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Partial Reinforcement in Game Biofeedback for Relaxation Training

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Abstract—This paper investigates the effect of reinforcement schedules on biofeedback games for stress self-regulation. In particular, it examines whether partial reinforcement can improve resistance to extinction of relaxation behaviors, i.e., once biofeedback is removed. Namely, we compare two types of reinforcement schedules (partial and continuous) in a mobile biofeedback game that encourages players to slow their breathing during gameplay. The game uses a negative-reinforcement instrumental conditioning paradigm, removing an aversive stimulus (random actions in the game) if players slows down their breathing. We conducted an experimental trial with 24 participants to compare the two reinforcement schedules against a control condition. Our results indicate that partial reinforcement improves resistance to extinction, as measured by breathing rate and skin conductance post-treatment. In addition, based on linear regression and correlation analysis we found that participants in the partial reinforcement learned to slow their breathing at the same pace as those under continuous reinforcement. The article discusses the implications of these results and directions for future work.

Index Terms— Biofeedback games, deep breathing, games for health, partial reinforcement, resistance to extinction, skill transfer, stress, video games, wearable sensors

1 Introduction

STRESS is a serious problem around the world that affects both health and quality of life. If chronic, stress can lead to serious health consequences, e.g. hypertension [1], lowered immune function [2], and increased risk of coronary heart disease [3]. It also severely impacts employers by reducing worker productivity and increasing healthcare costs. To remedy these issues, a number of technology-based interventions have been developed in recent years that allow individuals to acquire stress self-regulation skills. Examples include bio/neurofeedback devices [4], meditation apps [5], virtual reality [6] and videogames [7, 8]. Particularly promising are interactive tools for stress self-regulation that combine biofeedback with games. In this approach, physiological sensors are used to monitor the user's stress levels during gameplay, and the game is then adapted in a way that rewards relaxing behaviors [9]. Prior studies [10-14] have shown that this "game biofeedback" approach facilitates skill acquisition and skill transfer. To our knowledge, however, there is no prior work on its long-term effectiveness.

Game biofeedback (GBF) can be viewed as a form of instrumental conditioning in which reinforcements (i.e. rewards or penalties in the game) are used to modify voluntary behaviors (e.g. increase or decrease breathing rate). As such, it is possible that the long-term effectiveness of GBF may be improved by optimizing the timing and frequency of the reinforcements. In fact, a long history of behavioral research shows that the reinforcement schedule can have a significant impact on the behavior's resistance to extinction (i.e., the ability to maintain the behavior once feedback is removed) [15-18]. The reinforcement schedule determines the relationship between an instrumental response and its consequence [19]; specifically, a reinforcement schedule determines which instances of the responses are reinforced or penalized. These schedules can be broadly classified into continuous and partial (or intermittent) reinforcement, depending on whether all or only a percentage of the target responses are reinforced, respectively. The more often a behavior is reinforced during training, the faster it is learned. In contrast, the less frequently a behavior is reinforced, the harder it is to extinguish, in what is known as the partial reinforcement extinction effect (PREE) [19, 20]. This effect has been studied in biofeedback applications, including teaching control of heart rate [17] and muscle relaxation [15], but its effectiveness in game biofeedback for stress self-regulation remains open for investigation.

Accordingly, the goal of this study was to determine whether PREE could also be used in game biofeedback as a mechanism to improve resistance to extinction of relaxation skills. Following prior work [9], we used deep breathing (DB) as the voluntary behavior to be reinforced during gameplay. DB is regularly recommended as a way to address the autonomic imbalance that arises from exposure to a stressor [21]: DB recruits the parasympathetic branch of the nervous system and inhibits the sympathetic action, leading to a calmer state [21]. To answer the overarching question of this study, we tested two working hypotheses:

- *H1*: Partial reinforcement in GBF increases resistance to extinction of DB skills, compared to continuous reinforcement.
- *H2*: Continuous reinforcement in GBF promotes faster acquisition of DB skills, compared to partial reinforcement.

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To test these hypotheses, we conducted user studies where each participant received a single randomly assigned treatment (i.e., partial or continuous reinforcement) or a control condition (game without biofeedback). According to hypothesis *H1*, we expected that participants who received partial reinforcement would maintain slower breathing rates and lower arousal levels (as measured with electrodermal activity) *longer* in a post-training period than those who received continuous reinforcement. According to hypothesis *H2*, we also expected that participants who received continuous reinforcement would lower their breathing rates and arousal levels *faster* during training than those who received partial reinforcement.

The rest of the paper is organized as follows. Section 2 summarizes prior work on biofeedback games for relaxation training and also discusses partial reinforcement scheduling in biofeedback applications. Section 3 describes our system, including the implementation of continuous and partial reinforcement biofeedback schedule in an adaptive videogame. Section 4 describes the experimental protocol and methodological details, followed by results from our user studies in Section 5. Finally, Section 6 summarizes our findings and provides directions for future work.

2 RELATED WORK

2.1 Biofeedback games for stress self-regulation

A few studies over the past three decades have explored using biofeedback games to help patients regulate anxiety and stress [10, 12-14, 22-26]. In these games, biofeedback information is generally presented in the form of an audiovisual display or via game adaptation, which allows users to practice self-regulation skills during gameplay. Along with skill acquisition, a handful of studies have also assessed whether relaxation skills learned with biofeedback games transfer to scenarios where biofeedback is not present [10, 12-14, 22]. In an early study, Larkin et al. [14] examined the role of heart rate (HR) biofeedback in reducing cardiovascular responses to stress. The authors designed a 2×2 study with HR biofeedback and contingent reinforcement[1] as independent factors. Participants receiving contingent feedback with HR biofeedback showed a significant reduction in HR during post-training (game without biofeedback and a novel mental arithmetic task) compared to the other groups. In a subsequent study, Goodie and Larkin [25] trained participants to lower their HR while performing three tasks (video game, mental arithmetic, handgrip) with HR feedback. Then, participants were asked to repeat the three tasks and perform a novel task (spontaneous speech) without HR feedback. The authors observed skill retention (i.e., maintaining a low HR) when the three training tasks were performed without biofeedback immediately following the training, but only minimal skill transfer to the novel post-task or when the three training tasks were performed after a delay of 1-2 days. Their study suggests that successful skill transfer may require training under a number of conditions that mimic real-world scenarios.

Researchers have also evaluated the effectiveness of immersive games to provide stress training. Bouchard et al. [10] developed an immersive virtual reality video game with auditory and visual biofeedback to teach tactical breathing (a stress management skill) to soldiers. The authors compared this game-based relaxation against conventional classroom instructions. During biofeedback training, the treatment group played an immersive first-person shooter game for three 30-min sessions. In contrast, the control group received one 15-min briefing on stress-management training. Following treatment, both groups performed a stressful medical simulation as a post-test, during which no audio-visual feedback was provided. The authors found that the biofeedback game was more effective in reducing arousal (measured with salivary cortisol and HR) and also improved task performance during the post-test compared to the control group.

Sonne and Jensen [23] presented ChillFish, a breath-controlled biofeedback game for children with ADHD. ChillFish aims to maintain children's attention by combining a breathing exercise with a videogame, so they learn to calm down in situations of acute stress. During gameplay, children control the size of a pufferfish with their breath; slower breathing increases the size of the fish, which allows them to collect more rewards. The authors reported significant increases in heart rate variability (HRV) for the ChillFish group compared to other activities (talking and playing Pacman), but not when comparing ChillFish against relaxation exercises. Dillon et al. [24] studied the effectiveness of two mobile games combined with a commercial biofeedback device to reduce stress. The authors measured the player's electrodermal activity (EDA) during gameplay and used it to determine progress: the more relaxed the player, the greater the progress in the game. Their results showed that 30 minutes of training with the biofeedback game led to a significant reduction in HR and self-rated stress measures, compared to a control group.

Bhandari et al. [22] presented a music-based respiratory biofeedback system to teach DB while performing visually demanding tasks (i.e. driving). The intervention, termed *Sonic Respiration*, monitored the user's breathing rate and adapted the quality (e.g. signal to noise ratio) of the music to encourage slow and DB. The authors compared *Sonic Respiration* against two alternatives: auditory biofeedback, where the users heard white noise if their breathing rate was greater than the target, and listening to soothing music without biofeedback. *Sonic Respiration* led to lower arousal (as measured with EDA, HRV and subjective reports) than the two alternatives. More recently, Wang et al. [12] pro-

[1] In contingency reinforcement, the participant's score was determined by their game performance and ability to maintain a low HR.

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posed *BioPad*, an approach that allows off-the-shelf commercial videogames to be used as biofeedback tools for stress training. *BioPad* uses a cross-over gaming device to intercept signals from a game controller, and modifies them based on the players' physiology to promote low arousal states. The authors used an immersive car racing game and compared two biofeedback mechanisms: car speed and visual overlay. In the speed mechanism, *BioPad* modifies the speed of the car based on the player's breathing rate (BR) i.e., speed decreases with increased BR. In the visual overlay mechanism, a graphical overlay is used to alter the player's visibility during gameplay and convey physiological information. Experiments showed that, compared to a control group (game without biofeedback), both biofeedback groups were able to promote DB and reduce arousal (measured by EDA and HRV) during treatment, and also facilitate skill transfer during subsequent driving simulations.

In prior work [13], we evaluated the effectiveness of three physiological indices (BR, HRV, and EDA) as inputs to a game-biofeedback intervention for teaching relaxation skills. We found that adapting the game in response to the players' BR led to lower arousal during the intervention *and* higher skill transfer than adapting the game in response to the other two physiological indices. The breathing-based intervention was also more effective than a standard treatment (DB) and a control condition (game without biofeedback). In a follow-up study [11], we evaluated the effectiveness of three biofeedback mechanisms (visual biofeedback, game biofeedback and combined biofeedback) in teaching relaxation skills. We conducted a study to compare the three biofeedback techniques against each other, and against a control group in which participants played a game with no biofeedback. Our results showed that game biofeedback outperforms visual biofeedback in terms of lowering arousal during treatment and transferring these skills to a subsequent cognitively demanding task not used during treatment. We also found that delivering both forms of biofeedback simultaneously leads to higher skill acquisition and transfer than delivering them in isolation.

2.2 Partial reinforcement in biofeedback

Multiple studies have investigated the effects of partial reinforcement (PRF) and continuous (CRF) on skill acquisition and resistance to extinction [15, 18, 27-33]. In early work, Gatchel [28], compared a CRF schedule (100% reinforcement) against fixed ratio schedules of 20% (FR-5) and 10% (FR-10) in modifying (increasing and decreasing) user's HR. In a fixed ratio schedule, every 5th (FR-5) or 10th (FR-10) response was reinforced, i.e. HR biofeedback was presented through a visual display. The CRF schedule led to the highest increase in HR compared to the FR-5 and FR-10 schedules. When comparing the deceleration of HR, all three feedback groups (CRF and two PRF) performed better than control groups. The author also conducted a replication study and again showed that the ability to control one's HR varies systematically with the frequency of feedback. However, no results on resistance to extinction of skills were presented.

Gamble and Elder [30] investigated the effects of auditory biofeedback along with verbal encouragement on modifying (increasing/decreasing) diastolic blood pressure. The authors compared a CRF schedule (i.e. 100%) with PRF scheduled according to a variable ratio of 50% and 25% reinforcement (i.e. feedback was provided probabilistically on 50% or 25% of the desired responses) and a no feedback condition. The CRF condition led to faster acquisition of skills (i.e. changing blood pressure), whereas the PRF groups showed a greater resistance to extinction. In a follow-up study, they investigated the effects of different response magnitude criteria and feedback schedules (0%, 50%, and 100%) on acquisition and extinction of changes in diastolic blood pressure [29]. They found that CRF schedules of positive reinforcement produced more rapid acquisition of bidirectional blood-pressure control than the PRF and control groups. They also observed that PRF was superior to the control group in modifying blood pressure. The authors reported that the PRF condition showed marginally greater resistance to extinction than the other groups.

Mckinney et al. [17] studied the effects of contingently faded biofeedback on reducing HR. They compared a CRF schedule against faded PRF (75% reinforcement followed by 50% and 25%) that also included contingent rewards. Contingently faded PRF biofeedback led to a significantly larger reduction in HR during the training session compared to the CRF, and this effect was maintained during the extinction session. This result suggests that combining reinforcement fading (75% to 50% to 25%) and contingent reinforcement may be an effective paradigm for teaching individuals to reduce their HR and retain these skills post training. The authors noted that while HR reductions can be attained in a few sessions (3 sessions in their case), multiple training sessions may be necessary to develop resistance to extinction.

In more recent work, Cohen et al. [15] compared continuous and partial reinforcement schedules (variable ratio, variable interval, fixed ratio, fixed interval to increase forearm muscle tension. They trained participants with three sessions of biofeedback followed by one extinction session without biofeedback. CRF showed the highest electromyography (EMG) response, followed by fixed ratio and variable interval schedules. In their extinction trials, the author found resistance to extinction in the EMG response across both CRF and PRF groups. Variable ratio and variable interval schedules were found to be most resistant to extinction, and CRF the least, a result that is consistent with the PREE [19, 20]. In a related study, Voerman et al. [18] studied the influence of partial schedules of myofeedback training to relax the trapezius muscle. Feedback was provided in the form of an auditory tone based on a pre-determined muscle relaxation level. They chose an interval schedule for providing feedback with intervals of 5s, 10s or 20s; for example, in a 5s schedule, whether or not feedback should be provided was evaluated every five seconds. The authors found that a 10s variable-interval schedule resulted in the highest level of muscular relaxation. They also evaluated resistance to extinction of the trapezius muscle post-training. However, they did not find any of the three

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schedules to be resistant to extinction, which they argued could be due to the training period having been too short to learn and retain the motor skills.

To summarize, previous research has evaluated biofeedback games for stress self-regulation and found them to effective in reducing arousal and promoting skill transfer [10-14, 22]. Furthermore, the effects of continuous and partial reinforcement on modifying user's physiology (EMG, HR and blood pressure) and behavior with traditional biofeedback systems has also been extensively studied [15, 29, 34-36]. To date, however no prior work exists on studying the effects of scheduling of biofeedback in games for stress training. The proposed study addresses this gap.

3 Game Biofeedback

3.1 System overview

To test our working hypotheses, we used a biofeedback game based on the open source game of *Frozen Bubble*[2], as described elsewhere [11, 13]. In this game, the player is presented with a game arena containing a spatial arrangement of colored bubbles; see Figure 1. The objective of the game is to eliminate all the hanging bubbles before the ceiling collapses. For this purpose, the player controls the orientation and firing of a small cannon that shoots bubbles of random colors. Placing a new bubble next to two or more of the same color makes them disappear; otherwise they pile up until the arena fills up, at which point the game ends. The ceiling of the arena drops one notch every eight moves, which reduces the play area over time and adds an element of time pressure. Different initial arrangements of bubbles allow the experimenter to increase the challenge level as the player progresses through the levels[3]. The game was developed on a Google Nexus 5 running Android 5.0.

Following results in our prior study [13], we used breathing rate (BR) as the physiological signal for biofeedback in the game. Namely, the game presents biofeedback information as a combination of visual biofeedback (i.e. numerical display of BR and arrows to indicate if it is increasing or decreasing; see Figure 1) and game adaptation [11]. The game also displays a prompt "*Please try and relax!*" at the bottom of the screen (for 0.5 seconds) when the player's BR increases. Frozen Bubble provides a few parameters that are amenable to adaptation, such as auto-shooting rate, how fast the ceiling drops, or angular rate and lag of the cannon. Out of these, we used auto-shooting frequency as the parameter for game adaptation, as it demands immediate action from the player. In addition to the game penalty, the user also receives an auditory stimulus in the form of an *Error* sound to indicate that their BR is higher than the reference value. During gameplay, we adapt the game difficulty based on the player's BR relative to a target value (r_0): elevated BR increases game difficulty, whereas lowered BR reduces it.

Figure 1 Screenshots of the modified Frozen Bubble game showing BR and its trend. The number (in red square) indicates the game score. The text prompt is shown at the bottom (in yellow rectangle).

Table 1 Mapping between breathing rate ($\boldsymbol{BR}$), its rate of change ($\boldsymbol{\Delta BR}$), and penalty during the game. A reference breathing rate ($\boldsymbol{r_0}$) is measured during an initial paced breathing session.

	$BR \leq r_0$	$BR > r_0$
$\Delta BR >= 0$	No penalty	No penalty
$\Delta BR < 0$	No penalty	Penalty

Table 1 summarizes the effect of BR on game adaptation, whereas Figure 2 shows the relationship between BR and game penalty, which in our case is the frequency of auto-shooting. When BR is below the target value, there is no penalty in the game; as BR increases beyond this value the game difficulty also increases in a piecewise linear fashion.

The target BR for GBF is 6 bpm, which is significantly lower than the spontaneous BR for healthy adults of 12-20 bpm. We chose 6 bpm because breathing at this pace maximizes HRV [37]. Briefly, heart rate increases during inhalation and decreases during exhalation, a phenomenon known as respiratory sinus arrhythmia (RSA). This happens because inspiration inhibits vagal activity and increases the phasic HR, while exhaling activates the vagus nerve and therefore decreases HR [21]. These fluctuations in heart rate reach a maximum at approximately 6 bpm,

[2] https://github.com/robinst/frozen-bubble-android

[3] ref: http://people.math.sfu.ca/~kya17/computers/fblevels.html

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which is believed to be a resonant frequency of the cardiorespiratory system [37]. Moreover, RSA is an index of cardiac vagal tone, which provides parasympathetic control of the heart [38]. Thus, deep breathing at this pace maximizes RSA, which itself is an indicator of parasympathetic (i.e., relaxation inducing) activity. In addition, voluntary DB has been shown to synchronize elements in the central and peripheral nervous system via inhibitory impulses and hyperpolarization currents, leading to decreased metabolic activity and shifting the autonomic balance towards parasympathetic dominance [21]. The adaptation mechanism also rewards the player's efforts in relaxation by tracking the slope of BR (ΔBR): if the player's BR is higher than the target but decreasing (i.e., $BR > 6 \wedge \Delta BR < 0$), no penalty is applied.

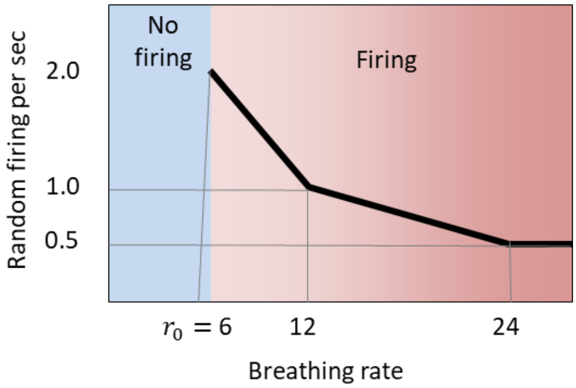

Figure 2 Relationship between the player's arousal and automatic shooting frequency when conditions for penalty ($\boldsymbol{BR > r_0}$ ***and*** $\boldsymbol{\Delta BR \geq 0}$) are satisfied; $\boldsymbol{r_0 = 6\ bpm}$

3.2 Game Biofeedback and instrumental conditioning

The central mechanism in our game-biofeedback intervention is instrumental conditioning: the process of presenting reinforcements (rewards or penalties) to the user based on their behaviors, in order to modify those behavior [39, 40]. Reinforcements can be categorized as appetitive (when the outcome is pleasant) and aversive (when the outcome is unpleasant). Whether the conditioning procedure increases or decreases a behavior depends on both the nature of the outcome (i.e., aversive or appetitive) and whether the behavior produces or removes the outcome. Accordingly, instrumental conditioning procedures can be classified into four categories [19]: Positive reinforcement, when the target behavior produces an appetitive outcome, which leads to a reinforcement of the behavior; Punishment, when the target behavior produces an aversive stimulus, which leads to a reduction in this behavior; Negative reinforcement, when the target behavior eliminates an aversive stimulus, which leads to a reinforcement of the behavior; and Omission training, when the target behavior eliminates an appetitive stimulus, which reduces the behavior.

Our GBF intervention can be viewed as a form of negative reinforcement instrumental conditioning (NR-IC). Namely, players must lower their arousal levels (i.e. the instrumental response) to reduce the game penalty (the aversive outcome), which otherwise prevents them from making progress in the game. In other words, there is a negative contingency between the instrumental response and the aversive outcome. This is a form of stress training that has been used in prior work for teaching stress self-regulation skills in military and other settings [41]. Therefore, by adapting the game in a way that encourages relaxing behavior, the user is prompted to modify their response to stressors and learn to self-regulate. Furthermore, NR-IC increases the likelihood that the instrumental behavior will be repeated in the future [19], which indicates that the skill has transferred.

3.3 Partial and continuous reinforcement with game biofeedback

To incorporate partial reinforcement (PRF) into the GBF intervention, we used a variable-ratio (VR) schedule. Under this schedule, reinforcement is applied after an unpredictable (but on average constant) number of responses has been elicited. For example, with a 75% PRF, 3 out of 4 target responses will be reinforced. During a GBF session, we evaluate the player's BR and slope once every second. If the BR is in the desired zone, no game penalty is applied for 1 second. If the conditions for game penalty are satisfied (i.e., $BR > 6$ *and* $\Delta BR \geq 0$), we apply autoshooting for 3 seconds according to a probability that is determined by the reinforcement schedule; see flow chart in Figure 3 for an illustration of PRF schedule of 75%. The auditory feedback (*Error Sound*) is played for 0.25 sec. at the beginning of each 3 sec. game penalty period.

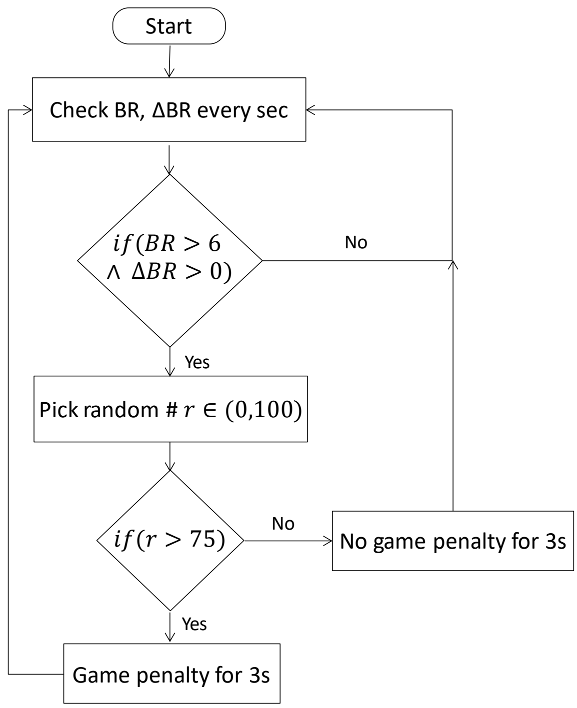

Figure 3 Flow chart for game adaptation under a 75% partial reinforcement schedule. A continuous reinforcement schedule can be realized by setting $\boldsymbol{r > 0}$

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In contrast, under the continuous reinforcement (CRF) schedule, the game adaptation mechanism checks the player's BR every second: if the user's $BR > 6$ and $\Delta BR \geq 0$ (i.e., high BR and increasing), a game penalty (i.e., auto-shooting) is applied for 3s. Therefore, under CRF we penalize all breathing responses that do not meet the target criterion. Consistent with PRF, the auditory feedback (*Error Sound*) is played for 0.25 sec. the beginning of each 3 sec. game penalty period Table 2 summarizes both reinforcement schedules.

Table 2 Game adaptation under the continuous and partial reinforcement schedule

	$BR \leq r_0$ or $\Delta BR < 0$	$BR > r_0$ and $\Delta BR \geq 0$
CRF	No penalty	Game penalty
PRF	No penalty	Penalty based on reinforcement schedule

4 Experiments

Experimental trials were conducted as part of an independent study with each participant randomly assigned to a single treatment (PRF or CRF) or to a control condition (play the game without biofeedback or adaptation). Participants were recruited by posting flyers across the Texas A&M University campus. Twenty four participants (8 participants per group) were recruited for this study: 8 females and 16 males, in the age range of 19-28 years. All participants reported experience with mobile games but no prior experience with biofeedback methods. Signed Institutional Review Board consent was received from each participant before the experimental session (protocol number IRB2009-0420F).

4.1 Protocol

The experimental session is summarized in Figure 4. It consisted of five phases: baseline, pre-treatment assessment (pre-test), training, treatment, and post-treatment assessment (post-test).

- Paced breathing**:** Participants follow an auditory pacing signal, which guides them to breathe at 6 breaths/min: inhaling for 4 sec and exhaling for 6 sec. This choice is motivated by prior work [42] showing that a respiratory pattern with a short inspiration followed by long expiration leads to a higher respiratory sinus arrhythmia. This phase lasts 5 min.
- Training/baseline: Participants are asked to sit comfortably and play the Frozen Bubble game without biofeedback or game adaptation. They are also asked to breathe at their normal pace. This phase gives participants an opportunity to familiarize themselves with the videogame while we measure their baseline physiology. This phase also lasts 5 min.
- Treatment: Participants are assigned to one of the three groups (*PRF*, *CRF* or *control)*. They play the corresponding version of the game for 3 sessions, each session lasting 5 minutes, with a one- minute break between sessions (17 min total). Under CRF, the players play the game with 100% reinforcement probability for the 3 sessions i.e., all 3 sessions are identical in terms of reinforcement scheduling. In contrast, for PRF we use a faded feedback procedure [16, 17], in which the reinforcement probability is gradually reduced with each session (i.e., 75% in session 1, 50% in session 2, and 25% in session 3). During the 1-min break periods between sessions, we give participants their relaxation score (see Section 4.3), and encourage them to improve it. Thus, the relaxation score acts as a secondary reinforcer.
- Extinction: In the last phase, we test the ability of participants to maintain a low BR post-treatment, without any biofeedback reinforcement. The extinction phase also consists of 3 sessions (5 min each) with a 1 min break in between. Participants are asked to maintain a low arousal state using the skills they acquired during the treatment sessions, while playing the stock version of Frozen Bubble. No biofeedback (visual, auditory, or game adaptation) is provided in this phase.

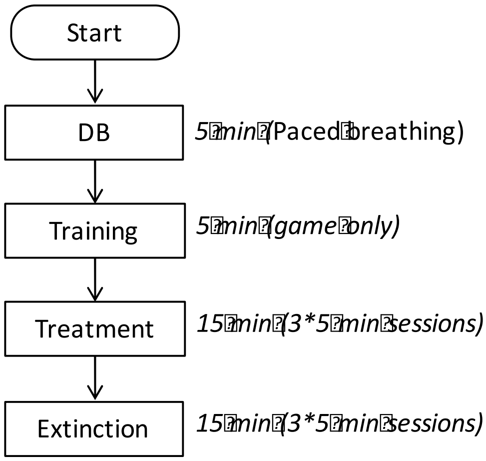

Figure 4 Experimental protocol with four phases and their respective durations. In the treatment phase participants are assigned to one of the three groups (PRF, CRF, or control)

Participants played the game using their dominant hand, while the phone was placed on a smartphone stand on a desk. We designed this setup to minimize motion artifacts in the non-dominant hand, to which the EDA electrodes were attached. Note that in a real-world setting, the game can also be played one handed (by placing the phone on a desk) or two handed (i.e. holding the phone with one hand while playing with the other), since the EDA signal is not part of the biofeedback loop. The experimental setup is shown in Figure 5.

Figure 5 Experimental setup with player playing the game with their dominant hand while EDA being measured on their non-dominant hand. The chest strap measures breathing rate.

4.2 Measures

We measure the participants' BR with a Bioharness BT chest strap (Zephyr Tech.) worn across the player's sternum, immediately below the pectoral muscles. The Bioharness uses Bluetooth to send data to the Frozen Bubble app, where it is used to adapt the game in real-time. In addition, we measure EDA using a FlexComp Infinity encoder (Thought Technology Ltd.) and disposable AgCl electrodes placed at the palmar and hypothenar eminences of the player's non-dominant hand. The raw EDA signal is processed with Ledalab [43] to extract the skin conductance responses (SCRs). A change in EDA is considered an SCR if the signal slope is positive and its amplitude is larger than a threshold of 0.02 μS [13, 43]. We also recorded player's game performance score during the treatment and extinction sessions. Finally, we also collected subjective ratings using the Dundee Stress State Questionnaire (DSSQ) [44] before and after the experiment. DSSQ provides an assessment scale for states associated with stress, arousal and fatigue and is a valid and reliable measure of subjective stress state [45].

4.2.1 Analysis

Prior to statistical analysis on the physiological measures, we validated the assumption that the data was normally distributed with same variance. We performed Kolmogorov-Smirov (KS) test on the null hypothesis that the data for the two physiological signals is normally distributed. The KS test on the data failed to reject the null hypothesis ($p<0.01$), which indicates that the physiology data (BR and EDA) was normally distributed. We also tested the assumption of homogeneity of variance (HoV). This assumption states that for performing statistical analyses the comparison groups should have similar variance. We performed two-sample and multiple-sample variance test (Bartlett) on the data with a null hypothesis that the data in the different groups comes from normal distribution with same variance. Both group-wise (comparing all three groups together) and pair-wise (comparing groups of two at a time) tests failed to reject the null hypothesis.

For statistical assessment, we performed various ANOVA analyses with an alpha level of 0.01. We performed 2-way ANOVA on the physiological results with treatment groups (PRF, CRF and control) and phase (treatment and extinction) as the factors. We also performed 3-way ANOVA on physiological measures with treatment group, phase, and session (T1-T3, E1-E3) as the factors. To ascertain the relative pace of learning between the two groups, we also performed correlation analysis. To compare the subjective results we performed 1-way ANOVA on the differences in the subjective measures captured before and after the experiment. We performed 2-way ANOVA with treatment groups and phase (pre-post) as the factors. Finally, to compare game performance we computed the average change in the scores between treatment and extinction given by $1/N(\sum_1^3 X_{Ei} - \sum_1^3 X_{Ti})$, where X_{Ei} refers to average game score during extinction and X_{Ti} is the average score during treatment.

We performed a power analysis to compute the required sample size to detect a statistically significant difference in BR before and after treatment across the three groups. For this analysis we used the physiology data from our previous study that compared different types of biofeedback for relaxation training [46]. We computed the effect size using Cohen's method [47] (i.e. calculating the mean difference between the two groups, and then dividing the result by the pooled standard deviation) in the G*Power software [48]. The effect size refers to the magnitude of the difference in BR between the means relative to the standard deviations of two groups (GBF and control) in a previous study [46]. The mean BR and standard deviation for the treatment and control group during the pre-test are: 18.07 ± 3.97 and 17.51 ± 7.43 and during post-test 5.46 ± 1.55 and 17.52 ± 3.05. This analysis resulted in a sample size of 12 participants per group.

4.3 Instructions to the participants

Following prior work [11], we give participants instructions at various points during the experiment:

- Common to the three groups:
  - Before treatment. "*Relax, try to breathe slowly, maintaining your breathing rate around 6 bpm. Try to do the best in the game*"
  - Before extinction. "*Stay calm by using the skills you learned during the treatment session. Try and do the best in the game*"
- Specific to biofeedback groups (before treatment):
  - CRF: "*The game will be affected by your breathing rate; higher breathing rates will make the game more difficult. In addition, during gameplay you will be shown your breathing rate and whether it is increasing or decreasing. You <u>will</u> also be presented with an auditory stimulus when your breathing rate is high*"
  - PRF: "*The game may be affected by your breathing rate; higher breathing rates may make the game more difficult. In addition, during gameplay you will be shown your*

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breathing rate and whether it is increasing or decreasing. You <u>may</u> also hear an auditory stimulus when your breathing rate is high"

- Scoring scheme (for both PRF and CRF): "*Your score will depend on both your game performance and how relaxed you are while playing the game. At the end of each game session, you will get two scores: your game score and relaxation score. Try to improve on both*"

– Specific to biofeedback groups (before extinction):

- "*You will not receive any biofeedback information or reinforcement based on your relaxation. You will receive your game score*"

Along with these instructions, participants in the two biofeedback groups receive their relaxation score verbally after each 5-min. treatment session [11, 49]. The relaxation score served as a measure of the participant's ability to maintain a slow BR during treatment. It was computed in 30-sec. windows (sliding by 1s) as follows:

1) If BR remained in the range of 4-8 bpm for the entire 30s window, the score was increased by 5 points;
2) If BR was outside that range consistently throughout the 30s window, the score was decreased by 5 points.
3) Otherwise, the score remained intact (0 points).

In addition to the relaxation score, players were also verbally informed of the change in relaxation score i.e. whether it increased or decreased compared to the previous session and by how much. Finally, all the participants received their game score after each session (and the delta) and were asked to improve their performance.

5 Results

5.1 Breathing rate

In a first analysis, we examined the average BR of participants in the PRF, CRF, and control groups at each phase of the experiment. Results are summarized in Figure 6. In the paced-breathing phase, all groups had a similar BR of approximately 6 breaths/min, which is the frequency of the pacing signal. In the training (game-only) phase, all groups showed a high BR, which is again expected since no biofeedback or pacing signal was provided to them. During the treatment phase, differences between the groups started to emerge, with CRF and PRF groups showing lowered BRs. The control group did not receive any biofeedback information and (as expected) maintained a high BR. During the extinction phase, the PRF group had a lower BR than the CRF group. Once again, the control group showed a high BR. Next, we examined BR across the six 5-minute sessions, 3 sessions of treatment and 3 sessions of extinction. Results are shown in Figure 7 and Table 3.

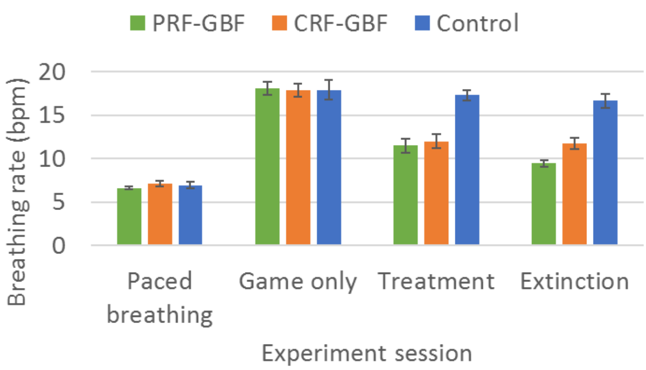

Figure 6 Average breathing rate and standard error of mean for the three groups over the four experimental sessions. PRF: partial reinforcement; CRF: continuous reinforcement; GO: game only

In the first treatment session (T1), both CRF and PRF groups showed higher BRs than during the paced breathing session (CRF: 15.48 bpm, PRF: 15.14 bpm.) The relatively high BR at T1 for both GBF groups may be attributed to the fact that this session directly follows the game-only session, in which participants were breathing at their natural pace. Furthermore, this is the first time during the experiment when participants are exposed to the game biofeedback, and therefore are becoming familiarized with the game-adaptation mechanism. Nonetheless, both GBF groups showed a lower BR at T1 than the control group. BRs continue to reduce for both biofeedback groups during the second and third treatment sessions (T2 and T3), with no significant differences among PRF and CRF: $F(1,14) = 2.42,\ p = 0.14,\ \eta^2 = 0.02$.

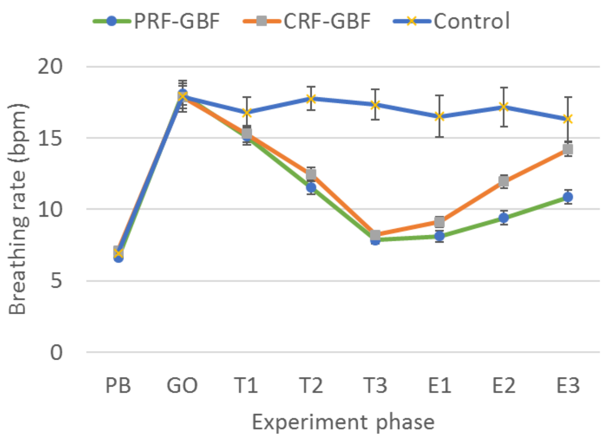

Figure 7 Breathing trend (average) for the three groups over the course of the experiment. Whiskers represent standard error of mean. PB: paced breathing, GO: game only, T1-T3: treatment session, E1-E3: extinction session

Interesting trends start to emerge during the extinction phase; both biofeedback groups show an increase in BR as the phase progresses, but the CRF group has a faster rate of increase. In the first extinction session (E1), the CRF group has a similar BR as the PRF group (BR difference between PRF and CRF = -1.40 bpm). This trend continues in the second extinction session (E2) (BR difference = -3.13

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bpm), and third extinction session (E3) (BR difference = -3.98 bpm). In other words, during the extinction phase (i.e., once the biofeedback is removed), participants in the PRF group are able to maintain a lower BR longer than those in the CRF group. These results indicate that partial reinforcement increases the resistance to extinction.

To evaluate the statistical significance of these results, we performed a 2-way ANOVA on the BR slope between the two GBF groups during the treatment session. The factors were the treatment group (PRF, CRF) and time (T1, T2, and T3). The slope was computed by linear curve fitting on the BR data for all participants during 3 treatment sessions. This analysis resulted in an insignificant main effect for treatment type $F(1,42) = 0.64, p = 0.43, \eta^2 = 4.83 \times 10^{-4}$, insignificant main effect for time $F(2,42) = 1.95, p = 0.16, \eta^2 = 0.017$ and an insignificant interaction $F(2,42) = 0.32, p = 0.72, \eta^2 = 4.90 \times 10^{-4}$. The insignificant main effect for the treatment indicates that the slope for the two treatment group was statistically similar during the treatment (indicating a similar skill acquisition rate). The insignificant main effect for time points to the fact that the BR slope during T1, T2 and T3 are similar, which is evident from Figure 7 . We also computed the correlation coefficient between BR time series for the two GBF groups during the treatment ($\rho = 0.90, p < 0.01$). The high correlation, similar slopes, and the trend in Figure 7 indicate that both partial and continuous reinforcement had a similar pace of learning. This result differs from those observed in other prior studies where a continuous reinforcement paradigm generally leads to faster skill acquisition compared to partial reinforcement. A 2-way ANOVA between the two GBF groups during extinction resulted in significant main effects for treatment type $F(1,42) = 59.64, p < 0.01, \eta^2 = 0.25$ and time $F(2,42) = 58.45, p < 0.01, \eta^2 = 0.06$ and an insignificant interaction between the two factors $F(2,42) = 5.47, p = 0.07, \eta^2 = 0.002$. This analysis highlights the difference between the two treatment groups during extinction. We also performed a 3-way ANOVA on the BRs with treatment group, session (T1, T2, T3, E1, E2, E3), and phase (treatment and extinction) as the factors. Our results indicated a significant main effect for treatment group $F(2,143) = 125.69, p < 0.01, \eta^2 = 0.28$ and phase $F(1,143) = 18.8, p < 0.01, \eta^2 = 0.02$ and an insignificant main effect for session $F(5,143) = 0.57, p = 0.68, \eta^2 = 7.7 \times 10^{-5}$. Finally, with a sample size of 8 participants per group, we achieved an effective power of 0.74 in this study.

5.2 Electrodermal activity

Figure 8 and Table 3 present the average EDA during the treatment and extinction phases, measured as the number of SCRs per minute, as described in Section 4.1. During the paced-breathing phase, all participants show a low SCR count. SCRs increase for the three groups during the training session, in agreement with the results on BR shown in Figure 6. Differences between the three groups start to emerge as the treatment phase begins. During the three treatment sessions, both game biofeedback groups show a reduction in SCR, with the CRF group showing a higher SCR count than PRF group. The two biofeedback groups reach similar SCR count in the third treatment session (T3). This trend corroborates with those observed with BRs. Differences between the two biofeedback groups emerge during the extinction phase. In the first extinction session (E1), the CRF group shows an increase in SCR relative to that attained during the final treatment session (T3), whereas the PRF group shows a further reduction in SCR. As the extinction phase progresses (E2 and E3), both biofeedback groups show an increase in SCR, with the CRF group having a faster rise compared to PRF. This is consistent with the BR trends, and indicates that the PRF group had a higher resistance to extinction. In contrast with the two biofeedback groups, the control group consistently has a higher SCR for all the treatment and extinction sessions. Of note, participants in the control group showed a slow but steady reduction in SCR as the experiment progresses; this decrease may be attributed to the SCR habituation effect – a gradual reduction in sudomotor activity (SCR count and amplitude) and eventual disappearance with a repeated stimulus [50].

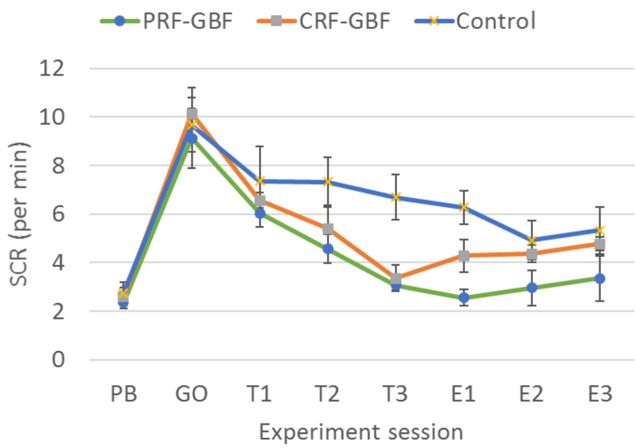

Figure 8 Average skin conductance response (per min) over the course of the experiment. Whiskers represent standard error of mean. PB: paced breathing, GO: game only, T1-T3: treatment session, E1-E3: extinction session

To test the statistical significance of these results, we performed a 2-way ANOVA between the three groups with treatment type and time as the two factors during the treatment phase showed a significant main effect for treatment type, $F(1,42) = 12.05, p < 0.01, \eta^2 = 0.02$ and time, $F(2,42) = 8.27, < 0.01, \eta^2 = 0.05$, but no interactions, $F(2,42) = 0.13$, $p = 0.87, \eta^2 = 1.36 \times 10^{-5}$ Finally, a 2-way ANOVA during the extinction phase revealed a significant main effect for treatment type, $F(1, 42) = 25.08, p < 0.01, \eta^2 = 0.12$, but not for time, $F(2,42) = 2.18, p = 0.12, \eta^2 = 0.003$ and no interactions, $F(2,42) = 0.34, p = 0.71, \eta^2 = 9.01 \times 10^{-5}$. This statistical analysis corroborates the results observed for BR, indicating the importance of treatment type during both the treatment and extinction phases. We performed a 3-way ANOVA with treatment group, session (T1, T2, T3, E1, E2, E3), and phase (treatment and extinction) as the factors. Our results indicated a significant main effect for treatment group $F(2,143) = 45.6, p < 0.01, \eta^2 = 0.14$ and phase $F(1,143) = 2.63, p < 0.01, \eta^2 = 0.01$ and an insignificant main effect

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for session $F(5{,}143) = 0.82, p = 0.44, \eta^2 = 1.3 \times 10^{-5}$.

5.3 Game performance

Next, we analyze the performance of the participants during the treatment and extinction sessions, shown in Figure 9. During the initial training (game only) session, all groups show similar performance. This is to be expected since all of them are playing the same game without any biofeedback. Following the training session, game performance in the two biofeedback groups decreases during the first treatment session (T1), but increases again during the two subsequent treatment sessions. During the extinction phase, the game score continues to increase for the two biofeedback groups. Further, the PRF group had higher game scores than the CRF group, though the difference was not statistically significant. The control group played a non-biofeedback version of the game for all sessions and showed a constant game score throughout the experiment. A 1-way ANOVA on the gains in game score from treatment to extinction showed a statistically significant difference between the three groups $F(2{,}21) = 8.1, p < 0.01, \eta^2 = 0.18$. Comparing the two biofeedback groups, however, did not show a significant difference $F(1{,}14) = 0.23, p = 0.63, \eta^2 = 2.6 \times 10^{-4}$.

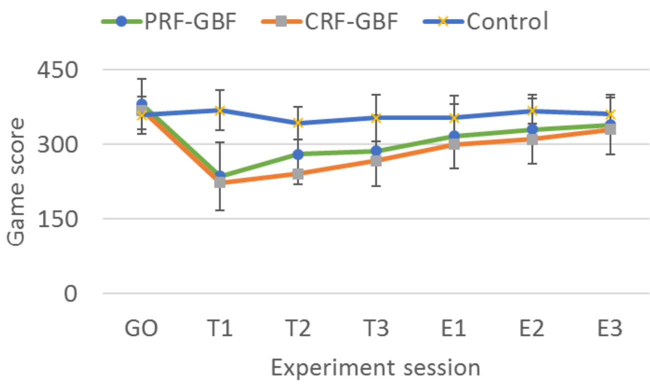

Figure 9 Average game score and standard deviation for the three groups over the course of the experiment. GO: game only, T1-T3: treatment session, E1-E3: extinction session.

5.3 Subjective analysis

We also collected subjective ratings from participants using the Dundee Stress State Questionnaire (DSSQ) [44]. We asked participants to complete the questionnaire before the start of the treatment phase, and again after the completion of the extinction phase. Figure 10 presents the DSSQ ratings for two factors: relaxation and anxiousness. These results indicate that participants in the two biofeedback groups showed a small increase in the perceived levels of relaxation and reduction in anxiety. These changes were the highest for the PRF group followed by the CRF group, whereas the control group did not show changes between pre- and post-assessment. Performing a 1-way ANOVA did not indicate a statistically significant difference between the three groups for relaxation $F(2{,}21) = 0.81, p = 0.45, \eta^2 = 0.005$ and anxiousness $F(2{,}21) = 0.54, p = 0.59, \eta^2 = 0.002$.

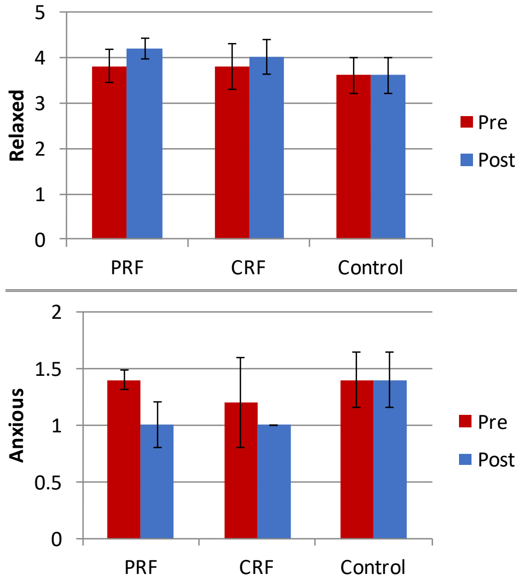

Figure 10 Dundee stress state questionnaire results (average and standard deviation) prior and after the treatment. (a) Relaxation (b) Anxious

Similarly, comparing the two biofeedback groups did not show statistically significant difference for relaxation $F(1{,}14) = 1.6, p = 0.22, \eta^2 = 0.01$ or anxiousness $F(1{,}14) = 0.85, p = 0.37, \eta^2 = 0.003$. A 2-way ANOVA for relaxation did not show a significant main effect for the treatment groups, $F(1, 42) = 1.24, p = 0.27, \eta^2 = 6.28 \times 10^{-4}$ or phase, $F(1, 42) = 2.09, p < 0.13, \eta^2 = 0.007$, and no interaction effects, $F(2, 42) = 0.93, p < 0.40, \eta^2 = 0.001$. There was no significant main effects for anxiousness (group, $F(1, 42) = 1.65, p = 0.20, \eta^2 = 0.001$, phase, $F(1, 42) = 1.96, p < 0.15, \eta^2 = 0.006$ or interaction, $F(1, 42) = 0.72, p = 0.49, \eta^2 = 8.65 \times 10^{-4}$.

6 Discussion

Reinforcement schedules are critical to learning and behavior change with instrumental conditioning. A number of biofeedback studies [15, 16, 18, 28] have shown that partial reinforcement improves resistance to extinction. Yet, we are not aware of prior studies investigating reinforcement schedules in the context of biofeedback games. To address this gap, this paper studied the effect of reinforcement schedules with a biofeedback game for stress-self regulation. The two scientific contributions of this work lies in applying the concepts of operant conditioning and partial reinforcement to improve the acquisition of relaxation skills with a biofeedback game. This includes developing algorithms to provide partial reinforcement in response to the player's breathing (see Figure 3) and experimentally demonstrating that our algorithms improve skill retention without affecting pace of skill acquisition.

Our primary aim was to compare two reinforcement schedules (partial and continuous) by their ability to help participants acquire relaxation skills and promote skill transfer. Our results indicate that partial reinforcement increases resistance to extinction, as measured by retention of deep breathing skills following treatment.

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This result validates hypothesis *H1*, as predicted by the partial reinforcement extinction effect (PREE) [19, 20], which states that the less frequently a behavior is reinforced the harder it is to extinguish. The PREE makes withdrawal of the reinforcement easier to detect following a CRF schedule than following after a PRF schedule: providing a reinforcement after every response during training (i.e. CRF schedule) creates the expectation that the reinforcement will also guide behavior after training [19]. In other words, a CRF schedule leads to a greater expectation of reinforcement compared to PRF. This can have a frustrating effect during the extinction phase [19, 51] and, in turn, lead to a more rapid extinction of the learned skills. In contrast, during training with a PRF schedule only a percentage of the responses are reinforced. Prior studies have shown that a PRF schedule leads to fewer frustrating reactions and that participants elicit the desired behavior longer compared to using CRF schedule during training [15, 35, 36].

While both biofeedback groups showed a reduction in BR and EDA during training, we did not observe differences in the pace of skill acquisition (as measured by how quickly participants were able to lower their BR) between both groups. This observation neither supports nor rejects hypothesis *H2.* This is an interesting result and requires further investigation since prior studies have shown that CRF schedules lead to faster rates of acquisition due to higher exposure to the reinforcers [15, 30]. Our results may be attributed to the short 3-second duration we used for CRF. This may have reduced the number of times the participants were exposed to the reinforcer (game penalty) compared to a continuous schedule where reinforcement is provided every second and not every three seconds. In addition, as noted by Cohen, et al. [15], much of the prior work on reinforcement schedules is based on animal models (e.g. mice). In these experiments, the animal has to move around and/or operate an external device (i.e., press a lever to get a reward). This is in contrast with a biofeedback mechanism, where the participant has to manipulate an internal physiological variable. In addition, operations such as lever pressing are discrete in time, whereas breathing and gameplay are both continuous processes.

Partial reinforcement schedules can be implemented in several ways, including variable ratio (VR), fixed ratio (FR), variable interval (VI), and fixed interval (FI). In FR schedules, the user must produce the target response a predetermined fixed number of times before the reinforcement is presented. In contrast, a VR schedule requires an unpredictable but on average constant number of responses; the average number of responses governs the schedules. A FI schedule is similar to FR except that along with an elicitation of the response, a fixed amount of time has to elapse before presenting the reinforcement. Finally, VI schedules require a response and a varying time interval before reinforcement is applied; the average interval defines the schedules. Prior studies have shown that variable schedules (i.e. VI and VR) lead to higher resistance to extinction compared to fixed schedules [15, 18]. This may again be attributed to the probabilistic nature of VI and VR methods, where only certain randomly chosen responses are reinforced. Furthermore, ratio schedules lead to a faster rate of responding therefore resulting in faster rate of learning. Our study used a VR-based PRF schedule; future work will investigate other schedules in GBF and their influence on skill acquisition rates and retention.

As discussed earlier, games have many elements that could be adapted during gameplay in response to the user's physiology. Therefore, an interesting extension of our work would be to modify different game elements

Table 3 Descriptive results. Average and standard deviation values for the BR, EDA, and game performance during the experiment. PB: paced breathing, GO: game only, T1-T3: treatment sessions, E1-E3: extinction sessions.

		PB	GO	T1	T2	T3	E1	E2	E3
BR	PRF	6.61 ± 0.34	18.07 ± 1.73	15.10 ± 1.24	11.53 ± 1.04	7.85 ± 0.65	8.13 ± 0.87	9.39 ± 1.06	10.86 ± 1.11
	CRF	7.13 ± 0.37	17.86 ± 1.66	15.27 ± 1.12	12.44 ±1.31	8.22 ± 0.70	9.11 ± 1.10	11.93 ± 1.12	14.19 ± 0.80
	Control	6.95 ± 0.35	17.90 ± 2.28	16.77 ± 2.19	17.75 ± 1.73	17.30 ± 2.24	16.51 ± 2.99	17.15 ± 2.83	16.30 ± 3.18
EDA	PRF	2.36 ± 0.51	9.13 ± 2.75	6.04 ± 1.32	4.56 ± 1.32	3.08 ± 0.48	2.56 ± 0.71	2.96 ± 1.64	3.36 ± 2.08
	CRF	2.60 ± 0.86	10.13 ± 2.37	6.56 ± 0.69	5.40 ± 2.12	3.36 ± 1.21	4.28 ± 1.48	4.36 ± 0.79	4.76 ± 0.62
	Control	2.76 ± 0.93	9.66 ± 2.49	7.36 ± 3.19	7.32 ± 2.28	6.68 ± 2.08	6.28 ± 1.55	4.92 ± 1.76	5.32 ± 2.18
Game score	PRF	-	381 ± 50.37	236 ± 68.44	280 ± 61.14	287 ± 71.16	316 ± 65.24	329 ± 69.53	339 ± 60.23
	CRF	-	368 ± 37.86	223 ± 40.24	241 ± 32.70	267 ± 47.59	300 ± 44.41	310 ± 24.99	330 ± 32.49
	Control	-	358 ± 40.69	368.75 ± 31.00	343 ± 29.17	353 ± 27.62	353 ± 35.81	367.5 ± 53.48	361 ± 49.49

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(e.g., autoshooting, angular rate of shooting, ceiling drop, arrangement of bubbles in the context of Frozen Bubble) using different reinforcement schedules to maximize skill acquisition and retention. In addition to the reinforcement schedules, other factors may influence resistance to extinction, including the history of reinforcement, the magnitude of the reinforcer, the degree of deprivation, and previous experience with extinction. Future work will examine these factors in GBF for relaxation skill transfer.

For breathing-based biofeedback, special consideration should be given to the ratio of expiration time to inspiration time (I/E ratio). During the initial paced breathing session, the participants were guided (using the pacing signal) to maintain an I/E ratio of 4/6 (i.e., 4-sec inspiration, 6-sec expiration). While we instructed the participants to maintain a similar I/E ratio during the game biofeedback session, we did not provide any feedback about their I/E ratio during the treatment sessions and we did not record this information. The question of I/E ratio biofeedback and its integration with a game will be studied in future work.

During GBF, the player is provided the biofeedback information in two ways: through a visual display of their BR and through game adaptation. Here, the former acts as information feedback while the latter acts as the reinforcement. In our implementation, the PRF schedule was integrated in the game in a way that it scheduled only the game adaptation process, while the players were provided with the information feedback throughout the experiment. Future work will also involve studying the effect of reinforcement scheduling on both game adaptation and information biofeedback (i.e. presenting or withdrawing the visual display of physiology based on a probabilistic schedule) on skill learning and skill retention.

Our experiments did not evaluate the effect of a yoked control on relaxation skill acquisition. In a yoked control design, a participant is paired with a participant in one of the treatment groups so that both receive the same biofeedback information. In other words, the yoked participants' will see the game adapt, but their own physiology will have no influence on the game. This manipulation allows the experimenter to study the influence of response-independent feedback in the game and whether it leads to the participants learning the relationship between their perceived arousal level and the game adaptation process. Future work will involve comparing the partial and continuous reinforcement schedules with a yoked control to study the effect of response-independent feedback.

An important aspect in any behavioral training method is its ability to engage the user (ensuring long term usage). While we did not explicitly measure motivation level or engagement, we asked participants to do the best they could in the game and to improve their score relative to the previous session. This served as a source of motivation, as is evident from the improvement in game performance during the treatment sessions for the two biofeedback groups. On a separate note, the main reason behind us choosing games as a way to provide stress training is their inherent engagement and immersiveness. The appeal of videogames stems from their ability to increase the user's motivation and engagement, which is particularly beneficial when the treatment involves painful procedures (e.g., chemotherapy) or is intrinsically boring and repetitive (e.g., physical therapy) [52]. Given the engaging nature of videogames, games are ideally suited to promote skill learning and practice [53]. Future work will include additional measures (e.g. Game Engagement Questionnaire) to measure user engagement level during GBF treatment.

Our study focused on short-term training and immediate assessment of skill retention and did not address long term retention of skills. As noted by Gentile, et al. [54], repeated exposure to a training process can lead to diverse long-term effects. One of the main challenges in building a stress training system is that individuals exposed to similar stressful conditions react differently [55]. In addition, learning theories have shown that individuals learn in different ways and a number of factors including task complexity, learning ability, perception of visceral states influence the effectiveness of a stress intervention. This suggests that there may not be a single solution for stress self-management that is effective for all users. An effective learning routine should include multi-dimensional training comprising of meditation, exercise, videos, and videogames [56]. Such programs may deliver self-guided stress training to a wider population. Therefore, an evaluation of long-term persistence effects of GBF intervention will require multiple training sessions with a multi-dimensional-appriaoch in real-world ambulatory settings. Future work will also involve detecting user stress levels in real-world settings, and triggering interventions when needed.

7 Conclusion

This study integrated partial reinforcement scheduling with a biofeedback game, and tested its ability to increase resistance to extinction of deep-breathing skills. Our results show that partial reinforcement does improves resistance to extinction, as observed in both breathing rates and electrodermal activity. In addition, our results indicate that training with partial reinforcement results in a similar skill acquisition rates compared to training with a continuous schedule. Stress training methods based on biofeedback games offer a number of advantages, including engagement, detachment and stress recovery, and self-regulation while performing an arousal inducing task [7, 8]. This paradigm of partial reinforcement in GBF can be easily extended to other games and biofeedback systems, and may also be used in the home and workplace.

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