a wide range of purposes.

One advantage of synchronous online learning using video conferencing tools is that it allows not only verbal communication but also the transmission of nonverbal cues, such as gestures and eye contact. These visual and bodily behaviors can play an essential role in enhancing students' online communication by fostering immediacy and social presence [18], [19]. However, discomfort and dissatisfaction arising from the excessive use of synchronous online meetings, commonly referred to as "Zoom fatigue" [5], have emerged as significant challenges. Numerous studies have examined the underlying causes of this phenomenon [20], [21], [22], [23], among which the influence of the video feed has been identified as a key factor. Viewing one's discussion partner increases public self-awareness and concerns about accountability [24]. In addition, Castelli and Sarvary [25] reported that the main reason for turning off cameras during synchronous online courses is concern about personal appearance. Wicks [26] also suggested that some students are distracted because they are hyperaware of and concerned about how they look and how others perceive them. These types of stress increase students' tension, thereby diminishing the quality of communication. As a result, many students choose to turn off their webcams, which in turn limits the use of nonverbal cues during online interactions [27], [28].

### B. STRESS RELIEF METHODS

To maximize the benefits of synchronous online learning, it is essential to reduce students' stress while they keep their webcams turned on. Related work has proposed various approaches, which can be divided into two categories: those that alter the user's surrounding environment and those that act directly on the user's body [16].

Ambient environmental modification approaches aim to create relaxing atmospheres by manipulating external stimuli that influence users' physiological and psychological states. These interventions include adjusting lighting [29], [30], ambient sounds or music [31], and vibratory stimuli [32]. However, these methods face challenges: individual preferences vary widely, and implementation often requires significant environmental restructuring, increasing costs and complexity in shared settings such as classrooms [16].

Direct bodily interventions act on users' physiological states through haptic stimulation or biofeedback. Hugging-oriented devices have been explored as a means of conveying affective touch remotely. Early systems such as Hug Over a Distance [33] introduced the concept of mediated hugging, though empirical validation of its effectiveness remained limited. Subsequent research provided stronger evidence for the benefits of haptic hugging devices. Huggy Pajama [7] and Hugvie [8] demonstrated that simulated hugging can increase feelings of closeness and being loved, with several studies reporting significant reductions in stress [9]. Notably, Sumioka et al. [10] provided objective endocrine evidence: participants who conversed using a huggable device showed significant decreases in cortisol compared with mobile-phone conditions. However, the effectiveness of such hugging-oriented devices is moderated by relationship context, with stronger benefits reported among romantic partners, families, and close friends than among strangers [7], [8], [9].

Biofeedback techniques, which provide real-time information about physiological states such as heart rate, muscle tension, or skin conductance [34], allow users to learn conscious control over these processes [35], [36]. However, many physiological functions are either fully automatic (e.g., heart rate) or difficult to regulate voluntarily, limiting the applicability of traditional biofeedback during cognitively demanding tasks. In contrast, respiration offers a unique advantage as an intervention target because it is semi-voluntary, normally automatic, yet consciously controllable. Psychophysiological research has shown that slow and deep breathing activates the parasympathetic nervous system, reducing heart rate, cortisol levels, and perceived anxiety [12], [37], [38]. Breathing at approximately 6 breaths per minute corresponds to the cardiovascular resonance frequency and enhances autonomic regulation [39]. In addition, prolonging exhalation relative to inhalation further enhances parasympathetic activation and promotes relaxation [11], [40]. Respiration also responds to both internal and external influences, making it accessible for indirect guidance.

### C. SYSTEMS AND DEVICES THAT CONTROL RESPIRATORY RHYTHM

Based on these advantages of breathing, various haptic systems have been proposed to guide respiratory rhythm through tactile stimulation. Sato et al. [15] demonstrated that tactile phantom sensations moving on the back could guide breathing timing. Breathing-oriented systems such as BreathingFrame [13] and breatHaptics [14] provide continuous, low-intensity tactile cues representing inhalation and exhalation patterns. These systems aim to create ambient emotional awareness rather than precise physiological control.

Relaxushion [16] is a cushion-shaped device that physically expands and contracts in patterns resembling abdominal respiration. When users embrace the device, its motion blends with their own bodily sensations, allowing breathing rhythm to be modulated without requiring deliberate control. A user study demonstrated that presenting respiratory motion can induce users' respiratory rhythm and depth and enhance relaxation, potentially improving task performance.

While a variety of respiratory-guidance systems have been proposed, the selection of an appropriate approach depends on the demands of the target context. In collaborative learning settings, particularly during video conferencing, participants must allocate sustained attention to discussion content and their partners. Visual feedback systems, such as BreathingFrame, may require users to divide visual attention between the interface and their partners. Some wearable haptic systems, such as breatHaptics, are designed to make users consciously aware of breathing cues, which may not align with situations where cognitive resources are primarily directed toward discussion tasks.

In contrast, cushion-shaped devices such as Relaxushion [16] operate by being held, without requiring additional visual focus or active attentional control. From the perspective of minimizing attentional demand and avoiding additional wearable equipment in everyday learning environments, hugging-oriented devices with integrated respiratory rhythm guidance represent a promising approach for supporting stress regulation and engagement in collaborative learning contexts. However, their effectiveness in task-oriented collaborative learning during video conferencing remains underexplored. In such environments, students must simultaneously manage discussion content, partner interaction, and consensus-building. This study addresses the lack of empirical evidence regarding the effectiveness of breathing-cycle-based haptic support in remote, task-oriented collaborative learning contexts.

## III. METHODOLOGY

We conducted a between-subjects experiment to investigate whether a cushion-shaped device designed to induce respiratory rhythm and depth could reduce student stress during discussion-based collaborative learning via video conferencing. This study received ethical approval from the Institutional Review Board (IRB) of the first author's university (approval code: D3C_2025-04), in accordance with the ethical guidelines of the Declaration of Helsinki.

### A. EXPERIMENTAL DESIGN

The experiment employed a between-subjects design with three conditions: No Feedback (NF), Cushion Only (CO), and Cushion with Breathing Feedback (CF). In the NF condition, participants performed the discussion tasks without any device intervention. In the CO condition, participants held the cushion device without actuation. In the CF condition, participants held the cushion while it delivered continuous breathing-cycle guidance. Condition CO was introduced to control for the potential effects of simply holding the cushion, including tactile contact and object holding. By comparing the CF and CO conditions, we aimed to isolate the additional

effect of breathing-cycle guidance beyond the physical presence of the device.

Participants were randomly assigned to one of the three conditions, with gender ratio controlled across groups to account for potential gender-related differences in communication behavior.

Participants were paired in same-gender dyads consisting of individuals who had never met before. Each pair engaged in two 10-minute discussion tasks via video conferencing, during which physiological signals, behavioral patterns, and subjective experiences were recorded.

### B. STIMULI

We employed a cushion-shaped device designed to induce respiratory rhythm and depth, as proposed by Ban et al. [16]. The device provides tactile actuation that mimics abdominal respiration patterns by physically expanding and contracting according to a predetermined breathing cycle, allowing users to perceive the motion when holding or embracing the cushion. This device was developed based on findings that physiological responses can be altered by providing feedback that overrides internal physiological sensations [41], [42]. When feedback is provided appropriately, it may implicitly influence internal physiological rhythms without requiring conscious regulation. Previous studies using this device have reported relaxation effects when individuals performed tasks alone [16]. Thus, this study examines the effects of this method in a synchronous remote collaborative learning context. The device consists of an internal mechanism that generates respiratory motion and a cushion cover that encloses the unit. The internal mechanism comprises a base unit and a top unit; variations in the distance between these units cause the cushion to expand and contract, thereby simulating target respiratory patterns. The breathing-cycle parameters were configured to induce relaxed, resting-state breathing. Specifically, the respiratory rhythm was set to six cycles per minute with a depth of 20 mm. This slow breathing rate is known to activate the parasympathetic nervous system and promote relaxation [12], [43], [44]. Regarding the inhalation-to-exhalation ratio, a previous study reported that paced breathing with a longer exhalation can increase vagal tone [45], so this study fixed it at 3:2. The device, including the cotton filling and cushion cover, measures 400 × 400 × 200 mm (the internal hardware measures 160 × 160 × 100 mm) and weighs 1.7 kg.

For the CO condition, the same cushion was provided with the respiratory actuation disabled to standardize weight and shape.

### C. TASK

Participants completed two 10-minute consensus-building discussion tasks on socially relevant topics. Two tasks were included to examine how the effects of the intervention differ between an initial, potentially tense interaction and a subsequent interaction after participants became more familiar with their partner and the consensus-building format.

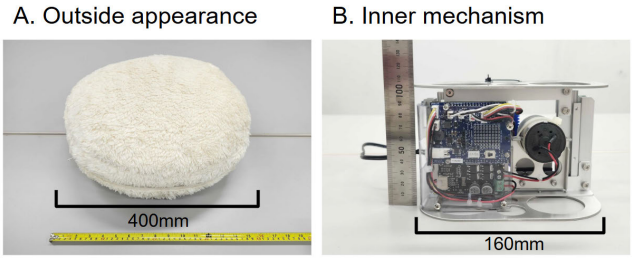



**FIGURE 1.** The breathing-guidance cushion device: (A) Appearance of the cushion, and (B) internal mechanism. The mechanism is housed within a two-layer cushion structure, where a cotton cushioning layer surrounds the device cavity. This design minimizes perceived stiffness and reduces motor noise during operation.

Both tasks followed an identical structure but addressed different Artificial Intelligence (AI)-related themes. In the first task, pairs discussed the benefits and risks of using generative AI in academic coursework and agreed on conditions under which its use should be permitted or prohibited (Appendix A-A). In the second task, pairs evaluated the advantages and disadvantages of AI-based job interviews and reached a shared position on whether they supported or opposed this practice (Appendix A-B).

The two topics were selected to be comparable in structure and complexity while differing in content domain. Both required value judgments rather than factual recall, thereby encouraging participants to articulate personal perspectives and negotiate differing viewpoints. The requirement to reach consensus increased social interdependence and necessitated active idea exchange. One minute before the end of each 10-minute period, a time reminder was sent through the chat interface to prompt final deliberation and answer submission.

### D. PARTICIPANTS

A total of 72 undergraduate and graduate students were initially recruited for the experiment and randomly assigned to one of three experimental conditions. Participants were paired with same-gender partners to minimize potential effects related to cross-gender communication dynamics, and gender balance was maintained across all conditions. However, 18 participants were excluded due to experimental issues, including absence ($n = 14$), missing recording data ($n = 2$), and occasional malfunction of the cushion device ($n = 2$). As a result, data from 54 participants were included in the final analysis (mean age = 21.27 years, $SD = 3.69$). The final dataset consisted of 18 valid participants per condition (NF, CO, and CF) for questionnaire responses and Zoom audio recordings. For physiological data, data from three participants were missing; therefore, 17 valid participants were retained in the NF condition, 16 in the CO condition, and 18 in the CF condition.

**TABLE 1. Correspondence between research question and evaluation indicators.**

| Research Questions | | Indicators |
|---|---|---|
| **RQ1** | Effect on reducing stress | Mean respiration rate (Δ Resp. rate)<br>Mean amplitude of breathing cycles (Δ Resp. amplitude)<br>Cardiac Sympathetic Index (Δ CSI)<br>Cardiac Vagal Index (Δ CVI)<br>NASA-TLX [46]<br>Subjective assessment of stress levels |
| **RQ2** | Effect on promoting communication | Total duration of speech in msec<br>Turn-taking<br>Subjective assessment of satisfaction with final answer<br>Subjective assessment of enjoyment of each task<br>Subjective assessment of engagement of each task |
| **RQ3** | Association with the degree of social anxiety | SIAS [47] |

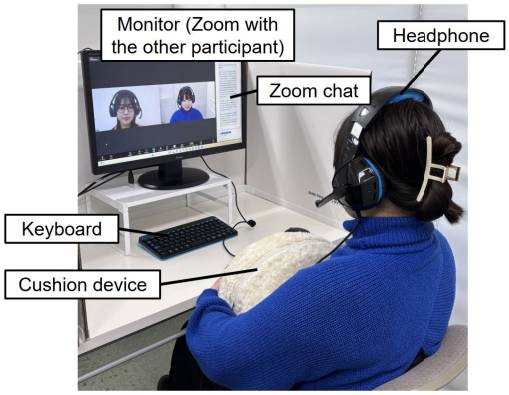



**FIGURE 2. Experimental setup showing a participant holding the cushion device during task execution.**

### E. EXPERIMENTAL SETUP

All discussion tasks were conducted using Zoom, a widely adopted video conferencing platform. Both video and audio were enabled throughout the sessions to simulate typical remote classroom or peer discussion settings. Task instructions and timing cues were delivered via the text chat interface to maintain consistency across sessions and minimize experimenter influence. Each pair was required to submit a single consensus response via the chat function at the end of each discussion period. In addition, participants in the CF and CO conditions were asked to hold the cushion device while engaging in the discussion, as shown in Figure 2. The cushion was placed on the participant's lap, and they were asked to support it lightly with their arms without tightly hugging or compressing it. Participants were allowed to maintain a natural seated posture, provided that continuous contact with the cushion was maintained.

### F. MEASURES

Table 1 shows the correspondence between the research questions and the evaluation metrics used in the experiment. We employed both subjective and objective measures to examine the three research questions. All questionnaires and open-ended responses were administered in Japanese, the participants' native language.

Regarding RQ1 on stress reduction, we used the mean respiration rate (breaths per minute) and mean breathing cycle amplitude as respiratory features. We also used the cardiac sympathetic index (CSI) and the cardiac vagal index (CVI), both derived from the Poincaré plot of R-R intervals [48]. In the Poincaré plot, each R-R interval is plotted against the subsequent one, forming an ellipse whose short-axis standard deviation (SD1) reflects short-term beat-to-beat variability, and whose long-axis standard deviation (SD2) reflects long-term variability. CSI was calculated as SD2/SD1, where higher values indicate sympathetic dominance, and CVI was calculated as log10 (SD1 × SD2), where higher values indicate parasympathetic dominance. A high CSI value indicates sympathetic dominance, signifying a state of tension or stress, whereas a high CVI value indicates parasympathetic dominance, signifying a relaxed state. These physiological data were collected using a biosignalsplux sensor and OpenSignals software by PLUX Biosignals. For each task unit, differences from the resting baseline were calculated, and the average values were used for analysis:

$$\begin{aligned}\Delta\text{Resp. rate} &= \text{Resp. rate}_{\text{task}} - \text{Resp. rate}_{\text{baseline}}\\ \Delta\text{Resp. amplitude} &= \text{Resp. amplitude}_{\text{task}}\\ &\quad - \text{Resp. amplitude}_{\text{baseline}}\\ \Delta\text{CVI} &= \text{CVI}_{\text{task}} - \text{CVI}_{\text{baseline}}\\ \Delta\text{CSI} &= \text{CSI}_{\text{task}} - \text{CSI}_{\text{baseline}}\end{aligned}$$

We hypothesized that all conditions would show increased CSI during the tasks (indicating engagement), whereas only the CF condition would maintain or increase CVI (indicating relaxation despite task demands).

In addition, post-task subjective stress was assessed using 5-point Likert-scale ratings (1 = not nervous at all, 5 = very nervous) for each task. The NASA Task Load Index (NASA-TLX) questionnaire [46] was administered after all tasks to capture perceived mental demand, effort, and frustration.

Regarding RQ2 on communication promotion, we used speech ratio, defined as the proportion of total speaking time to the total discussion duration, and turn-taking frequency,

defined as the number of shifts in the active speaker during the discussion. These speech features were computed from Zoom audio recordings using Hylable Discussion. Turn-taking frequency was calculated using 20-second windows, which corresponds to the default setting of the Hylable Discussion system. In addition, post-task ratings on 7-point Likert scales (1 = strongly disagree, 7 = strongly agree) were used to assess satisfaction with the final answer, enjoyment, and engagement in the discussion for each task.

Regarding RQ3, we used the Japanese version of the Social Interaction Anxiety Scale (SIAS) [47]. The SIAS consists of 20 items rated on a 5-point scale (0 = not at all applicable, 4 = extremely applicable). Scores for reverse-scored items were inverted before summing all items to compute a total score. Higher total scores indicate greater levels of social interaction anxiety, and scores of 36 or higher suggest probable social anxiety [49]. Based on this criterion, participants were categorized into high and low social anxiety groups, and communication tendencies were visualized for each group.

Additionally, for participants in the CF condition, supplementary questions assessed awareness of the cushion's movement and perceived comfort during use.

### G. ANALYSIS

For objective measures, one-way analysis of variance (ANOVA) was conducted when the assumption of normality was satisfied based on the Shapiro–Wilk test. When normality was not satisfied for objective or subjective measures, the Kruskal–Wallis test was used.

IBM SPSS Statistics (Version 26) was used for all analyses. $p$ values less than .05 were considered statistically significant.

### H. PROCEDURE

Each experimental session lasted approximately 90 minutes. Upon arrival at the laboratory, participants watched a brief explanatory video outlining the study protocol and provided informed consent. They were then equipped with electrocardiogram (ECG) electrodes and a respiration sensor band. A 10-minute baseline recording was conducted while participants remained seated quietly at rest.

Following baseline data collection, participants were introduced to their discussion partner via the video conferencing interface and received instructions for the first task through the chat window. After completing the first 10-minute discussion and submitting their consensus response, participants proceeded immediately to the second task using the same procedure. Throughout both tasks, participants in the CO and CF conditions held the cushion device as instructed, with tactile breathing guidance active only in the CF condition. After completing both discussions, participants removed the sensors and completed all subjective questionnaires.

## IV. RESULTS

### A. PHYSIOLOGICAL AND BEHAVIORAL DATA

Tables 2 and 3 summarize the physiological and behavioral results.

Across both tasks, no significant differences were observed among conditions for any physiological indices, including respiratory rate, respiratory amplitude, cardiac sympathetic index (CSI), or cardiac vagal index (CVI).

Similarly, no significant differences were observed in behavioral measures, including total speech ratio and turn-taking frequency.

### B. QUESTIONNAIRE DATA

Table 4 summarizes the results of the subjective evaluations.

For NASA-TLX, which was administered once after both tasks, a significant difference was observed among conditions, $\chi^2(2) = 8.53$, $p = .01$, $\varepsilon^2 = .12$. Post-hoc comparisons with Bonferroni correction indicated that perceived mental workload was significantly lower in the CF condition than in the NF condition ($p = .01$).

For Task 1, significant differences were observed for satisfaction, $\chi^2(2) = 6.24$, $p = .04$, $\varepsilon^2 = .08$, and engagement, $\chi^2(2) = 6.20$, $p = .05$, $\varepsilon^2 = .08$. Post-hoc comparisons indicated that satisfaction was higher in the CF condition than in the NF condition ($p = .04$), and engagement was higher in the CF condition than in the CO condition ($p = .04$).

No significant differences were observed for subjective stress or enjoyment in either task, nor for any subjective measures in Task 2.

### C. DEVICE AWARENESS AND COMFORT (CF CONDITION ONLY)

Among participants in the CF condition, 17 out of 18 (94.4%) reported noticing the device's motion.

Comfort ratings for the device motion, measured on a 7-point scale, yielded a median of 5.0 (interquartile range: 5.0–6.0).

Qualitative comments indicated that participants generally perceived the device as non-intrusive, calming, and helpful in reducing awkward silence during the discussion. Several participants described the tactile feedback as providing a grounding presence during remote interaction.

### D. SUBJECTIVE ASSESSMENT BY SOCIAL ANXIETY LEVELS

The following analysis is descriptive and exploratory in nature.

Participants with an SIAS score of 36 or higher were classified as having high social anxiety [49]. Based on this criterion, participants were categorized into high and low social anxiety groups (Low: NF = 8, CO = 4, CF = 9; High: NF = 10, CO = 14, CF = 9). Table 5 presents the median subjective ratings across conditions and social anxiety levels.

**TABLE 2. Physiological measures by condition and task.**

| Task | Measure | NF | CO | CF | Test | Statistic | p | Effect size |
|---|---|---|---|---|---|---|---|---|
| 1 | Δ Resp. rate | 1.74(3.46) | 1.31(1.77) | 2.61(2.04) | Welch's ANOVA | $F(2, 30.59) = 1.84$ | .18 | $\eta^2 \approx .11$ |
| | Δ Resp. amplitude | −172.29(1430.61) | −1654.13(2395.47) | −1343.28(1632.40) | One-way ANOVA | $F(2, 48) = 2.82$ | .07 | $\eta^2 = .11$ |
| | ΔCSI | 0.09 (-0.65–0.69) | 0.01 (-0.77–0.87) | -0.02 (-0.50–0.44) | Kruskal–Wallis test | $\chi^2(2) = 0.71$ | .70 | $\varepsilon^2 = .00$ |
| | ΔCVI | 0.06 (-0.07–0.35) | 0.13 (-0.06–0.35) | 0.20 (0.07–0.35) | Kruskal–Wallis test | $\chi^2(2) = 0.93$ | .63 | $\varepsilon^2 = .00$ |
| 2 | Δ Resp. rate | 1.07(3.37) | 1.60(2.00) | 1.69(2.69) | One-way ANOVA | $F(2, 48) = 0.24$ | .79 | $\eta^2 = .01$ |
| | Δ Resp. amplitude | −578.36(1443.16) | −1751.14(2241.50) | −1373.37(1796.96) | One-way ANOVA | $F(2, 48) = 1.65$ | .20 | $\eta^2 = .06$ |
| | ΔCSI | 0.26(1.10) | 0.23(1.02) | −0.21(1.19) | One-way ANOVA | $F(2, 48) = 0.92$ | .41 | $\eta^2 = .04$ |
| | ΔCVI | 0.10 (-0.07–0.40) | 0.15 (-0.11–0.36) | 0.33 (0.09–0.47) | Kruskal–Wallis test | $\chi^2(2) = 2.68$ | .26 | $\varepsilon^2 = .00$ |

Values are presented as Mean (SD) for normally distributed variables and Median (IQR) for non-normally distributed variables.
$\eta^2$ values for Welch's ANOVA are approximated using $F$ and adjusted degrees of freedom.

**TABLE 3. Behavioral measures by condition and task.**

| Task | Measure | NF | CO | CF | Test | Statistic | p | Effect size |
|---|---|---|---|---|---|---|---|---|
| 1 | Speech ratio | 50.13 (41.31–56.24) | 50.30 (42.86–56.90) | 42.09 (37.80–55.86) | Kruskal–Wallis test | $\chi^2(2) = 1.65$ | .44 | $\varepsilon^2 = .00$ |
| | Turn-taking | 8.00 (5.25–9.75) | 8.00 (6.00–9.00) | 9.50 (8.00–10.00) | Kruskal–Wallis test | $\chi^2(2) = 5.36$ | .07 | $\varepsilon^2 = .06$ |
| 2 | Speech ratio | 51.12(10.95) | 48.40(10.60) | 48.75(12.69) | One-way ANOVA | $F(2, 51) = 0.30$ | .74 | $\eta^2 = .01$ |
| | Turn-taking | 7.00 (6.00–8.00) | 7.00 (7.00–9.00) | 7.00 (7.00–8.00) | Kruskal–Wallis test | $\chi^2(2) = 0.99$ | .61 | $\varepsilon^2 = .00$ |

Values are presented as Mean (SD) for normally distributed variables and Median (IQR) for non-normally distributed variables.

**TABLE 4. Subjective evaluation measures by condition and task, based on Kruskal–Wallis tests.**

| Task | Measure | NF | CO | CF | Statistic | p | Effect size |
|---|---|---|---|---|---|---|---|
| Overall | NASA-TLX | 61.67 (56.33–72.67) | 51.33 (48.33–62.67) | 47.33 (34.00–62.33) | $\chi^2(2) = 8.53$ | .01 | $\varepsilon^2 = .12$ |
| 1 | Stress level | 3.00 (2.00–4.00) | 2.00 (2.00–4.00) | 3.00 (2.00–4.00) | $\chi^2(2) = 0.21$ | .90 | $\varepsilon^2 = .00$ |
| | Satisfaction | 4.00 (2.25–6.00) | 5.00 (4.25–6.00) | 5.50 (5.00–7.00) | $\chi^2(2) = 6.24$ | .04 | $\varepsilon^2 = .08$ |
| | Enjoyment | 5.00 (4.25–5.75) | 6.00 (4.25–6.00) | 6.00 (5.00–6.00) | $\chi^2(2) = 2.13$ | .35 | $\varepsilon^2 = .00$ |
| | Engagement | 6.00 (5.00–6.00) | 5.00 (4.25–6.00) | 6.00 (6.00–7.00) | $\chi^2(2) = 6.20$ | .05 | $\varepsilon^2 = .08$ |
| 2 | Stress level | 2.00 (1.00–2.00) | 2.00 (1.25–2.75) | 2.00 (2.00–2.00) | $\chi^2(2) = 1.88$ | .39 | $\varepsilon^2 = .00$ |
| | Satisfaction | 6.00 (5.00–6.00) | 5.00 (5.00–5.75) | 6.00 (5.00–6.00) | $\chi^2(2) = 4.00$ | .14 | $\varepsilon^2 = .04$ |
| | Enjoyment | 6.00 (6.00–6.00) | 6.00 (5.00–6.00) | 6.00 (5.25–6.00) | $\chi^2(2) = 0.96$ | .62 | $\varepsilon^2 = .00$ |
| | Engagement | 6.00 (5.00–6.75) | 6.00 (5.00–6.00) | 6.00 (6.00–6.75) | $\chi^2(2) = 1.32$ | .52 | $\varepsilon^2 = .00$ |

Values are presented as Median (IQR).

**TABLE 5. Median subjective ratings across experimental conditions and social anxiety levels. Colors indicate rank order within each task and anxiety group (green = highest, yellow = second, red = lowest).**

| Task | Measure | Low | | | High | | |
|---|---|---|---|---|---|---|---|
| | | NF | CO | CF | NF | CO | CF |
| 1 | Stress | 2.00 (2.00-2.25) | 2.00 (2.00-2.50) | 3.00 (2.00-3.00) | 4.00 (3.25-4.00) | 3.00 (2.00-4.00) | 3.00 (2.00-4.00) |
| | Satisfaction | 3.50 (2.00-5.25) | 5.00 (4.75-5.25) | 5.00 (5.00-7.00) | 4.50 (3.00-6.00) | 5.00 (4.25-6.00) | 6.00 (5.00-7.00) |
| | Enjoyment | 5.50 (5.00-6.00) | 2.50 (2.00-4.00) | 6.00 (6.00-6.00) | 5.00 (4.00-5.00) | 6.00 (5.00-6.00) | 5.00 (3.00-6.00) |
| | Engagement | 6.00 (5.75-6.25) | 5.00 (5.00-5.25) | 6.00 (6.00-7.00) | 6.00 (5.00-6.00) | 5.50 (4.00-6.00) | 6.00 (5.00-7.00) |
| 2 | Stress | 1.00 (1.00-1.25) | 2.00 (2.00-2.00) | 2.00 (1.00-2.00) | 2.00 (2.00-2.75) | 2.00 (1.00-3.00) | 2.00 (2.00-3.00) |
| | Satisfaction | 6.00 (6.00-6.25) | 5.00 (4.25-5.25) | 6.00 (6.00-7.00) | 6.00 (5.25-6.00) | 6.00 (5.00-6.75) | 6.00 (5.00-6.00) |
| | Enjoyment | 6.00 (6.00-7.00) | 5.50 (5.00-6.25) | 6.00 (6.00-7.00) | 5.50 (5.00-6.00) | 6.00 (5.00-6.00) | 6.00 (5.00-6.00) |
| | Engagement | 6.00 (5.75-6.00) | 4.50 (3.75-5.00) | 6.00 (5.00-7.00) | 6.00 (5.00-6.00) | 5.00 (5.00-6.00) | 5.00 (5.00-6.00) |

In Task 1, among participants with low social anxiety, the CF condition showed relatively higher satisfaction, enjoyment, and engagement than the other conditions, along with higher stress ratings. Within the same group, the CO condition showed lower enjoyment and engagement than the NF condition. Among participants with high social anxiety, the CF condition appeared to show higher ranks for satisfaction, and both the NF and CF conditions showed relatively higher engagement ranks than the CO condition.

In Task 2, among participants with low social anxiety, satisfaction, enjoyment, and engagement ratings in the NF and CF conditions appeared higher than in the CO condition. For subjective stress level, the NF condition tended to show

lower ratings than the other conditions. No consistent patterns were observed among participants with high social anxiety in Task 2.

## V. DISCUSSION

### A. RQ1: EFFECT ON REDUCING STRESS

We observed no corresponding changes in cardiac autonomic indices or respiratory patterns, unlike previous studies targeting individual tasks [16].

One possible explanation is that a mismatch between participants' baseline respiratory rates and the fixed breathing pace used to induce a slower rhythm may have limited respiratory guidance. In addition, compared to the individual N-back task [50] commonly used to assess working memory capacity in prior research, the high level of immersion required for consensus-building discussions may have maintained sympathetic nervous system activation, potentially masking any parasympathetic effects of the breathing guidance. Consistent with this interpretation, subjective tension levels did not differ significantly across groups.

In contrast, the NASA-TLX results indicated that the CF group reported significantly lower perceived mental workload than the NF group. Because NASA-TLX was administered once after both discussion tasks, this score reflects participants' overall appraisal of the session rather than the demands of an individual task. Mental workload reflects the perceived cognitive demands required to perform a task, and this finding therefore suggests that the hugging-oriented device with respiratory rhythm guidance may have altered how demanding the session felt overall, even if it did not reduce physiological stress responses. A plausible mechanism is that the rhythmic tactile feedback provided a stable sensory reference during socially evaluative exchanges. Participants commented, for example, ''I felt as though the cushion eased the awkwardness'' and ''The cushion's subtle movement distracted me in a good way'' (both translated from Japanese), which may indicate that it supported attentional regulation or reduced perceived task difficulty without directly altering autonomic activity. Thus, rather than reducing stress per se, the device may have influenced participants' subjective appraisal of task demands.

### B. RQ2: EFFECT ON PROMOTING COMMUNICATION

The hugging-oriented device with respiratory rhythm guidance was associated with significantly higher engagement compared to the CO condition and greater satisfaction with the final answer compared to the NF condition in Task 1. Overall perceived mental workload was also significantly lower in the CF condition. Because NASA-TLX was collected once for the session as a whole, this result cannot be attributed to Task 1 specifically; however, the pattern is consistent with the higher engagement and satisfaction ratings observed in that task.

In contrast, no such effects were observed in Task 2. This difference may reflect variations in discussion topics rather than familiarity alone. Although both tasks followed an identical structure, they addressed different AI-related themes, which may have differed in perceived difficulty, personal relevance, or ease of discussion. In addition, participants may have become more accustomed to the discussion format, their partners, and the remote communication environment in the second task, potentially reducing reliance on external support.

No significant differences were observed in behavioral measures, including speech ratio and turn-taking frequency. The 10-minute paired discussion format may have limited the variability of these measures. In a dyadic conversation, speaking opportunities are structurally interdependent, which may constrain observable variation in speech ratio and turn-taking frequency. Thus, the 10-minute discussion format may have had limited sensitivity for detecting subtle differences between conditions.

### C. RQ3: ASSOCIATION WITH THE DEGREE OF SOCIAL ANXIETY

The following interpretation is exploratory in nature. In Task 1, participants with high social anxiety tended to show lower tension and higher satisfaction in the CO and CF conditions compared to the NF condition. This pattern is consistent with prior findings suggesting that hugging-oriented devices can alleviate tension [10], [51], [52]. Under conditions of heightened self-monitoring, the presence of the cushion may have helped reduce psychological inhibition. The device may have functioned as a bodily anchor during interaction, potentially mitigating excessive self-focus among socially anxious participants.

In contrast, among participants with low social anxiety, the CF condition was associated with relatively higher satisfaction and engagement, alongside slightly elevated tension ratings. This pattern may indicate that breathing guidance enhanced task involvement or attentional focus rather than directly reducing cognitive load for this group.

In Task 2, the moderating effect of social anxiety was less apparent, with both anxiety groups showing similarly high ratings across conditions. As discussed for RQ2, this may reflect differences in discussion topics or increased familiarity with the interaction format in the second task.

## VI. LIMITATIONS

Several limitations should be considered when interpreting the findings of this study.

First, participants were all university students interacting in a controlled laboratory setting with experimentally assigned partners. It remains unclear whether breathing guidance would function similarly in other contexts. For example, students collaborating on authentic course projects with established classmates may respond differently from pairs of strangers discussing hypothetical scenarios.

Second, we employed a single breathing pattern (six cycles per minute with a 3:2 inhalation-to-exhalation ratio) for all participants. This one-size-fits-all approach may have limited

effectiveness for users whose natural breathing rhythms differed substantially from the device's pattern. Adaptive systems that monitor users' real-time physiological states and dynamically adjust guidance represent a promising direction for future work, particularly in contexts where task demands and emotional states fluctuate during conversation.

Third, although the two discussion tasks followed an identical structure, they differed in thematic content and were presented in a fixed order. Variations in topic familiarity, perceived difficulty, or personal relevance may have influenced engagement and subjective evaluations. Thus, differences observed between Task 1 and Task 2 cannot be attributed solely to familiarity effects or repeated exposure to the discussion format; task content, order of presentation, and increasing familiarity with the partner and the device remain confounded. Future research should counterbalance the order of tasks, or adopt a Latin-square design if more than two topics are used, so that these factors can be separated.

Fourth, the analysis of social anxiety was exploratory. Participants were categorized based on a cut-off score rather than through a priori stratified sampling, and the sample size within each anxiety-by-condition subgroup was small, ranging from 4 to 14 participants. This limited the statistical power to detect interaction effects. Future research should recruit larger and more diverse samples stratified by social anxiety level to more robustly examine individual differences in responsiveness to breathing-based haptic support.

Finally, although we included multiple physiological indicators, the absence of significant changes in autonomic indices may reflect the inherent complexity of measuring subtle regulatory effects during collaborative learning tasks requiring consensus-building. Physiological signals collected in conversational contexts are influenced by speech production, posture shifts, and interpersonal coordination, which may obscure fine-grained autonomic modulation. Furthermore, the 10-minute paired discussion task may have been insufficient to capture variability in conversational metrics such as speech ratio and turn-taking. Future research could extend discussion duration or employ multi-party discussions to increase variability in conversational measures and improve the sensitivity of behavioral indicators.

## VII. CONCLUSION

This study examined whether a hugging-oriented device with respiratory rhythm guidance can influence stress-related and engagement-related experiences during remote collaborative learning. The findings indicate that a breathing-cycle cushion device can lower perceived mental workload across a session of remote discussions and can enhance subjective engagement in an initial discussion with an unfamiliar partner.

No significant changes were detected in physiological or behavioral indices, so the present findings speak to subjective experience rather than to autonomic regulation or conversational behavior. Within that scope, the results suggest that subtle haptic support, delivered without requiring visual attention or explicit breathing instructions, can shape users' appraisal of task demands in evaluative communication contexts.

## APPENDIX A
## TASK

### A. DISCUSSION 1: REPORT AND ASSIGNMENT CREATION USING GENERATIVE AI

In recent years, technology known as ''generative AI'' has developed rapidly. Tools like ChatGPT can now generate natural text simply by inputting a question. While it holds promise as a tool to support learning, concerns have been raised. AI-generated text may contain errors or biases, and input information could potentially be used for AI training, necessitating careful handling of personal and confidential data. Furthermore, there is concern that over-reliance on AI could weaken the very process of independent thinking, which is considered the essence of learning. Please discuss the following questions.

1) What are the advantages and disadvantages of using generative AI to create reports or assignments?
2) When using generative AI in learning, what do you consider appropriate ways to use it?

Finally, considering each other's opinions, think of one answer as a pair to the following question and enter your response in the text chat. Under what conditions or rules do you think using generative AI for assignments should be permitted (or not permitted)?

### B. DISCUSSION 2: AI INTERVIEWS

In recent years, AI (artificial intelligence) has increasingly been introduced into job interviews and aptitude tests. AI is said to analyze applicants' speaking style, facial expressions, and the content of their words, quantifying traits like ''teamwork,'' ''leadership,'' and ''integrity.'' While this offers companies the potential for efficient and fair selection, applicants may feel uneasy or uncomfortable about ''having their humanity judged by AI.'' Please discuss the following questions.

1) What are the potential advantages and disadvantages of AI conducting interviews?
2) How much can we trust AI's judgments?

Finally, considering each other's opinions, think of one answer as a pair to the following question and enter your response in the text chat. Are we for or against AI conducting interviews? Summarize your reason in one sentence.

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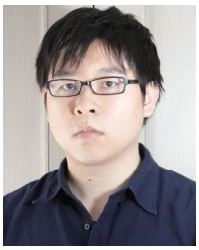
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