RELAXATION EFFECTS OF VISUAL FEEDBACK FROM A BREATH-SYNCHRONIZED INTERACTIVE DEVICE: A COMPARISON OF SYNCHRONIZED AND DELAYED CONDITIONS

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ABSTRACT

Sensory sensitivities are prevalent across a wide range of individuals and can cause stress and fatigue (Horder et al., 2014). Sensory rooms—spaces designed to regulate sensory input and promote relaxation—employ items such as bubble tubes (Su et al., 2025). Recently we developed a device equipped with an RGB-Depth camera to detect respiration in real time that deforms a hyperboloid structure in response to breathing (Katsube et al., 2025). However, the mechanisms underlying their relaxation effects remain poorly understood (Su et al., 2025). This study tested two hypotheses. First, based on predictive coding theory (Friston, 2010), we hypothesized that the perception of regular, predictable motion promotes relaxation. Second, we hypothesized that visual feedback synchronized with one's own breathing further enhances relaxation (Betka et al., 2023; Blum et al., 2020). To test these hypotheses, we tested our interactive device in synchronized and delayed feedback conditions. In the experiment, 54 participants (aged 18–35) were randomly assigned to a synchronized (real-time feedback) or delayed (2.5-second lag) group. We measured respiratory rate and amplitude, heart rate variability (HRV), salivary amylase, and self-report measures; sensory profiles were assessed using the Adolescent/Adult Sensory Profile (AASP) to confirm group equivalence. Both groups exhibited relaxation effects; however, the synchronized group demonstrated significantly greater reductions in respiratory rate (from 15.6 to 10.9 breaths/min, sustained throughout the session), approximately 1.7-fold increases in breathing amplitude, and decreased salivary amylase levels compared to the delayed group. lnRMSSD increased over time in both groups, with no significant group difference. That both groups relaxed is consistent with the first hypothesis that predictable, regular motion promotes relaxation (Friston, 2010). The stronger effects in the synchronized group are consistent with the second hypothesis that breathing synchronization further enhances relaxation (Betka et al., 2023; Blum et al., 2020). The results offer design implications for personalized sensory environments.

Keywords: *breath-synchronized feedback, predictive coding, relaxation, sensory room, respiratory biofeedback*

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1 INTRODUCTION

Sensory sensitivities are prevalent across a wide range of individuals and can cause stress and fatigue (Horder et al., 2014). Sensory rooms employ items such as bubble tubes to promote relaxation, but the mechanisms by which they induce relaxation remain poorly understood (Su et al., 2025). One factor is stimulus predictability. According to predictive coding theory (Friston, 2010), the brain minimizes prediction error—the discrepancy between predicted and actual sensory input. Stimuli with regular, predictable movements may reduce prediction error and promote relaxation. Another factor is breathing regulation: breathing patterns are closely related to emotional states, and external stimuli synchronized with breathing could enhance breathing awareness.

We developed a breath-synchronized interactive device that detects respiration via an RGB-Depth camera and deforms a hyperboloid structure accordingly (Katsube et al., 2025). This study compared synchronized (real-time) and delayed (2.5-s lag) feedback to test two hypotheses: (H1) regular, predictable motion promotes relaxation regardless of synchronization, and (H2) breath-synchronized feedback further enhances relaxation.



Figure 1. The breath-synchronized interactive device. (a) System components: hyperboloid structure, Kinect v2, and motor. (b) Deformation during inhalation and exhalation.

2 METHODS

54 participants (38 women, 16 men; aged 18–35; M = 24.6) were randomly assigned to a synchronized (n = 27) or delayed group (n = 27) based on an a priori power analysis (f = 0.25, α = .05, 1 – β = .95). The device (Figure 1) comprised a Kinect v2 camera, a motor, and a hyperboloid structure that twisted during inhalation and reversed during exhalation. In the synchronized group, the device responded in real time; in the delayed group, with a 2.5-s lag. After a 5-minute rest, participants viewed the device for 15 minutes while breathing naturally. Respiratory rate, amplitude, and heart rate variability (lnRMSSD, lnHF; Polar H10) were measured at four time points (rest 2–5 min; viewing 2–5, 7–10, 12–15 min); salivary amylase was measured before and after viewing. Mixed ANOVA (time × group) was used for physiological indices; nonparametric tests for salivary amylase. After viewing, participants completed self-report ratings including overall comfort; sensory profiles were assessed using the AASP (Brown & Dunn, 2002) with no significant group difference (Pillai's Trace = 0.032, p = .802). Exploratory associations between sensory characteristics and subjective responses were examined using Spearman's rank correlations. The study was approved by the institutional ethics committee (GEI025-1).

3 RESULTS

3.1 Respiratory rate and amplitude

The time × group interaction was significant for both respiratory rate ($F(2.47, 128.64) = 4.95$, $p = .005$, $\eta p^2 = .087$) and amplitude ($F(3, 156) = 3.71$, $p = .013$, $\eta p^2 = .067$). The synchronized group's respiratory rate decreased from 15.6 to 10.9 breaths/min (2–5 min), remaining at 11.5 (12–15 min), whereas the delayed group showed only an initial decrease (14.9 → 12.3 → 13.2 breaths/min). Amplitude increased approximately 1.7-fold in the synchronized group (5.1 → 8.5–8.9) versus a smaller change in the delayed group (4.2 → 5.4–5.6; Figure 2).

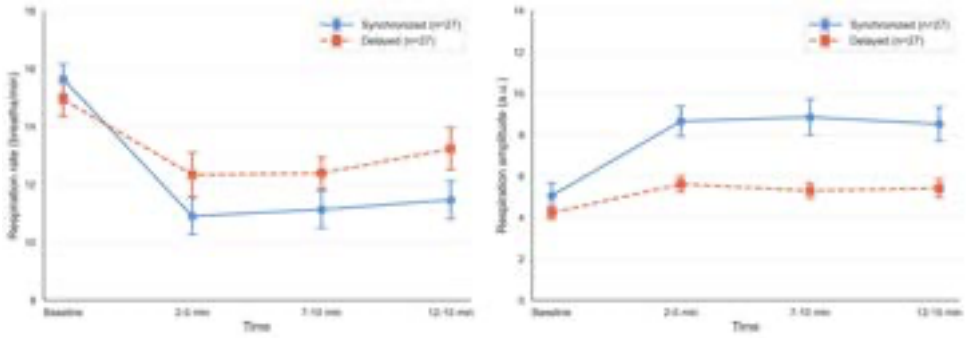


Figure 2. Respiratory rate (left) and amplitude (right) across time points. Error bars indicate standard errors.

3.2 HRV

For lnRMSSD, the main effect of time was significant ($p = .033$), but the time × group interaction ($p = .197$) and group effect ($p = .899$) were not. For lnHF, no significant effects were found.

3.3 Salivary amylase

Salivary amylase decreased significantly in the synchronized group (from 19.0 to 14.0 kIU/L; $W = 220.0$, $p = .013$, $r = .594$) but not in the delayed group (Figure 3). The between-group difference was significant ($U = 533.5$, $p = .003$, $r = -.464$).

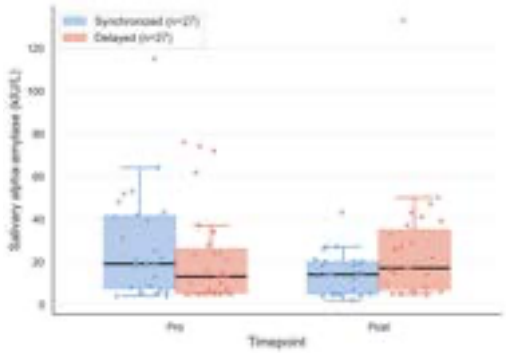


Figure 3. Salivary amylase levels (kIU/L) before and after viewing. Thick lines indicate medians.

3.4 Associations with sensory characteristics

In exploratory analyses, higher Sensory Sensitivity scores on the AASP were associated with lower overall comfort in the delayed group ($rs = -.396$, $p = .041$) but not in the synchronized group, while higher Low Registration scores were associated with greater comfort in the delayed group ($rs = .387$, $p = .046$).

4 DISCUSSION AND CONCLUSION

Both conditions induced relaxation-related changes, suggesting that the device's regular motion may have contributed to reduced prediction error (Friston, 2010), consistent with H1. The stronger effects in the synchronized group can be interpreted through Seth's (2013) interoceptive predictive coding model and are consistent with previous findings (Betka et al., 2023; Blum et al., 2020), supporting H2. These findings suggest that synchronized feedback may be suitable as a default mode for sensory environments, as delayed feedback may reduce comfort among users with higher sensory sensitivity. Future studies should examine clinical populations, broader age ranges, longer-term use, and larger samples for individual-difference analyses.

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