Nature vs. Stress: Investigating the Use of Biophilia in Non-Violent Exploration Games to Reduce Stress

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Games hold the potential to help many address health-related issues such as chronic stress. We investigated the use of biophilia, an affective response to nature grounded in the psychology literature, as indirect physiological input for biofeedback games. We designed and developed a non-violent exploration game, and conducted an empirical study that examined affective and physiological responses to gameplay in virtual nature and urban settings. Our results did not identify a difference in stress levels experienced by players between these two settings, but point to improved attention when playing in nature settings. We discuss implications of these findings, and discuss both difficulties in and potential future strategies for applying biophilia to the design of biofeedback games.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**.

Additional Key Words and Phrases: biophilia; biofeedback; exploration game; stress;

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1 INTRODUCTION

Stress is a pervasive, chronic, yet preventable contributor to illnesses such as depression, anxiety, and obesity that affects nearly one third of adults in North America [2]. While stress is widespread in adult populations, it often emerges in young adults — a recent American College Health Association survey notes high prevalence of anxiety (28%), depression (17%), and stress (38%) in college students [3]. For young adults, the consequences of stress can be especially detrimental, as habits that lead to stress may become entrenched in an individual's lifestyle. Excessive stress can reduce effectiveness at school and work, establish unhealthy habits, and contribute to addiction, crime, absenteeism, and burnout [11]. Even as mental health awareness has increased, students lack the tools and motivation to enact change, suggesting a need for a better understanding of how it can be addressed in practice.

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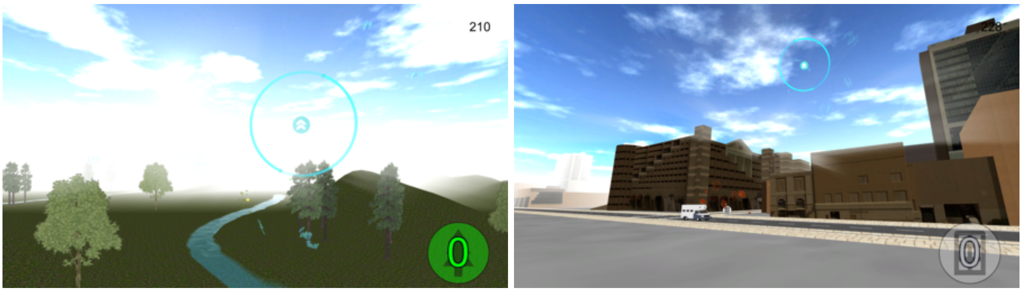

Fig. 1. We designed and built a non-violent exploration game that emerges players into a virtual world. In our game, players explore either a 'Nature' (left) or 'Urban' (right) environment.

The long-term objective of this research is to develop tools that assist people in identifying stress in their lives, and that can motivate them to take action to reduce its negative effects. Gaming has been identified as a particularly promising area of investigation, due to the pervasiveness of stress in young adults and their proclivity towards gaming [7, 21]. We believe that improving stress management skills at a young age has the potential to improve health across an individual's lifespan, and to help prevent related chronic illness such as depression, anxiety, and obesity. As a first step towards this long-term goal, we explore the potential of *biophilia*, a human's inherent proclivity to natural settings, to reduce player stress [12, 27, 29]. Research in psychology and affective computing has found that differences in audio and visual stimuli, such as those between a busy street or park, can prompt an emotional response in an observer [25, 27]. While the effects of biophilia have been shown for passively consumed still imagery [26] and non-interactive virtual reality [25, 27], there is no evidence that this effect persists in interactive video games. In this paper we present the design of a simple interactive game (Figure 1) in which a player can explore a procedurally-generated world with both urban and natural backdrops. The game allows simple navigation using the mouse, as well as common game mechanics that include collecting items and planting trees or constructing buildings. We also present a first assessment of our game and the use of biophilia in an interactive context. In particular, we make two contributions:

(1) The development of a proof-of-concept game that shows how changes in player stress can be detected during gameplay with indirect physiological sensors (e.g., heart rate and GSR) that are available today on modern wearable devices, and
(2) Our results suggest an opportunity for indirect biofeedback, but not biophilia-based design, in stress reduction games. We reflect on why results from psychology surrounding biophilia and stress may not readily transfer from controlled lab experiments to more realistic computer games.

2 RELATED WORK

The biophilia hypothesis [29] states that humans have an "urge to affiliate with other forms of life", and that interacting with nature is highly important for an individual's health and well-being [12, 13, 27]. Since its proposal, research has explored this hypothesis, and demonstrated that when individuals fail to interact with the natural world, they can experience negative emotions such as fear and anger, chronic stress, and diminished life satisfaction [12]. Conversely, interactions with the natural world have been shown to improve cognitive abilities and reduce stress [25, 27]. These responses are automatic, and consistent across individuals [4, 5, 27], suggesting that they are ideal for integration into biofeedback games as indirect physiological control.

To take advantage of this phenomenon, some work has sought to establish the benefits of biophilia in computing contexts. For example, it has been shown that its restorative effects can be realized through exposure to artificial representations of nature (i.e., videos or photos) [23, 24], instead of nature itself. Similarly, work by Valtchanov et al. [25, 27] has shown that individuals exposed to nature via virtual reality experienced lower stress levels and improved affect during experimental trials. In turn, these findings have led to the development of psychological models that can be used to assess emotional response to images (e.g., [26]). However, this research has largely focused on creating reactive systems that respond to a player's current emotional state, rather than understanding how they may be used to more directly impact players and actively take on a role in reducing their stress. Our research builds on previous work to better understand how to effectively design games that encourage stress awareness, that can respond to a player's stress levels, and that promote stress management.

2.1 Biofeedback Games

The emergence of computing software and devices that can monitor and react to human physiology, called *biofeedback*, provides an opportunity to develop new tools to help individuals monitor and cope with stress. Building on work that established connections between physiological and affective responses (e.g., [15]), biofeedback games have been developed to respond to players using physiological control, such as heart rate (HR) and galvanic skin response (GSR). In particular, research has often strategically reached out to educate youths on health-related issues such as stress management due to their prevalent involvement with gaming [6, 22].

Work addressing stress has often investigated the use of *direct* physiological control into games, defined as control via physiological input that a player can control voluntarily, such as flexing muscles or shifting eye gaze [16]. The use of direct physiological control is particularly useful when training users, such as in teaching breathing or meditation techniques to help cope with stress. For example, Al Rihawi et al. [1] developed *Dodging Stress*, a game that trains players in deep breathing techniques by increasing game difficulty when the player's breathing rate differs from a prescribed target. Similarly, Parnandi et al. [17] developed *Chill-Out*, a game that aims to control breathing rates by penalizing those that were too high with increased game difficulty. Both projects were found to be effective in transferring deep breathing skills and reducing arousal during a stress inducing task.

However, a drawback to direct physiological control is the need for specialized hardware to monitor phenomena such as breathing. Such hardware can be expensive, invasive, and intimidating to players. On the other hand, wearable devices, such as a smartwatch or a fitness tracker, often have a built-in heart rate monitor that can be used in sync with traditional game controllers to enable *indirect* physiological control. For example, *Nevermind* [18] is a biofeedback-enhanced adventure horror game aimed to help individuals cope with fear. While research has often explored direct physiological control to promote stress management, an open question is whether indirect physiological controls can be used to monitor and address stress in games.

Our research seeks to understand how indirect physiological control can be used in the design of biofeedback games to address stress. In particular, we explore how biophilia, might be used in conjunction with indirect physiological input to monitor, respond to, and ultimately affect a player's stress levels.

3 GAME DESIGN AND DEVELOPMENT

To understand how biophilia might be applied in a game context, we decided to develop our own experimental computer game that would allow us to control a player's exposure to nature, and test its potential influence on stress. Our intention was to show how biophilia would impact a realistic *gaming* environment. That is, to show how biophilia might transfer from non-interactive to interactive media (i.e., [27]).

Since the game was intended to serve as an experimental platform for our study, we also strategically designed it to improve our ability to observe any effect of biophilia on stress. For instance, we wanted to avoid potential confounds to our measurement of stress, such as narrative or in-game achievements, and selected a minimalist, non-violent exploration game to do so. Similarly, we chose to focus on inducing biophilia, and not implementing a full biofeedback system, to enable us to better isolate and measure the size of any potential effects.

We developed a non-violent exploration game that drew inspiration from *Flower* by Thatgamecompany (Figure 1). We chose to emulate Flower due to its popularity on the PlayStation gaming console, its focus on positive emotion and relaxation rather than 'fun', and because of its similarity to games used in past studies of biophilia [25, 27]. As an exploration game, our game has no explicit objective; instead, players explore a 3D world, collect seed packages and boosters, and plant various objects throughout the environment.

We created two versions of our game, based on either a natural (Figure 1 left) or urban (Figure 1 right) environment. While the underlying mechanics are identical for both games, audio and visual features differ; the natural environment is designed to evoke a calming effect via biophilia, with an emphasis on blue/green colours and curved surfaces that are known to be associated with calming effects [25, 27]. On the other hand, the urban environment's brown/yellow palette and sharp edges have been shown to be perceived by humans as more stressful. In the natural setting, seeds allow the player to plant trees and bushes, whereas in the urban setting they allow the player to place buildings. Players also experience realistic audio while playing (e.g., traffic in urban settings, or running water of nearby streams in natural settings).

The game's controls are simplistic, and are entirely constrained to a mouse (with scroll wheel). Players hold down the left mouse button to move forward and change direction by moving the mouse. Flying through a marker (blue circles in Figure 1) allows players to pick up power-ups. Players also have the option of passing through boosters that are distributed throughout the environment allowing them to increase their travelling speed for a short time. As seeds are collected, players can scroll through their inventory using the scroll-wheel, and 'fire' items (e.g., plants or houses) using the right mouse button. As players explore the world and collect power-ups, their inventory is displayed in the bottom right corner of the screen. During our study, the game was set to time out after five minutes of play, with a countdown displayed in the top right corner. The game's interface is shown in Figure 2.

The game was developed in C# using Unity 5 over a four-month period. Nature and urban scenery is generated procedurally, and so "infinite" navigation is possible, and constraints can control how much urban vs. nature is visible. A unique feature of the game is support for indirect biofeedback, and in particular, the ability to monitor and respond to player heart rate via in-game mechanics (e.g., by increasing nature scenery when a player is stressed). We discuss the appropriateness of this design, as well as areas for future work, at the end of this paper. As one contribution of this research, the game's source code is available via https://osf.io/k5pvh/.

4 VIABILITY STUDY

To explore the viability of indirect physiological measurement of biophilia in a game setting, we used our prototype game to experimentally expose players to either nature or urban settings. By controlling a player's exposure to nature, we sought to confirm findings from the psychology literature that suggest that biophilia can be a useful tool in addressing stress, but within the context of an interactive game [14]. In particular, we expected that participants playing in an urban environment would experience a smaller decrease in stress and arousal than those in a natural setting [27]. In addition, the study provided an opportunity to assess the sensitivity of self-reported and physiological measures of stress within gaming contexts.

4.1 Pilot

We first conducted a pilot study with 10 participants, with an experimental design and procedure similar to that reported below. Initial results were promising, with collected HR data revealing significant differences before and after gameplay. However, no effects of biophilia were found. We consulted local standards in HCI [8] and best pracrices for CHI PLAY [28], and decided to perform a follow-up study to further investigate these effects. We performed a power analysis in G*Power. Our pilot data and work by Valtchanov et al. [25] both suggested a large effect size (η_p^2 = .766). Thus, we used Cohen's recommendations for a large effect size of 0.7 and a power of 80.75% [9]. Our analysis suggested that 20 participants would be sufficient to identify large effects in a follow-up study.

4.2 Participants

We recruited 20 participants (10 male-identifying, 10 female-identifying) from a local university and randomly assigned them to one of two GAME TYPE conditions. Participants' age ranged from 19 to 33 years (Mdn = 23). Each participant received a $2 gift card for a local coffee shop.

4.3 Procedure

First, participants were introduced to the study, and asked to read and sign an informed consent form and brief demographic questionnaire. Next, photoplethysmography (PPG) finger sensor and galvanic skin response (GSR) electrodes were attached to the participant's non-dominant hand.

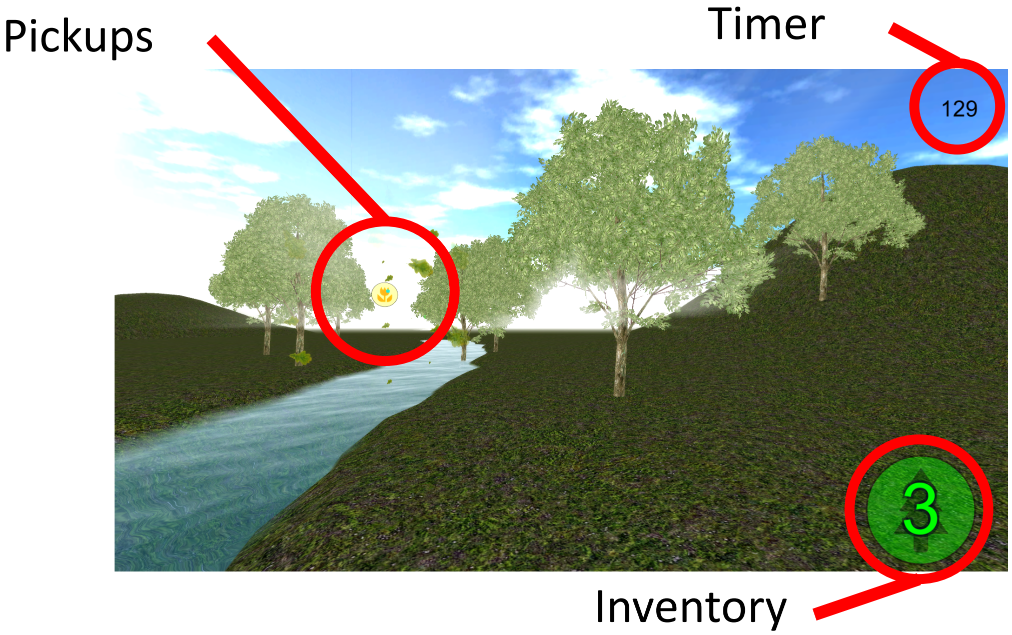

Fig. 2. The game interface comprises overlaid displays for inventory and time remaining. As players navigate the environment, they come across pickups for items such as plants and trees.

Each participant's non-dominant arm was then fitted into a sling to minimize sensor noise caused by arm movement, and help prevent participants from accidentally moving their arm or using their non-dominant arm to control the mouse or keyboard. In addition, participants were instructed to keep this arm as still as possible throughout the duration of the study, which comprised three phases. The first phase was used to collect a baseline assessment of stress. Participants then sat in front of the gaming computer where they completed a brief training session of the game. During the training phase, participants were instructed to play the game until they felt comfortable with the controls ($min = 15s$; $max = 218s$; $M = 72s$; $SD = 47s$). The training session was followed by a baseline self-reported assessment of stress. While participants completed this questionnaire, baseline physiological data was also collected. Next, participants completed a stress-induction phase. To ensure that all participants were experiencing an elevated level of stress and negative affect prior to playing the game, they completed the Markus & Peters Arithmetic Test [10] as a stressor task. During the test, participants used mental arithmetic to solve 10 difficult multi-step questions (e.g., $15 \times (17 + 19)$) within a $60s$ per question time limit, without aids. Throughout the stress-induction task, participants wore headphones that played loud street traffic noises. Before moving on to the experimental game, participants completed a second self-reported assessment of stress while physiological data was recorded. Finally, participants completed the treatment phase of the study, in which they were exposed to either nature or urban versions of the experimental game. During this phase, participants played the experimental game for a period of 5 minutes, during which physiological data was continuously recorded. Following the gameplay session, a final self-reported assessment of stress was collected.

4.4 Experimental Design

We used a mixed study design with 2 × GAME TYPE and 2 × GENDER[1] as between-participants factors and 3 × PHASE as a within-participants factor. Participants were recruited such that their GENDER was balanced between GAME TYPE, and randomly assigned to play the game in either a nature or urban setting. For all participants, dependent variables were collected across all three study phases: baseline, post-stress-induction, and post-gameplay. We collected data related to six dependent variables: heart rate (HR) and electrodermal activity via galvanic skin response (GSR) [20], and self-reports of positive affect, negative affect, and attentiveness via the Zuckerman Inventory of Personal Reactions (ZIPERS) [30]. All study materials are available via https://osf.io/k5pvh/.

4.5 Experimental Setting & Apparatus

The study was administered in a laboratory at the University of Waterloo. Participants completed all experimental tasks on a high-end gaming machine (Windows 10, Intel i7 3.6 GHz, 16 GB RAM, NVIDIA GeForce GTX 980) at a desk with a keyboard and mouse. While interacting with experimental software, participants wore headphones with the system volume set to 22. Throughout each session, we collected heart rate via a photoplethysmography fingertip sensor (PPG) and electrodermal activity as galvanic skin response (GSR) via two disposable electrodes on the participants' middle and ring fingertips (Figure 3). These sensors connected via wire to a BioPac 2-channel BioNomadix module (BN-TX, v4.3) worn on a participant's forearm. This module was wirelessly paired to a BioPac M150 system (v1.1.22), which itself was connected to a PC identical to the one described above. All data was recorded at 2 kHz using BioPac AcqKnowledge (v4.4.0).

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[1] We acknowledge that gender is not binary, but no participants in our study identified as non-binary.

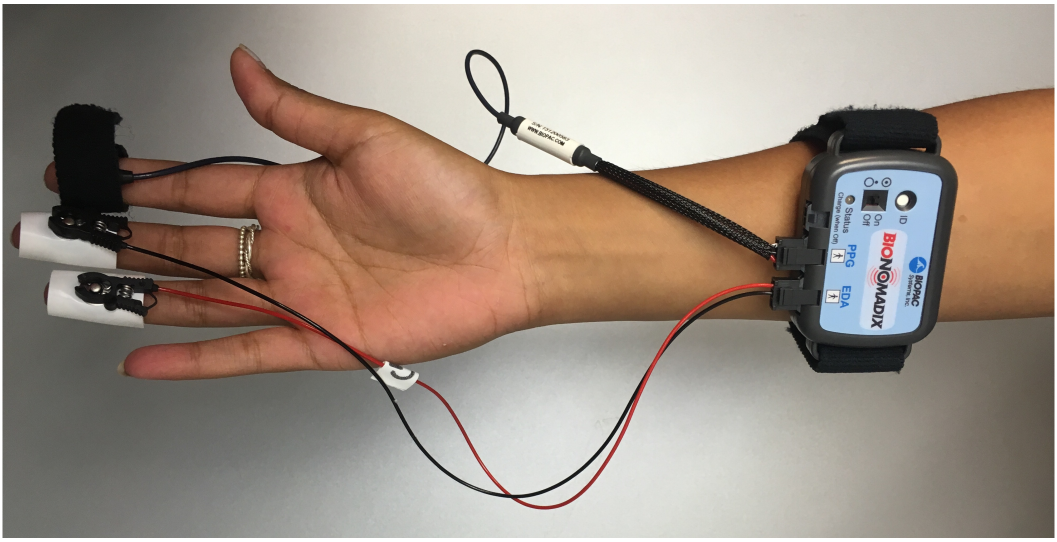


Fig. 3. Physiological data was collected using a BioPac 2-channel BioNomadic module: heart rate (HR) via a fingertip sensor on a participant's index finger, galvanic skin response (GSR) via two electrodes on participants' middle and ring fingers.

4.6 Data Collection and Analysis

We used BioPac AcqKnowledge to calculate HR from the raw PPG data (R-R intervals [bpm]) and to apply a 1Hz low-pass filter. To reduce noise, we then averaged HR and GSR data into 1 second epochs (2,000 samples) and removed all samples in which HR was below 40 beats per minute (bpm) or above 110 bpm. To account for between-participants variability in physiological data, we then calculated per participant z-scores for all epochs. Finally, we averaged z-scores for all three PHASES. ZIPERS includes measures of positive affect (i.e., happiness, friendliness, playfulness, and affection), negative affect (i.e., anger, sadness, avoidance), and attentiveness. We aggregated participants' ZIPERS responses (13 questions) into five categories (anger and aggression, fear arousal, sadness, attentive coping, and positive affect) as suggested by Zuckerman [30] and then further averaged fear arousal, anger and aggression, and sadness into a single negative affect category [25, 27]. For our analysis of physiological data, we used an RM-MANOVA with PHASE, GAME TYPE, and GENDER as factors and HR and GSR as dependent variables. Our rationale was that HR and GSR data might be linearly dependent, and we wanted to avoid the risk of inflating our p-values. We report all multivariate tests for Pillai's trace; all post-hoc tests were adjusted with Bonferroni-correction; where necessary, we used Greenhaus-Geisser correction for non-spherical data. For ZIPERS data, we used three RM-ANOVAs (positive affect, negative affect, and attentiveness) with PHASE, GAME TYPE, and GENDER as factors. All post-hoc tests were adjusted with Bonferroni-correction; where necessary, we used Greenhaus-Geisser correction for non-spherical data.

4.7 Results

All participants played for the entire 5-minute period, and on average picked up 14.5 (SD = 4.3) item packs in-game, used 4.1 speed boosters, and 'fired' 71.1 (SD = 57.7) objects into the environment. These activities correspond on average to one in-game action every 4s. We next present the results of the physiological data and self-reports of stress, separately.

4.7.1 Physiological Data. There were significant main effects of Phase ($F_{4,13} = 33.1, p < .001, \eta_p^2 = .91$) and Gender ($F_{2,15} = 4.3, p < .05, \eta_p^2 = .36$), but not of Game Type ($F_{2,15} = 2.0, p > .1, \eta_p^2 = .21$). We did not find any significant interactions. A summary of collected physiological data is shown in Figure 4a. A post-hoc analysis revealed a significant difference in HR between all three phases: baseline and stressor ($p < .001$), stressor and game ($p < .001$), and baseline and game ($p < .05$) (baseline: $M = -0.20$, stressor: $M = 0.58$, and game: $M = -0.56$). Similarly, post-hoc analysis revealed a significant difference in GSR between baseline and stressor ($p < .001$) as well as baseline and game ($p < .01$) (baseline: $M = -1.02$, stressor: $M = 0.32$, and game: $M = 0.11$).

4.7.2 Self-Reported Data. There was a significant effect of Phase for positive affect (PA) ($F_{2,32} = 26.8, p < .001, \eta_p^2 = .63$), for negative affect (NA) ($F_{1.3,20.7} = 22.6, p < .001, \eta_p^2 = .59$), and attentiveness (Att) ($F_{2,32} = 4.5, p < .05, \eta_p^2 = .22$), but not of Game Type (PA: $F_{1,16} = 0.6, p > .4, \eta_p^2 = .04$, NA: $F_{1,16} = 1.4, p > .2, \eta_p^2 = .08$, and Att: $F_{1,16} = 0.2, p > .6, \eta_p^2 = .01$) nor of Gender (PA: $F_{1,16} = 0.1, p > .8, \eta_p^2 = .00$, NA: $F_{1,16} = 0.0, p > .9, \eta_p^2 = .00$, and att: $F_{1,16} = 0.3, p > .8, \eta_p^2 = .00$). No significant interactions between independent variables were found. A summary of collected physiological data is shown in Figure 4b.

A post-hoc analysis revealed a significant difference in positive affect (PA) and negative affect (NA) between baseline and stressor (PA: $p < .001$; NA: $p < .001$) as well as stressor and game (PA: $p < .001$, NA: $p < .01$) (PA baseline: $M = 2.8$, PA stressor: $M = 1.7$, PA game: $M = 2.9$; NA baseline NA: $M = 1.1$; NA stressor: $M = 2.1$; NA game: $M = 1.2$). There was also a significant difference in attentiveness between baseline and stressor as well as between baseline and game (both $p < .05$) (baseline: $M = 3.1$, stressor: $M = 2.6$; game $M = 2.7$).

5 DISCUSSION AND IMPLICATIONS

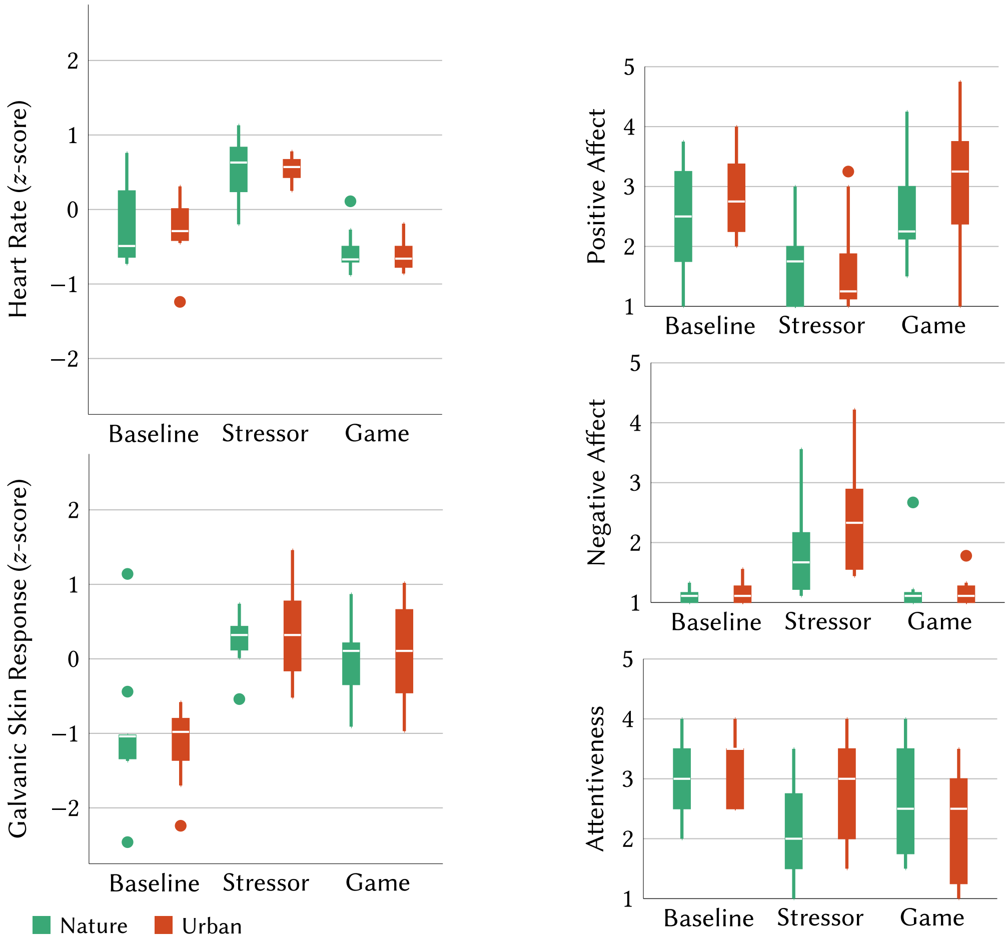
Previous research suggests that the restorative effects of computer-generated nature (via biophilia) can be used to reduce player stress [27]; however, we did not observe this effect in our study. Indeed, our observed effect size shows that Game Type accounted for a small amount of the variance in our analysis (HR $\eta_p^2 = .07$, GSR $\eta_p^2 = .02$). That is, Game Type had little effect on players in our study for most measures, with the possible exception of self-reports of attentiveness. We now propose explanations for these results, and discuss issues they raise for the design of biofeedback games and stress.

5.1 Does in-game nature relieve stress?

Results across all of our dependent variables show an increase in stress between baseline and stressor Phases, followed by a decline during the experimental game. The most immediate conclusion from our study is therefore that stress was reduced during non-violent exploration gameplay, regardless of whether in urban or nature settings. In short, we did *not* observe differences between the two game environments. Several of our game design choices, and differences between our study and those in the literature, can help to explain why we did not observe an effect of biophilia.

First, previous studies (i.e., [27]) identified restorative effects of nature where the environment and in-game interactions were limited to walking around a virtual environment. While players could freely move about on the ground, they could not alter the game environment by firing objects as they could in our game. Further, our game allowed players to 'fly' through the environment, which often meant that they could spend extended periods of time viewing the sky, rather than the (experimentally controlled) game setting. Our results surrounding gameplay suggest that players engaged with these aspects of the game, potentially limiting the overall effect of biophilia.

Second, the restorative effects of computer-generated nature have previously been studied using high-fidelity VR settings, which likely provide a more immersive, realistic experience than our



(a) A summary of heart rate and galvanic skin response data collected during the study. Our analysis revealed a significant increase between baseline and stressor data, and a significant decrease between stressor and game data for both measures.

(b) A summary of Positive Affect, Negative Affect, and Attentiveness self-reported ratings collected during the study. All measures were aggregated across 5-point Likert scale questions from the ZIPERS questionnaire.

Fig. 4. Summary of physiological (Figure 4a) and self-reported (Figure 4b) dependent measures collected during our experiment. For both sets of measures, we observed the anticipated increase in stress following the stressor math test followed by a decrease during gameplay. These trends are indicative of our experimental design working as intended. However, we found no significant differences between the Nature and Urban game settings for any of our measures.

desktop game. While existing results are promising for those exploring VR games, our results suggest that biophilia may not be as pronounced on two-dimensional displays, such as desktop monitors, televisions, or those available on mobile devices.

Third, the level of graphical fidelity may also be important. Previous work has provided high-fidelity replications of nature and urban settings using the Elder Scrolls: Oblivion game engine.

Our decision to implement the game using less photo-realistic graphics was driven by the tools available to us, and the technical requirement to incorporate indirect biofeedback features directly into the game. The research community has identified factors that can influence how an individual perceives a static image as 'natural' (e.g., [26]). Some factors like colour, hue, and saturation are immediately actionable by game designers. However others, like shape, complexity, and contour may not be, and require additional research and support by the HCI community.

Given research from pschology, biophilia *can* be an effective tool against stress. A limitation of this work, and an area for future work to address, is understanding which of the above factors most prominently acted against it in our study.

5.2 What do the observed differences in attentiveness mean?

We found no differences in heart rate, galvanic skin response, positive affect, or negative affect measures across the study; however, a possible interaction effect was observed for self-reports of attentiveness. While differences in attentiveness were not significant, there was a small difference between nature and urban responses to questions about attentiveness.

In particular, attentiveness dropped below baseline levels during the stress-induction task, and remained at those levels during gameplay, revealing an interaction effect between PHASE and GAME TYPE. That is, players in the nature environment experienced improved cognitive function when compared to those in the urban environment. It may be that with higher statistical power, smaller effects like this would be observable—a separate study sufficiently powered for cognitive function would be required to confirm those effects. Nonetheless, it is clear that reproducing the effects of biophilia in realistic gaming contexts introduces some challenges.

A reasonable explanation for these observations is that both the stress-induction task and game session required a player's attention. However, the interaction effect and increased attentiveness scores for the nature scenery suggests that players experienced the improved cognitive function predicted by the biophilia hypothesis. These results are especially noteworthy, given that they are predicted by the biophilia hypothesis [12, 27, 29], and were observed by Valtchanov et al. [25, 27] during their VR study. Our study is therefore a first-step towards showing biophilia-based cognitive benefits in-game, and an important next step is to revisit the differences between our game and those discussed above, to tease out which factors may contribute to the different results we observed.

5.3 Can games for stress use indirect physiological control?

Our work was motivated by the need to develop stress-aware games that do not rely on the use of specialized hardware and direct physiological control. While different GAME TYPES did not appear to influence player stress, our results show an effect on player attentiveness, and the stress-induction task serves as an effective proof-of-concept. Our dependent measures were useful in detecting changes in player state: increases in player HR and GSR were successfully detected during the stress-induction task, followed by decreases during gameplay.

Where existing research has largely focused on direct physiological control, integrated with specialized hardware and game mechanics that directly map to in-game breathing exercises (e.g., [1, 17]), our study demonstrates the potential of indirect physiological control for stress-aware games. For example, our study used a math-based stress-induction task which we believe demonstrates the potential of mapping game mechanics to more subtle stress-awareness techniques such as meditation [13, 19]. This math test could easily be replaced by other in-game events designed to cause stress, as deemed appropriate by a game designer.

Our work contributes an important design and first evaluation of an indirect, stress-aware biofeedback game that runs on a traditional desktop computer. We expect that, for example, use of an off-the-shelf smartwatch or wearable HR monitor could be sufficient to develop mobile games that use similar game mechanics. However, there is a need for more in-depth exploration and iteration over these concepts to understand which game mechanics are most useful, and can evoke an affective response from players.

6 LIMITATIONS & FUTURE WORK

We set out to probe the viability of biophilia to foster stress reduction in video games. While we were not able to replicate results from the psychology literature in this initial study, several of its limitations can inform future work. We now briefly discuss those limitations, and how our work can support future investigations of biophilia in video games.

First, we have already discussed how the fidelity of in-game graphics and audio may have limited opportunities to observe the effect of biophilia. However, other design decisions also may be important to reconsider. We intentionally developed an experimental platform as a game first, with an emphasis on emulating existing games like *Flower*. Future work may instead choose to focus on a player's experience with nature, for instance by adding gameful design elements to a nature-focused experience like the one studied by Valtchanov et al. [25].

Second, we conducted a short-term, laboratory study designed to identify large effects. Results may differ when considered in the context of daily use, over a longer period of time, or when stress is not induced before gameplay. A larger sample size might also be used to identify a smaller effect than we had anticipated. Our work provides some initial data on the effectiveness of biophilia in the context of video games, but additional work is needed to understand any potential mediators of those effects.

To that end, we have provided the full source code for our game and all materials used for this study. We hope by making our game available to the broader research community, that these results can be replicated and extended. Since it was developed in Unity, our game can be easily re-used and modified in future lab-based studies, and easily deployed to a wide range of devices.

7 CONCLUSION

We developed an experimental game that uses indirect physiological controls (e.g., heart rate and galvanic skin response) to conduct an empirical study of the effects of in-game nature on stress and cognitive benefits. Our study was unable to replicate results from psychology surrounding reduced heart rate, positive affect, and negative affect, suggesting a design challenge of incorporating biophilia in the realistic context of a simple game. In presenting these results, our work provides two major contributions to HCI: 1) we developed a proof-of-concept game and made its source code freely available to the community, 2) we demonstrate challenges in replicating biophilia results from psychology in a gaming context and discuss contributing factors to these results.

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