Biofeedback Game Design: Using Direct and Indirect Physiological Control to Enhance Game Interaction

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ABSTRACT
Prior work on physiological game interaction has focused on dynamically adapting games using physiological sensors. In this paper, we propose a classification of direct and indirect physiological sensor input to *augment* traditional game control. To find out which sensors work best for which game mechanics, we conducted a mixed-methods study using different sensor mappings. Our results show participants have a preference for direct physiological control in games. This has two major design implications for physiologically controlled games: (1) Direct physiological sensors should be mapped intuitively to reflect an action in the virtual world; (2) Indirect physiological input is best used as a dramatic device in games to influence features altering the game world.

Author Keywords
Psychophysiology, affective computing, affective gaming, entertainment, physiological input, biofeedback, games.

ACM Classification Keywords
H.5.2 [Information Systems]: User Interfaces; K.8.0 [General]: Games; J.3 [Life and Medical Sciences].

General Terms
Design, Experimentation, Human Factors, Measurement.

INTRODUCTION
Computer games have evolved considerably since the initial days of Pong (Atari, 1972) and Space Invaders (Midway, 1978). Computer graphics techniques have advanced the realism of graphics, rendering, and simulation; artificial intelligence systems have improved the vividness of virtual worlds; and hardware has evolved. New game input devices have seen commercial success, (e.g., Nintendo Wiimote, Microsoft Kinect), which provide natural and realistic interaction and experiences. Throughout this evolution of digital games, researchers and developers have also been exploring physiologically controlled game interfaces.

Since the early 1980s, researchers have been exploring physiological input in biofeedback games for stress reduction (see *Related Work*). In the last decade, there has been increased commercial interest in using physiological input in digital games, not only for biofeedback training, but also to enhance immersion and engagement for players. Yet even with all of the technical advances surrounding physiological game input, and all of the ludological advances surrounding game design, physiological input in gameplay is still limited mainly to relaxation games using indirectly controlled physiological signals, such as heart rate (HR), galvanic skin response (GSR), or brain waves as a replacement for the game controller.

The indirectly controlled forms of physiological input previously used, such as GSR, are excellent at helping users train themselves to relax precisely because they are indirectly controlled. For example, GSR – which measures skin conductance as a proxy for psychological arousal – is a commonly used physiological input in biofeedback applications that is not directly controlled by the user. To raise or lower their GSR, players must try and relax or excite themselves, which is good for training people to relax, but limiting in terms of gameplay. To date, there has been very little work on directly controlled physiological input. In this paper, we define direct physiological control as measures that a user can manipulate and control directly (e.g., muscle flexion, eye gaze). In contrast, indirect physiological control refers to measures that cannot be explicitly influenced and changes as an indirect result of other direct bodily activation (e.g., HR, GSR).

Replacing traditional controllers with physiological sensors has been a good approach for initial testing of physiological game input. However, traditional game controllers are very good for certain game-related interaction tasks such as pointing and clicking. In addition, traditional controls may be superior in terms of performance, may be preferred by users, or may produce a better user experience (UX).

To make physiological input more desirable for the mainstream computer and video games market, we need to answer two main questions:

1. How do users respond when physiological sensors are used to augment rather than replace game controllers?

2. Which types of physiological sensors (indirect versus direct) work best for which in-game tasks?

In addition, we were interested in exploring how we could effectively integrate gaze location as a game input (using a monitor-based eye tracker) without negatively affecting the game through unintentional activation of game events from users looking at the display simply to play.

To investigate our research questions, we designed a side-scrolling platform shooter game that uses a traditional game controller as primary input. We augmented this traditional interaction with physiological sensors. Physiological input was considered to be either directly or indirectly controlled by the user although we acknowledge that this distinction can be fuzzy and dynamic in practice. Directly-controlled sensors included muscle flexion, breathing patterns, and temperature change (through blowing hot air). Indirectly-controlled sensors included HR and GSR. Gaze location was also integrated to augment controller input. Using our game, we conducted a study where participants played with three combinations of physiological and traditional input.

Through a combination of participant observation and survey data, we discovered: that players enjoy using physiological input; that they prefer directly-controlled physiological input; that indirectly-controlled input is best used for altering background variables; and that gaze input can be effectively integrated into game play. As game design and development continues to press for more novel and thrilling experiences for players, our work can help by informing the design of physiologically controlled games.

RELATED WORK

Prior related work on physiological game interaction has focused on adapting games to a user's physiological state [4] and on developing emotional models to understand the psychophysiological input from a user [9].

Physiological control and adaptive gameplay

Recent research in human-computer interaction (HCI) has explored the potential of physiological computing to tailor user experience to players' cognitive, motivational, and emotional responses (see [3] for an overview). Computer games are an excellent application area in which to explore the benefits and drawbacks of physiological HCI as they are a low-risk domain – if a game misinterprets a physiological signal or adapts incorrectly, there is less fallout than if a critical command-and-control system did the same.

Industry manufacturers have investigated physiologically-controlled biofeedback techniques for gaming since the late 1970s and early 1980s. For example, Canadian biofeedback equipment manufacturer Thought Technology investigated physiological input in their CalmPute[1] software packaged with a modified GSR2 sensor (i.e., an Apple II mouse with GSR electrodes) and the racing game CalmPrix in 1984.

Other attempts at integrating biofeedback into gaming systems included the unreleased Atari Mindlink in 1983, The Journey to Wild Divine in 2001, and the Nintendo 64 bio-sensor included in the Japanese version of Tetris 64 in 1998. This electrocardiographic (EKG) sensor measured users' HR and adapted game speed. Eventually, it was taken off the market, but Nintendo recently revisited this idea by announcing its Wii Vitality sensor, a pulse oximeter connected to the Wiimote designed to be used in relaxation games. Similarly, Ubisoft has announced a similar product for 2011, called Innergy, another pulse oximeter, which was demonstrated with a stress relaxation game[2].

Additionally, many hardware manufacturers are aiming at providing cheap input solutions that use brain signals to interact with a computer, such as Emotiv EPOC, Neurosky Mindset, or OCZ Neural Impulse Actuator (NIA).

Game Design for Physiological Game Interaction

Physiological game interaction is generally called *affective gaming* by the academic community. A definition of affective gaming was proposed by Gilleade et al. [5] as an activity where "the player's current emotional state is used to manipulate gameplay." Thus, an affective gaming system should sense a player's emotion and arousal, and loop this information back into the system. However, the simple replacement of user controls with biofeedback information does not make a game effective. A popular example for this is the unreleased *Bionic Breakthrough* game (a clone of the *Breakout* game) for the Atari Mindlink, which used forehead EMG sensors to replace the conventional joystick input device. Mindlink players frequently reported headaches as a result of moving their eyebrows in an attempt to control the game.

Part of the reason why game publishers are targeting biofeedback control as a replacement of traditional input devices is that learning to control biofeedback consciously or subconsciously can be challenging and fun for some players. Games are rule-based formal interactive systems geared toward teaching a player how to interact with the simulated world and its entities. Part of the fun of gaming is figuring out these interactions. However, not every game design and mechanic can (or should be) supported through physiological interaction (e.g., using brain signals for quick-reaction events). An alternative approach to affective gaming is to adapt games based on physiological input [4].

Adaptive affective games [4, 5] change either technical parameters or user preferences based on recordable user behavior such as error-rates, button pressure, controller movement, or physiological responses. It is important to correctly distinguish affective states of the user, such as at-game or in-game frustration [4]. Physical failures, (e.g., inability to execute a command), will result in at-game frus-

[1] http://www.thoughttechnology.com/thewall2.htm

[2] http://www.physiologicalcomputing.net/?p=389

tration and mental failures (e.g., not recognizing game objectives), will result in in-game frustration. Physiologically adaptive games must propagate affective feedback [1]. Replacing conventional execution of input commands is regarded by Gilleade et al. [5] as "straight-forward biofeedback."

Direct or Indirect Physiological Control

Most examples of prior research on physiologically-controlled games use indirect control – that is, the game uses a player's affective state without giving players the option of controlling it directly. For example, consider physiological games such as the relax-to-win racing game [1] or the Brainball game [6]. In these games, winning conditions are controlled by a player's ability to relax – in the former by allowing a dragon to race faster, and in the latter by rolling a physical ball across a table towards an opponent. These games demonstrate how physiological input is not directly controlled, but mediated by some other player interaction, such as meditation or deep breathing. This is different from "implicit commands" or indirectly controlled brain-computer interfaces (BCIs). Zander et al. [15] introduced this concept of directly and indirectly controlled BCIs, where indirect control refers to modulation of brain activity in response to external stimulation.

Players can get satisfaction out of learning to control their biofeedback through indirect physiological control. Playing the game AlphaWoW, in which players trigger their shapeshifting ability using electroencephalography (EEG) [11], provides players with the satisfaction of learning to control their brainwaves. In all of these cases, biofeedback is trained competitively in order to gain advantage and win the game, whereas an alternative approach would aim to improve player experience rather than chances of winning. For example, Dekker et al. developed a game modification using the Source SDK and Half-Life 2, GSR and HR were used to control game shader graphics, screen shaking, and enemy spawn points (i.e., number of locations in which enemies are put into the game world) [2].

Although most games have used indirectly-controlled physiological sensors, there is an unexplored opportunity for direct physiological control to map directly to specific game mechanics, or to enhance the player experience.

Awareness of Control

In all previous examples, players were aware that their physiological input controlled some aspect of the game or experience. Kuikanniemi et al. [8] explored the difference between players that are aware of and not aware of their biofeedback when playing a first-person shooter (FPS) game and referred to this as implicit and explicit biofeedback. The biofeedback modulated player-character-related game mechanics including walking and turning speed, aiming direction, recoil amount, and firing rate. The results show that people enjoyed the explicit biofeedback conditions more and their conscious control of the respiratory sensor led to a better game experience.

Physiological studies of gameplay experience

Instead of being used as input to a game, physiological sensors such as GSR, cardiovascular measures, and EMG, have been used to objectively quantify user emotion during interactions with gaming systems [9]. An overview of game research using psychophysiological measures [7] notes two general approaches having emerged from previous work: Studying phasic psychophysiological responses to game events [12] and research studies of tonic responses to variations in game design dubbed affective ludology [10].

A Primer of Used Physiological Measures

For a synopsis of physiological measures in games, see [7].

Gaze Interaction. Tracking the location of a user's gaze (GAZE) supports analysis of visual attention. Gaze-related data includes the position and movement of gaze on the screen, and pupil dilation. Eye trackers, which can be integrated into a computer monitor, record patterns and distributions of gaze fixations and saccadic eye motion. Gaze input is considered as direct physiological control.

Electromyography (EMG) describes the measurement of electrical activation of muscle tissue. While facial EMG is used in emotion detection, EMG has also been used to sense muscle activation as a more direct form of input [13].

Electrodermal activity (EDA, also: skin-conductance level or SCL) or *galvanic skin response* (GSR) is a common psychophysiological measurement with easy application. EDA is regulated by production of sweat in the eccrine glands, where increased activity is associated with psychological arousal. GSR is an indirect form of input.

Electrocardiography (EKG) is the sensing of heart activity through physiological sensors on the body. It is hard to control directly, but hyperventilation or increased physical activity often results in an increased HR. HR is an indirect input mechanism for a game.

A *respiration (RESP) sensor* is stretched across an individual's chest to measure breathing rate and volume. Strain sensors can be directly controlled.

A *temperature sensor* (TEMP) is directly controlled in our experiment, through blowing hot air on it; TEMP could also be an indirect measure if placed on the surface of the skin.

A GAMING SYSTEM FOR AFFECTIVE INPUT

To investigate direct and indirect physiological control, we developed a single-player 2D side-scrolling shooter game that used standard controller mappings in Xbox360 shooter games. Physiological input was controlled separately.

Building a Game for Physiological Input

The single-player 2D side-scrolling shooter, features many obstacles, including increasingly difficult enemies, moving platforms, and a final boss. Players can save their progress by reaching checkpoints. If a player's character dies after that, they are returned to the most recent checkpoint that they reached and given half their health back. To encourage players to interact with enemies and have a more challenging experience, a checkpoint is only registered if a player has killed all enemies leading up to that checkpoint.

Game Mechanics under Variable Control Schemes

To explore different variations of traditional game control and physiological input, we implemented five game mechanics that could be controlled using different physiological sensors. We describe the game mechanics here and present the control mappings in the study section.

Enemy Target Size

Because performance in 2D shooting games is primarily about the accuracy of aiming at targets, we manipulated the enemy target size through physiological control. Rather than increasing the size of the entire sprite, we displayed a shadow of the enemy that grew (See Figure 1). Pilot testing showed that increasing the enemy size directly was counter-intuitive, since easier-to-hit enemies looked more threatening. Hitting an enemy shadow counted as a hit.

Figure 1. Target enemies increase in size.

Flamethrower weapon: Flame length

The game featured three weapons: a regular projectile weapon, an ice projectile weapon, and a flamethrower weapon with unlimited ammunition. To avoid deadlocks in a game when a player runs out of ammunition, many games feature a fallback weapon (e.g., the crowbar in Half-Life 2). We made our fallback weapon more interesting by placing the flame length under variable control (see Figure 2).

Figure 2. Flamethrower weapon: flame length was increased

Speed and jump height

Many side-scrolling platform games employ power ups that increase avatar speed and jump height temporarily. We linked this to a single variable which was controlled using physiological input.

Final boss battle: weather conditions and boss speed

At the end of our test game level, the player enters an icy area, eventually leading to the final game boss. Gentle falling snow was implemented throughout this area. In heavy snowfall (see Figure 3), it was more difficult for players to see platforms and enemies, thus affecting the accuracy of their shots. The rate of snowfall was under variable control. In addition, the boss behavior was linked to the snowfall rate – with lighter snowfall, the boss would get warmer, would start to steam (a visual effect only) and would also move more slowly (thus being easier to target).

Figure 3. Behavior of the final boss (a yeti) and the snow effect were controlled together in a variable.

Eye tracker feature: Medusa's gaze

We implemented one game mechanic under physiological control that was designed specifically to use gaze control. Gaze control can be difficult to implement well because players should not inadvertently activate gaze-controlled features simply by looking around the display.

Figure 4. The Medusa's Gaze feature in the game.

We used gaze control as a power-up that temporarily froze enemies and moving platforms, called Medusa's Gaze. To acquire this power-up, users needed to pick up a special item, which would then display a blue circle at the location of their gaze (see Figure 4). Looking at enemies and moving platforms would freeze them temporarily. Frozen enemies and platforms turned green and then transitioned back to their normal color, indicating the amount of time left in their frozen state. To keep the game balanced and avoid eyestrain, Medusa's Gaze was only available for 20 seconds after picking up the special item.

Game Implementation and Architecture

To integrate physiological sensors, we wrote a custom C# library called SensorLib, which is a multi-threaded library written in C# that provides an interface for external third-party sensors. It handles the connection to the sensors, the data-buffering, digital signal processing, and offers the data through a high-level .NET interface. It aggregates third party SDKs into a single interface so programmers can create sensor-dependent applications.

Sensor	SDK	Measure	Processing
Audio	DirectX 10	Amplitude of sound waves.	None
Gaze	TobiiSDK	Tracks where user is looking on computer screen.	None
BVP	TTLAPI	Blood flow through a finger.	Downsampled by 64
GSR		Skin conductance	Downsampled by 64
EKG		Senses heart beats.	Heartbeat Detection
EMG		Contraction of muscles.	Smoothing; Normalized
RESP		Amount of strain on a chest strap.	Downsampled by 64; Normalized
TEMP		Temperature change.	Downsampled by 64; Normalized
Raw		Receives data from any TTL sensor with no processing.	None

Table 1. Digital signal processing in SensorLib.

Table 1 shows the SDKs used by each sensor in SensorLib and the digital signal processing each sensor does. All digital filters are Chebyshev type II filters with lower filter length and no ripple in the passband. The game architecture, implemented in C# using XNA and SensorLib is shown in Figure 5.

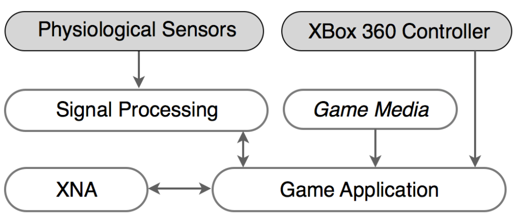

Figure 5. Game Architecture

STUDY

To evaluate the relative appeal of direct and indirect physiological control, participants played three versions of a game, two augmented with physiological input and one control condition. The sensor mappings and their respective thresholds for each game mechanic were developed using iterative prototype testing for five months, gathering feedback from more than 50 individuals before this study.

Game Conditions

Two of the game conditions mapped two direct and two indirect sensors to the four game mechanics under variable control described previously, while the third condition used no physiological input. Although it would have been useful to include only direct physiological input in one condition and indirect in the other, this was not possible as the indirect sensors are difficult to control independently.

The physiological sensors used as direct control were respiration, EMG on the leg, and temperature. The indirectly-controlled sensors included GSR and EKG. Mappings of the sensors to the game mechanics for each condition are shown in Table 2.

Mechanic	Cond. 1	Cond. 2
Target size	RESP	GSR
Speed/jump	EKG	EMG
Weather/boss	TEMP	EKG
Flamethrower	GSR	RESP
Avatar control	Gamepad	Gamepad
Medusa's Gaze	Gaze	Gaze

Table 2. Game conditions. Direct sensors are shaded in dark blue, and indirect in light blue. Gaze tracking is a special case of direct sensor control; the gamepad was used in all cases.

Medusa's gaze was available in both physiological conditions, but not in the control condition. The third control condition used only the gamepad for avatar control and did not make use of the game mechanics implemented for the physiological sensors.

Experimental Procedure

The study used a three-condition (2 physiological variations, 1 control with gamepad only) within-subjects design. All participants played all three conditions, which were presented using a randomized ordering. Each participant played through an initial training level to get accustomed to the game controls before the trial started. EMG, RESP, and gaze tracking were recalibrated before each game condition. After providing informed consent, the participants completed a demographics questionnaire, which also asked questions about their gameplay experience. Participants were then fitted with the physiological sensors and briefed on how to control them both directly and indirectly. For example, to increase their GSR, players were advised to laugh, bite their lip, flick themselves, or think about exciting things[3], whereas they were told to flex their foot to increase their EMG response. Participants played each game condition for 10 minutes or until they completed the level (10-35 min.), a common playing time in game research [7]. After each game, players completed a survey, rating their gameplay experience using game-specific questions. Following completion of all conditions, players completed a final survey soliciting their opinions of physiological control in video games.

Apparatus

The game was played on a Dell computer running Windows XP. The monitor was a 24" TFT display running at a resolution of 1080p (1920x1200), with an integrated Tobii T60 XL eyetracker running at 60 Hz (see Figure 6). Physiological data was collected using the Flexcomp Infinity hardware by Thought Technology, and integrated into the game using our custom sensor library SensorLib, described briefly in the previous section.

[3] While it might be argued that biting one's lip is a somewhat direct physiological influence, the directness of the action here is the biting, but the resulting change in GSR is still indirect. For example, in contrast measuring lip-biting pressure would be a direct measure.

Figure 6. A participant playing the game using the physiological sensors and the eye tracker

Participants

Ten participants (7 male), aged 21 to 40 (M=25.8, SD=5.5) completed the study. Six of the participants played video games at least monthly; the others played only a few times a year. Participants were not very experienced with side-scrolling shooter games, indicating an average expertise of 2.5 on a scale of 1 (novice) to 5 (expert). When asked about their experience with novel forms of input to games, participants primarily reported having used the Nintendo DS and Wii, with fewer participants having experience with the WiiFit balance board and the Rock Band controllers.

RESULTS

Ratings data were analyzed with non-parametric techniques, while open-ended survey responses were clustered into overarching themes. We present results on fun and novelty ratings, followed by sensor preference.

Physiological Control: Fun Ratings

We asked players to rate their fun in each condition on a scale of 1 (not much fun) to 5 (very fun). A Friedman test for 3-related samples showed differences in players' fun ratings depending on game condition (χ^2_2=7.3, p=.026). Pairwise Wilcoxon Signed Ranks tests showed that players found both physiological control conditions to be more fun than the no physiological control condition (both Z=2.1, both p=.033, see Figure 7), but no difference between the physiological control conditions was found (Z=0, p=1.0).

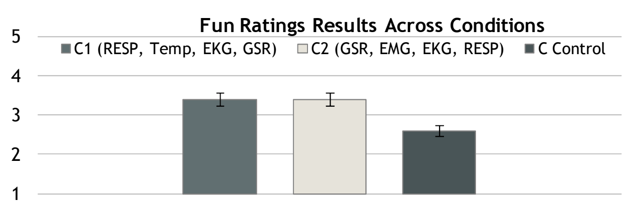

Figure 7. Mean (CI:95%) fun rating (higher is more fun).

When asked at the end of the experiment whether they preferred to play with or without sensors, 9 of 10 players preferred to use physiological control.

The players who enjoyed physiological control commented that having to use more than one input device *"made for a very immersive game, out of what is basically just a very simple platform shooter." (P7, Male)*. In line with this statement, *"the sensors added a new dimension to the game, and gave a greater sense of involvement." (P2, Female).* This involvement and enjoyment seemed to be especially strong when *"more parts of the body are involved in the game." (P1, Male)*

With the increase of immersion came also a greater sense of challenge, a feeling of greater *"variation, and more enjoyment while playing because there are always new skills to improve on." (P4, Male)*

The controls were usually perceived as best when they matched a natural input, such as thawing snow with temperature increase, freezing enemies by staring at them, or running faster by flexing the leg muscle.

"Jumping higher and running faster by flexing the leg is so intuitive. I'm sure many do it instinctively anyway." (P5, Male)

The one dissenting participant commented that the *"sensors [made the] game complicated. (P3, Female)"*.

Novelty of Physiological Control

We asked participants how they would rate the novelty of physiological control on a scale from 1 (not novel) to 5 (extremely novel). Participants agreed that the physiological control was novel (M=4.2, SD=0.79). To better understand their view of the novelty of physiological control, we asked if there was something special about using their body to control the game, or whether it was more like a new type of game controller.

"At times it felt like a new type of controller that I had to actively think about, but other times it felt like more than that—almost that I was physically part of the game." (P2, Female)

Some players mentioned that there was a learning curve involved in learning to use the sensor, but once they learned to use it, the experience was more rewarding. Additionally, players mentioned that they were more aware of some sensors than others and that some felt more like controllers:

"The breathing sensor and GSR sensor felt like controllers though, because I was very aware they were attached to me. The EKG and EMG were completely unnoticeable and fun to use…" (P4, Male)

"[The] muscle and breathing sensors were simple enough that they were practically like a new button on the controller for me, but very awesome ones since rather than tapping a button, it was an instinctive action." (P7, Male)

Sensor Preference

After each game, we asked participants which sensor they preferred to all others. Over the course of the two games, 12/20 votes were for gaze input, 5 were for RESP, and one for each of TEMP, EMG and GSR. Although these choices are also affected by controlled game mechanic, only 1/20 votes was for an indirect sensor. We also asked players to rate their enjoyment of the five game mechanics explored.

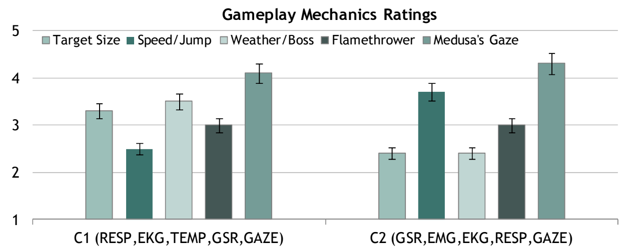

Figure 8. Game mechanic ratings (CI:95%) for each condition.

Figure 8 shows how participants rated the direct controls higher than the indirect controls for target size increases, speed/jumps, and weather/boss speed, but not for the flamethrower. In the post-game questionnaire, we asked participants about their preferred sensors (see Figure 9).

Figure 9. Player choices for physiological control by game mechanic. Dark wedges are direct sensors, light are indirect.

For target size increases and flamethrower length, players preferred RESP to GSR. For speed and jump height they preferred EMG to EKG. For controlling the weather and speed of the yeti, players preferred TEMP to EKG.

As shown in Figure 9, for each game mechanic more participants preferred the direct control than the indirect control. We also asked players which they would choose if they could only play with one combination of RESP/EMG/TEMP (direct) or EKG/GSR (indirect). Eight of the ten participants chose the direct sensors combination. We present participant comments for each of the physiological controls individually.

Opinions about GSR Sensor (Indirect)

Many participants reported problems with controlling the GSR sensors, because it only responded indirectly. Some perceived the indirect control as unnoticeable or "not working." Players used different strategies for trying to control GSR, and some of them not pleasant:

"I liked that it was always a challenge to control just with my thoughts […] and forced me to use a part of my brain I wouldn't normally use in a video game." (P4, Male)

"I disliked the fact that one of the only ways that I found I was able to use the GSR was by biting my lip which isn't actually all that fun after it starts hurting." (P8, Male)

Another issue for participants was the location of the GSR sensor on the pinkie and ring finger of the left hand during controller-based gameplay, which one participant found *"uncomfortable and awkward." (P4, Male)*

"I didn't like that it got in the way a bit with holding the controller. After I got used to it I was fine though." (P9, Male)

One participant also mentioned the close relationship of the control of GSR to control of EKG, saying he was *"not even sure what this one controlled in the second game." (P4, Male)*

Opinions about the EKG Sensor (Indirect)

Similar to participant response to the other indirect sensor (GSR), participants felt that EKG was hard to control and therefore was not perceived as working accurately.

"[…] I couldn't control as instantly as the others—the effect from it tended to last over longer periods of time." (P2, Female)

Players also thought that because EKG seemed slow to respond, it might be *"better suited to changing the game context than what the character is doing." (P5, Male)*

Opinions about the EMG Sensor (Direct)

Comments on the direct control using EMG were split between positive and negative experiences. Some noted that they were *"wishing it was a bit more sensitive or easier to trigger [the sensor by flexing the muscles]." (P2, Female)*, while others felt that it was easy to use:

"It was fairly easy to use. It was effective and worked." (P8, Male)

Players generally liked the mappings of the EMG sensor:

"I really liked this one. Flexing your leg to move faster or jump higher? Definitely cool." (P7, Male)

"[…] having this sensor tied to jumping/speed felt natural" (P2, Female)

It was also noted that the muscle could become strained if the sensor is used continuously for input, but some players liked the idea of a physical workout by playing a video game.

Opinions about the RESP Sensor (Direct)

This sensor was praised for its very easy controllability and the immediate feedback it provided to participants' actions.

"It was neat to see the immediate reaction from my body to the game." (P10, Female)

"This was also cool, as it was very easy to activate, didn't really have to put much thought into it." (P7, Male)

Due to its responsive nature, participants also noted that they felt *"it got you more into the game." (P8, Male)*

"[It] felt very natural, particularly when it was tied to target size in the game […]. It's one I felt I could control to a fine degree." (P2, Female).

Opinions about the TEMP Sensor (Direct)

This sensor was initially experienced as easy-to-use; however, using it over longer periods of time became tedious, since the participants had to remember to keep on blowing on it.

"It was easy to use for short periods of time but hard to remember to breathe deep into the sensor […]." (P8, Male)

"It was easy to control but the effect didn't last long in the game so I [had] to constantly breathe out […]." (P6, Male)

The natural mapping to control the snow in the environment by the heat of the sensor was perceived positively although some players noted the limited applicability in games.

"I like […] when it was tied to weather […], because it felt like a natural thing to do. […]" (P2, Female)

"I'm not sure how many games you could actually include it in […] Limited applicability would be the only thing I dislike about it." (P7, Male)

One participant found that controlling TEMP would cross activate HR, because she was breathing rapidly.

"*Breathing rapidly to increase temperature also brought my heart rate up." (P2, Female)*

Opinions about the Gaze Sensor (Direct)

Gaze was chosen by many players as their favorite input control, because many found that it was easy to control and worked well.

"Now that was just cool […] I liked being able to roast one frozen combatant while immobilizing another." (P5, Male)

"It worked remarkably well and was easy to control. I found the effect useful in the game." (P6, Male)

Some noted that it became inaccurate if posture was changed rapidly during gaming. Another participant noted that it obscured her intended gameplay at some parts.

"I loved the eye tracking input. It was cool, and unique! It worked pretty well, but if I changed my posture it didn't work as well." (P9, Male)

"I found it frustrating when you would look at a platform intending to jump on it and end up freezing it." (P2, Female)

Additional comments from participants

Many participants noted that direct control was their preferred way of controlling the game mechanics as they felt it provided direct feedback to them and made the game more responsive. The eye tracker was a favorite of many, because it did not require the application of a sensor on the body of the participant, making it incredibly easy to use.

The idea of having multiple modes of input in an extended (or augmented) controller struck a chord with many players.

"I like the idea of using multiple physiological inputs. Distributing the functions around the body is intuitive in some cases." (P5, Male)

"[It] basically boils down to an "extended controller" where the buttons are not buttons but other actions, similar to waving a Wii remote." (P7, Male)

DISCUSSION

We investigated the use of direct and indirect physiological control in games. Our main results were:

- The physiological augmentation of game controls provided a more fun experience than using only a traditional control scheme for game interaction.
- Physiological control was a fun game mechanic in itself because it provided enjoyment by adding an additional challenging dimension to gameplay.
- Participants preferred physiological sensors that were directly controlled because of the visible responsiveness.
- Physiological controls worked most effectively and were most enjoyable when they were appropriately mapped to game mechanics.
- Indirect control was perceived as slow and inaccurate, and was not preferred; however, users recognized its potential to show passive reactions of the game world (e.g., atmospheric changes) or as a dramatic device.

We explore these main findings further and discuss the relative advantages of direct and indirect control, the relevance of appropriate mappings, and how to best integrate physiological sensors into traditional control schemes. In addition, we address the limitations of our work and present future research opportunities.

Indirect versus Direct Physiological Control in Games

It is not surprising that players preferred direct physiological control, since the benefits of directly controlled physiological input are compatible with the nature of many action games requiring a quick reaction to a presented stimulus. The feeling of control over the game world is an important factor in gameplay enjoyment. Direct physiological input was easier for players to activate and provided better and instantaneous feedback, which was likely perceived as more or better playing control.

Indirect physiological control does not have a 1:1 mapping of player action and game reaction and is therefore not equally suited as game input for fast-paced action games. This was made evident in participants' comments noting the slow response of indirect physiological sensors to their actions. However, this disadvantage could be turned into a strength if indirect physiological control was used to affect slow-changing environmental variables of the game that could allow these sensors to function as a dramatic device. This would be in line with prior work on affective feedback games [1,5], which intelligently respond to players' physiological states, or games that dynamically adjust to provide player satisfaction [14]. Our work suggests that indirect control may be best used for peripheral environmental variables (i.e., features altering the game world to change player experience) or as a dramatic or aesthetic or artistic device that does not directly influence game mechanics.

Another important game enjoyment factor related to the feeling of control is the feeling of action accomplishment. The disproportionally positive feedback for a simple action is one of the reward mechanics used in games. For example, pressing the right combination of buttons (a fairly simple task) could result in a special action that moves a player's avatar in unrealistic and exciting ways, such as flying or jumping over a building. The greater feeling of control that resulted from direct physiological input could have enhanced a player's sense of accomplishment. In addition, since the in-game actions using direct sensors were triggered using the body as input (e.g., flexing leg) rather than the traditional controller (e.g., pressing button), the sense of accomplishment may have been heightened and made the experience more immediate and personal.

The distinction between direct and indirect physiological control may change with increased use. One could argue that initially indirect measures become direct with exposure over time since a user's intuitive ability to control their physiological response would increase. This is the basic premise of biofeedback training, and presents interesting questions and challenges for physiological game designers over the long term. As users learn to intentionally manipulate indirect physiological measures, it opens the door to physiological cheats and exploits. For example, in Tokimeki Memorial Oshiete Your Heart (Konami, 1997) players cheated by going for a jog before playing to increase their body sweat and the resulting success of a virtual animated date [4].

Relevance of Control to Game Context

Many participants mentioned that they most enjoyed using the sensors when they felt their physiological actions mapped naturally to the in-game reaction. For example, when breathing out triggered a longer flame of the flamethrower, blowing hot air on the temperature sensor decreased the amount of snow, or flexing the leg muscle increased speed and jump height. Natural mappings create an intuitive method for interacting with the game world.

For example, in some game contexts, it might be difficult to find natural mappings, or multiple mappings may exist. Our participants show this in their ratings and rankings of RESP versus GSR for the flamethrower length. When asked directly, participants preferred the RESP to GSR input, but the rating of the game mechanic was equal across conditions, indicating that both sensors were suitable for controlling the game mechanic. Natural mappings may present more intuitive game interfaces, but also limit the flexibility and generality of the sensors for game control. This tension between innovating new uses of physiological controls and sticking with standard mappings will present future challenges for physiological game designers.

Replacing or Augmenting Traditional Game Controllers

Most previous work has focused on replacing direct control with a physiological sensor [1], and this trend is still evident in the game industry with the announcement of the Wii Vitality and the Ubisoft Innergy. Physiological input—whether direct or indirect—will not be suitable for all tasks. For example, playing a button-mashing game with brain signals does not seem like a good design choice. In our approach, we focus on augmenting traditional input devices with physiological information to reward players with a richer experience. In addition, we feel that augmenting traditional game controllers with physiological input will allow for a gentle learning curve as players become used to physiological control. Having the possibility to enter the game world using a common interaction modality such as the game controller would allow players to feel more competent in the game and would facilitate trying out the "new powers" they gain through physiological control.

Integrating Physiological Sensing into Controllers

Augmenting traditional controllers with physiological input will be a challenge for industrial designers. In addition, cooperation is needed between the hardware manufacturers who make the devices and the game developers, who include physiological input in their game controllers. The recent collaboration between Ubisoft and MindMedia, a Dutch biofeedback company, for the development of Innergy demonstrates that this can successfully be done. PC games can draw upon the availability of physiological input devices in the consumer market, such as the Lightstone from The Journey to Wild Divine, the Neurosky Mindset, and the Emotiv EPOC, which all use indirect physiological input. Direct sensors, such as GAZE, RESP, and EMG were preferred by our participants, but there are currently no consumer-level sensors available. Both RESP and EMG use standard components and would be inexpensive to produce.

Game and hardware designers must also consider the willingness of players to adopt wearable technology. In our work, we have found that players are very comfortable wearing sensors if they perceive the added value in gameplay. The broad consumer acceptance of fitness games that require wearing sensors also suggests that this is not an issue for players. Our participants mentioned they were fully aware of using muscle activation as control in the game and some entertained the thought that this might be a great way to improve their fitness. Because the combination of several sensors was mentioned as a positive feature by many participants, there are great opportunities to integrate physiological sensors (e.g., EMG) with fitness game input.

Limitations

Our study shows support for augmenting game control with direct and indirect physiological input; however, it was a preliminary investigation and therefore is limited in its generalizability. First, we explored a small number of specific game mechanics in a certain genre. Choosing different gameplay mechanics, interaction mappings, or game genres would likely result in different player experiences. Second, our participants played for a short time; as with any new technology, it will be interesting to see how user experience changes over long-term repeated use. Third, our participants were mostly casual game players. To fully explore the range of possibilities with physiological input, it will be important to involve players of all experience levels into the game design process. And finally, as this is an initial explorative study, we must acknowledge both the role of novelty in our results and the small number of participants. Large-scale, long-term deployment to address these issues will be feasible after additional small-scale targeted studies.

FUTURE WORK

Our initial investigation into direct and indirect physiological control opens many future research opportunities. One of our participants noted that triggering one physiological control (i.e., breathing warm air on the temperature sensor) co-activated another physiological response (i.e., increasing HR). As many indirect physiological sensors are triggered as a result of a more direct action, using this co-activation as a game mechanic has great potential. For example, for fitness games, an objective could be to flex a muscle a certain amount of time, but only within a certain arousal threshold to make sure the exercise is being performed within a healthy range. This would combine the power of using direct physiological control and indirectly influencing the game state and come in the appealing marketing package of a fitness game fostering exercise and mobility.

Our players also mentioned that physiological sensors could be integrated into an extended version of a controller that uses multiple physiological inputs simultaneously. The co-activation of multiple direct physiological sensors could provide new gameplay challenges such as using gaze to unlock a door and then slowly breathing out to push it open.

CONCLUSION

As we create new forms of input, we need to consider whether these will replace or augment well-established methods of interaction. Traditional interaction forms may be superior in terms of performance, may be preferred by users, or may produce a better experience, while new forms may provide additional capabilities or be more immersive. We propose *augmenting* traditional controller input with physiological input. Therefore, we investigated this combination in an exploratory study, and have two main results for designing a game for physiological input: first, *direct* physiological sensors should be mapped naturally to *reflect an action* in the virtual world; and second, *indirect* physiological control is best used as a *dramatic device* in games to influence environmental variables.

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