Serious Game to self-regulate Heart Rate Variability as a management technique of arousal level through cardiorespiratory biofeedback.

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Abstract

Background: Heart rate variability biofeedback (HRVB) is an established intervention to increase heart rate variability (HRV) in the clinical context. With this technique, participants become aware of their HRV through real-time feedback and can self-regulate it.

Objective: The aim of the study is double: first, to develop a serious game that applies the technique of HRVB to teach participants to self-regulate HRV, and second, to test the app with participants in a pilot study.

Methods: For the study, the HRVB App developed was called FitLab Game. To go through the game, users must move a main character up and down the screen, avoiding colliding with obstacles. The wavelength that users must follow to avoid these obstacles is based on the user's basal heart rate and changes in instantaneous heart rate (iHR). To test the FitLab Game, a total of 16 participants (23 ± 0.69 years) were divided into a control (n= 8) and experimental group (n=8). A 2x2 factorial design in a single session was carried out, participants in the experimental condition were trained in breathing techniques.

Results: The change in frequency and time domain parameters of HRV, and the game's performance features were evaluated. Significant changes in RR mean and RMSSD were found between groups (p = .020 and p = .037, respectively). No significant changes were found regarding performance, but both groups showed a tendency to increase the evaluated outcomes from baseline to test condition.

Conclusions: The results can indicate that playing different screens leads to improvement of the game's final score by repeated training. The tendency of changes in HRV may reflect a higher activation of mental system of attention and control in the experimental versus the control groups. In this line, learning simple and voluntary strategies through the developed serious game can aid to improve self-control and arousal management.
FitLab Game appears as a promising serious game due to its easy functionality, high engagement and enjoyability provided by the instantaneous feedback.

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Conclusion: The results can indicate that playing different screens leads to improvement of the game's final score by repeated training. The tendency of changes in HRV may reflect a higher activation of mental system of attention and control in the experimental versus the control groups. In this line, learning simple and voluntary strategies through the developed serious game can aid to improve self-control and arousal management.
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Keywords: Serious Game; Heart Rate Variability; Biofeedback; mHealth; app.

Introduction

Heart rate variability (HRV) represents the temporal variation between successive heart beats (R-R interval) and it is presented in milliseconds (ms) [1]. HRV is a biomarker of cardiovascular [2] and mental [3] health, reflecting the balance between the parasympathetic (PNS) and sympathetic (SNS) branches of the autonomic nervous system (ANS) [4]. HRV has been considered an objective and non-invasive health indicator, with higher resting HRV being associated with less cardiovascular risk [5], reduction of negative emotions through acute stress [6], flexible and adaptative response to environmental demands [7] and improved fitness [8]. This reflects the numerous applications of HRV in different fields.

Heart rate variability biofeedback (HRVB) is an established intervention to increase HRV in the clinical context, having proven to be effective as a treatment for anxiety and depression [9,10]. With this technique, participants are aware of their HRV through real-time feedback and can self-regulate it, restoring its homeostasis [11]. HRVB is based on the physiological phenomenon of respiratory sinus arrhythmia (RSA), which is defined as the variation in heart rate caused by respiration [12]. The analysis of RSA shows that heart rate increases during inhalation and decreases during exhalation. Furthermore, HRVB can help to establish a connection between mind and body through voluntarily controlled physiological behaviours, such as breathing, facilitating the learning process and self-control.

HRVB is becoming more widely used due to its ease application and high costs-benefits potential, particularly due to the current accessibility to health technologies through mobile devices (mHealth) [13,14]. The mHealth technology is allowing the development of game-based mobile applications, which are known to increase transfer of learning and motivation towards practice [15], and its utilization as health of educational interventions allows the participants to immerse in the virtual environment and absorb more complex information [16]. In particular, the so-called serious games, rather than geared towards entertainment, are aimed at educating, training and informing the player about a specific topic [17]. Serious games are being used in different health’s branches [18–20]. For instance, in the field of HRVB, they can be a way to tech participants to control HRV through breathing techniques in an interactive environment.

With the information provided above, the aim of the present study is double: first, to develop a serious game that applies the technique of HRVB to teach participants to self-regulate HRV; and second, to test the app with participants in a pilot study.

Method

This study has two phases: (1) the development of a serious game biofeedback app, called Fitlab Game and (2) the testing of the app with participants in a pilot study.

Phase 1: App development

Visual environment and game explanation

Menus

The game’s menus are designed in landscape mode and are presented in Spanish. The first screen that appears when opening the app is the main screen, which allows to choose the sensor used to input data: either the device’s camera (“*Cámara de vídeo*”) or a HR band ("*Banda Pectoral*"). We will be using the later for the purpose of this article. Once connected to the sensor, the app allows access to the game's mode, where the player can select between the option "*Jugar*" (“Play”), in which the user overcomes different levels in an orderly manner so that the difficulty of the game gradually increases, or the option “*Práctica*" (“Practice”), in which the user can activate an independent session. The tab “*Opciones*” (“Options”) refers to the game’s settings (Figure 1).

(Figure 1)

Screens

FitLab Game has a total of 9 screens distributed in 3 visually different worlds (Figure 2). Each world has 3 scenarios or levels of difficulty that the user must overcome in a set order to be able to access the next one when in "*Jugar*" ("Play") mode. To overcome a scenario, the user must move the main character up and down the screen to avoid colliding with obstacles that keep appearing. Touching an obstacle results in a loss of a life, and losing all lives means the game is over and needs to be re-started. The movement of the main character reflects cardiac variability and can be controlled by different voluntary strategies such as breathing.

(Figure 2)

The upper and lower limits and the obstacles in each scenario of the game are not placed randomly. They follow a specific waveform determined by a previously recorded RR intervals, corresponding to a real recording. Each scenario represents a real RR series transformed and visualized as instantaneous heart rate (iHR), with different difficulty to imitate depending on the scenario. This level of difficulty depends on the particular and distinct RR series (represented as a curve of iHR values) on which each scenario is based. Before starting the game, a calibration of the data is carried out in order to establish an initial heart rate (HR) range of the user (based on iHR from RR intervals). An algorithm was created specifically for the game, which takes this initial HR and displays it on a "grid" (invisible to the user) where each box is 1 second wide per 1 second high. With this algorithm, the screen is configured to place the character in the central area vertically, and the width of the screen is adjusted so that it is proportional to the range of variability presented by the user. Also, the upper and lower limits and the obstacles, based on the previously recorded RR series, are placed above and below the defined waveform, leaving a margin for the character to pass in between (Figure 3).

As a result of the initial calibration, all users start the game with similar conditions, while also having the level of difficulty of each scenario of the game adjusted to their own HR values. Overall, the configuration of each game is a dynamic and individual process.

(Figure 3)

The left part of Figure 3 illustrates the algorithm that defines the ideal pathway of the character. The blue line represents the waveform defined by the pre-recorded iHR curve (from a specific RR serie), and the dark grey boxes represent the upper and lower limits of this curve, where the obstacles would be positioned. On the right part of Figure 3 an example of how this algorithm would be seen in the game is shown. Once the obstacles are placed, the objects and landscape of the scene are chosen. For each world there is a bank of images that can be used (mountains, animals, houses, etc.) and placed by distributing them according to their size. Larger objects form the background plane, such as the mountains. Medium objects, such as houses, gradually fill the spaces that the first type of images could not fill due to their size, and small objects such as birds, trees or other details are placed in the spaces that are missing to be filled in, which in Figure 3 are the dark grey boxes. Notably, the placement of obstacles is not exhaustive, meaning that it is not intended to fill all the space reserved for obstacles, otherwise the screen would be saturated with objects. The goal is to place objects in the most harmonious way possible, but clearly marking the path that the main character should follow.

App Architecture

Programming language and functionalities

The architecture of the app consists of two parts: (1) the base of the game, and (2) the container of the app and the communication with another device. The base of the game refers to the visual part, the game's engine, screen management, menus, and navigation. This entire part has been implemented with HTML (HyperText Markup Language, WHATWG) assisted by CSS (Cascading Style Sheets, World Wide Web Consortium) and JavaScript (Oracle Corporation, US) technologies, so that it can be run in any web browser, whether hosting the application on a web server or running it directly on the local computer or mobile device. Note that opening the game in a web browser will not allow the use of the sensors and hardware, so on a web browser the game can only run in test mode. Nonetheless, in test mode, it is still fully functional using the cursor on a computer keyboard or by tapping on the screen of a mobile device, which allows to move the character up and down the screen manually.

The container refers to what allows to install the game as a mobile application on an Android or iOS operating system. In addition, it is what provides the necessary functionality to access the device's camera and process the images, as well as establishing Bluetooth connections with HR sensors and processing the data inputted. In this case, processing of data is what is used in the game as data input, replacing the usual input methods including the keyboard or touch screen (for testing purposes). That is, it is with iHR data (from real time RR intervals) that the user can move the main character up and down the screen, using the variation of each iHR beat with respect to the previous one. This app container has been implemented using a cross-platform environment for writing applications for Android and iOS operating systems called Titanium SDK (TiDev, Inc., US).

The game engine has been written in JavaScript and is based on a constant loop where, at each step, the current position of the character is evaluated with respect to its environment (screen boundaries, obstacles, and prizes) and the input of the user (iHR data) (Figure 4). The game's engine, menu screens and navigation are written in web languages compatible with any browser. Finally, both operating systems (Android and iOs) allow the introduction of web components within the app to be able to reproduce web code (i.e. HTML+CSS+JavaScript) as if it were part of the same app. The current game app takes advantage of this feature to separate the game itself from the app's container, which allows communication via Bluetooth with other devices. When the container part receives a command via Bluetooth, the app container code sends the corresponding interpretation of this command to the game part. For example, when instantaneous HR data is received over Bluetooth, the app container unpacks the received frame, gets the specific iHR data and sends it to the game, which interprets it and moves the character. Figure 4 shows a game flow representation, where the user wearing a chest band sends iHR via Bluetooth and the game algorithm evaluates iHR, time playing, bonus achieved and position, on a constant loop.

(Figure 4)

Data collection and Bluetooth connection

Before communication between the sensor (HR sensor) and the Fitlab Game occurs, a connection must be established between the entities. Such connection is established via Bluetooth, and it is known as pairing. In this type of connection, one of the devices acts as a host or receiver of data, and the other as a client or sender. The device acting as a receiver can establish connections with multiple sending devices, but a sending device can only connect to a single receiver. The present app currently only allows one streamer to be connected to the device because each game is calibrated to a user's iHR.

It should be noted that the iHR reading device used for the Fitlab Game could be any, but it must offer a Bluetooth® low energy (LE) connection so that the app can obtain the data. This Bluetooth's version can define specific data formats through standard attribute profiles (GATT, Generic Attribute Profile). This allows, for example, to establish Bluetooth communication in Heart Rate Profile mode between the data sensor (the sender) and the app (the receiver). In this way, the receives can interpret the data in the given format it is packaged and is able to obtain the iHR information regardless of the manufacturer and model of the sending device, always as long as it uses Bluetooth® low energy (LE) with Heart Rate Profile mode.

At present, when the app is opened, the user is asked to select the data entry method. When Bluetooth is selected, a screen with detected nearby Bluetooth devices is displayed (Figure 1.B). The list of displayed devices is filtered to only show those in Heart Rate Profile mode. The user can select a device from the list of available devices and establish the connection. This process may take 1 or 2 seconds and the user is confirmed if the connection has been successfully established or if an error has occurred. Once the connection is established, the application takes the user to the game's playing menu (Figure 1.C).

Data Processing

For each game that is carried out in the app, iHR data is collected, together with other metadata including the start and the end time of the game, a user's identifier code, an ID assigned to the session, the level of the game played, the bonus achieved and the iHR calibration. All this data is packaged, saved in the contained of the app, and can later be exported for analysis. Multiple user sessions can be stored locally, that is, in the application, but an Internet connection is needed to export the data to a server. Note that the game does not need an internet connection to work, only a Bluetooth wireless connection to establish a connection between the sender and the receiver in proximity. For research purposes, the sessions that are temporarily saved on the device are accessible from a configuration menu by an application manager. To export data, the manager needs to select the sessions wanted and indicate an email address to which the anonymized data will be sent, that is, identified by user codes and never by names or other identifying data.

Phase 2: Pilot Study

Study Sample

A total of 16 participants (9 men and 7 women, 23 ± 0.69) were divided into two groups: a control group (4 men and 4 women, 23.25 ± 0.99) and an experimental group (5 men and 3 women, 22.75 ± 1.01). All participants were older than 18 years old and did not suffer any cardiovascular disorder nor did they take any medication that could affect HRV. Descriptive statistics for participants are presented in Table 1. All participants, selected via a convenience sample of university students, were volunteers and provided written informed consent. The study was conducted according to the Local Ethics Commission for Human Experimentation (protocol code CEEAH-5745).

(Table 1)

Table 1. Descriptive data of the participants of the study.

Variable	Group			*p*
	Control (n=8)	Intervention (n=8)	Total (n=16)	
Gender				NS
Male (%)	4 (50%)	5 (62.5%)	9 (56.3%)	
Female (%)	4 (50%)	3 (37.5%)	7 (43.7%)	
	m(sd)	m(sd)	m(sd)	
Age	23.25 (2.82)	22.75 (2.87)	23 (2.76)	NS
Height (cm)	170 (10.53)	173.88 (8.34)	171.94 (9.39)	NS
Weight (kg)	66.5 (13.86)	66 (9.41)	66.25 (11.45)	NS
BMI	22.84 (3.38)	21.78 (2.50)	22.31 (2.92)	NS
POMS				
Tension	1.67 (0.91)	1.04 (1.47)	1.35 (1.23)	NS
Total Score	9.13 (1.86)	9.71 (5.40)	9.42 (3.91)	NS

NS: nonsignificant difference

Material and Instruments

Control Measures Self-report. Prior to attending the session, participants were recommended, by e-mail, to avoid taking non-essential drugs (up to 24h before the session), as well as caffeine, smoking, or any other psychostimulant (up to 2h before), alcohol (10h before), heavy meals (3h before) or eating in general (1h before). They were also asked to avoid high intensity physical activity or an unusual exercise (20h before), to sleep at least 6h, and to wear comfortable clothes to the laboratory. A brief questionnaire was used just before the laboratory sessions to control those conditions. Participants were also asked to report weight and height.

Profile Of Mood States (POMS). A short version of the POMS [21] was used to assess the mood profile of participants. The short version of the POMS is a multidimensional questionnaire consisting of fifteen items that measure mood via five scales: tension, depression, hostility, fatigue and vigor. Each of the 5 scales includes three items that are scored from 0 = ‘‘nothing’’ to 10 = ‘‘very much’’. The total score for each scale corresponds to the average of the scores of its three items.

Polar Band H10. A cardiac chest band H10 (Polar Electro, Finland) was used to record the RR intervals signal (transformed to iHR), as validated by [22]. The signal was sent and collected to the FitLab Game App (iOS version 1.0 – Build 1; Health&SportLab S.L., Barcelona, Spain), active in an iPad Air 2 (version 12.1.4).

Procedure

The study consisted of one individual session per participant, which lasted for about 35 minutes and took place in the Basic Psychology Laboratory of the Universitat Autònoma de Barcelona. The day before this session, each participant was provided a list of recommendations, based on the *Control Measures Self-report***,** to control variables that may affect HRV, including physical activity and intake of caffeine, psychostimulants, alcohol, drugs, and food. Then, at the beginning of the session, the H10 cardiac band was placed on the participant's chest so that he or she could familiarize with the sensation of the band. The band was applied with a few drops of conductive gel to facilitate good contact with the skin. Once the band was placed, the participant answered the questionnaires *Control Measures Self-report* and the POMS. Then, participants were first introduced to the Fitlab Game. Play time was divided into three parts, with the first and third parts being recorded for the study. In Part 1 (Figure 5.A), the Baseline Phase, each participant played two screens of the game to get used to the functioning of the App, without time constraints. In Part 2 (Figure 5.B), the Practice Phase, participants practiced on a different screen for six minutes, or a maximum of 3 screens. Finally, in Part 3 (Figure 5.C), the Test Phase, each participant played the same two screens as in Part 1.

(Figure 5)

A few techniques to self-control iHR (and thus manage HRV) were explained to the participants of the experimental group, but not to those of the control group. To increase HRV (and reduce iHR), it was recommended to either breathe at a pace where the exhalation was longer than the inhalation [23–25], or to hold the breath [26]. To reduce HRV (and increase iHR), participants were instructed to slightly hyperventilate [27], to perform muscle movements [28], or to swallow saliva voluntarily all at once [29].

For each screen and session that the participants played, the Fitlab Game calibrated a baseline iHR, which allowed to place the game's character in the center of the screen, in such a way that the starting point and the difficulty of iHR series were equal for all participants. Then, participants had to follow the same pre-established route corresponding to each screen and session, collecting apples (Bonus), which marked the correct route, and avoiding other elements such as unhealthy foods, tobacco or the up and low limits marked by the floor and the ceiling of the screen. To follow the route (or avoid certain elements), the main character had to move up or down the screen, which was controlled via changes in iHR. Participants in the control group were given no instructions on how to do so, whereas participants in the experimental group had been given the techniques mentioned above. All participants started the game with 20 lives, and the game ended when they ran out of lives or when they reached the end of the screen without losing all these lives.

Data analysis

Descriptive statistics are reported as mean and standard deviation (SD). A 2x2 MANOVA following a general linear model (GLM) was used to analyse the differences between Baseline and Test situations. The Baseline values were calculated as the average of the two games played in Part 1, and the Test values were calculated as the average of the two games played in Part 3 of the procedure (see Figure 4). This statistical analysis was carried out to analyse the Baseline vs Test data obtained from HRV parameters, as well as time and bonus, all separately. Statistical analysis was performed using IBM SPSS Statistics, version 28.0 (IBM, Chicago, IL, USA).

The raw RR interval values recorded by the Polar H10 cardiac chest band were processed to remove artifacts due to false positive or false negative detections, afterwards the RR intervals were filtered and the corresponding iHR values were shown in real time on the screen when the participant was playing. This same processed RR interval values were saved and analyzed to calculate HRV parameters. A time domain HRV analysis was performed to calculate RR intervals average

(RRmean), standard deviation of RR intervals (SDRR), root mean square of differences between adjacent RR intervals (RMSSD), and percentage of consecutive RR intervals that differ more than 50ms between them (pNN50). A frequency domain analysis was used to calculate the low frequency band (LF; 0.04–015 Hz) and the high frequency band (HF; 0.15–0.4 Hz). HRV analysis followed the guidelines recommended by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996). HRV analysis was performed with MATLAB® (R2021 Update 3 for 64 bits Windows).

Results

Change in Gaming Performance (Pilot Study)

To analyze the participant's performance in the game, the change in the number of apples collected (Bonus) and the total time played in seconds (Time), was considered, as presented in Table 3. No significant changes were found in Baseline versus Test situation, when comparing the experimental to the control group. There was, however, a tendency for both groups to increase Bonus and Time from the Baseline to the Test condition.

(Table 3)

Table 3. Game outcomes in Baseline and Test phases, in the control and experimental groups.

Variable	Session		*p*
	Baseline	Test	
Group	mean (SD)	mean (SD)	
Bonus			NS
Control	16.75 (10.91)	18.06 (9.54)	
Experimental	15.75 (5.34)	20 (10.15)	
Time			NS
Control	91.08 (26.79)	109.05 (58.17)	
Experimental	91.07 (26.79)	116.67 (52.31)	

Bonus: number of apples achieved in the game.
Time: total playing time in seconds.
NS: nonsignificant difference.

Change in HRV Parameters

When analysing the changes in HRV before and after the game, the results showed some differences between the experimental and the control group (Table 2). In particular, the experimental group showed a decrease in RR mean from Baseline to Test that is different from the increase shown in the control group (p=.020) (Figure 6). On the other hand, the experimental group showed a decline in RMSSD from Baseline to Test that was more pronounced than in the control group (p=.037). No other HRV parameters presented a significant or tendential change.

(Table 2)

Table 2. MANOVA of HRV variables in Baseline and Test conditions, in the control and

experimental groups.

Variable / Group	Session: Baseline mean (SD)	Session: Test mean (SD)	*p*
RR mean			.020
Control	800.33 (109.02)	816.89 (106.59)	
Experimental	1004.52 (148.41)	930.90 (132.45)	
SDRR			NS
Control	62.55 (24.12)	65.64 (20.16)	
Experimental	111.35 (33.97)	109.81 (32.44)	
RMSSD			.037
Control	43.10 (19.96)	41,60 (20,16)	
Experimental	93.80 (40.71)	80,07 (31.73)	
pNN50			NS
Control	23.83 (17.53)	20.77 (17.25)	
Experimental	42.90 (18.63)	34.64 (17.52)	
LF			NS
Control	3063.58 (2789.61)	2595.49 (2190.80)	
Experimental	6612.13 (3438.65)	6972.52 (3760.22)	
HF			NS
Control	661.70 (458.82)	739.14 (547.80)	
Experimental	2985.17 (2311.75)	2046.96 (1594.17)	

Abbreviated variables stand for: average RR intervals (RR mean), Standard deviation of RR intervals (SDRR), Root mean square of differences between adjacent RR intervals (RMSSD), percentage of consecutive RR intervals that differ more than 50ms between them (pNN50), Low Frequency (LF) and High Frequency (HF). Time-domain analyses are presented as milliseconds (ms) Frequency-domain analyses are presented as milliseconds squared (ms^2). *NS: nonsignificant difference.*

(Figure 6)

Discussion

The aim of the present study was double: to develop a serious game that teaches the user to self-regulate iHR using HRV biofeedback (HRVB), as well as carrying out a pilot study to test the developed game with participants. For the later, a total of 16 participants took part in the trial and were divided into a control and an experimental group. Results were analysed in two parts: one focused in changes in performance of the game and the other in fluctuations in HRV parameters. The results, also related to the usefulness of the game, are discussed below.

Game and App Performance

Analyzed globally, gaming performance in all participants went in line with the results of another gaming study [30], in which both the control and the experimental group improved their gaming level. These results can indicate that playing a given game, in itself, leads to improvement of its final score by repeated training and/or habituation. That is, both groups got to experiment and learn how to move the game's character. Regarding the differences in performance between groups, the results show that the experimental group had a greater improvement in all indicators compared to the control group, even if the differences were not significant. The experimental group showed a greater improvement in Bonus score (increase of 4.25 bonus points in the test with respect to the baseline), compared to the control group (increase of 1.31 bonus points in the test) (see Table 3). The same trend is observed in the total playing time, where the experimental group kept playing 7.6 seconds longer than the control group (see Table 3). All these results are consistent with the idea that the application of specific strategies in the experimental group could have improved the self-regulation of heart variability, more than the simple practice of the game (as shown with the control group). However, these results should be interpreted with caution due to the small sample size and the high values of the standard deviations shown in Table 3.

At a qualitative level, the game seemed to be easily understood by all participants, who grasped the concept, the goal and the rules that applied. In that sense, FitLab Game appears as a promising serious game due to its easy functionality. Additionally, the instant feedback provided by the game may have helped produce high engagement and enjoyability for the participants, as noted by Siriaraya et al [31]. At the same time, the fact that the screen of the game is adapted to each participants' cardiac record means that each person plays in a personalised environment, thought to increase motivation towards the game [32]. Lastly, regarding the app functionality, we highlight the possibility of using either Bluetooth devices or photoplethysmography sensors [33] allowing participants to play in different contexts and with different resources in hand. For future works, it would be interesting to ask participants how they felt during the game in order to know their level of motivation and satisfaction.

HRV Analysis

Regarding HRV, the results of the pilot study showed some differences in the cardiac behaviour of the experimental and control groups (Table 2 and Figure 6). This suggests that the strategies that the experimental group used to compete in the game improved their control of cardiac variability, which in turn may have enhanced their performance. Being a pilot study with few participants, the exact reasons behind this relationship between control of cardiac variability and performance cannot be argued. Nonetheless, it is possible that the results reflect the activation and the control of attention mechanisms in the experimental groups. If we consider that the game requires a certain level of concentration and attention in order to play, especially if the participants is remembering and applying the techniques that were just learnt, some arousal level is needed, reflected in a reduction in the activity of the PNS, as shown with a reduction, although not significant, in the experimental group (HF parameter) compared to the slight increase in the control group. This result is consistent with the increase, also not significant, in the LF values in the experimental group compared to the decrease in the control group. There is evidence that higher LF values are related to greater activation of the SNS [34]. At the same time, a significant reduction in cardiac variability was observed in the experimental group, as shown on the RR mean and RMSSD parameters. The set of previous results could explain the improvement in the control of arousal or activation in the experimental group. In line with this idea, Fuentes-García et al [35] found that in chess games, the player's level and the difficulty of the game determined the activity of the autonomic nervous system of the individuals, with higher demands in attentional focus resulting in lower HRV. Thus, in the present study, the experimental group may show reduced vagal activity and cardiac variability because they were given techniques to control their HRV, requiring higher attention when playing [36]. In that sense, HRV is an indicator that the experimental group was active and applying what had been taught.

On the other hand, our results could seem to contradict the majority of studies using the HRV biofeedback technique (HRVB), which conclude that this technique helps to improve HRV [37,38] with the general aim of achieving relaxation. However, this is not the case. These articles use set breathing paces, usually between 4.5 and 6.5 times a minute, as HRVB to induce relaxation [39,40]. For example, in the topic of gaming, Al Osman et al [41] used a game-based biofeedback to control the activity of ANS, and showed that HRV increased following a controlled breathing rate. Differently, the goal of the present study was not to increase, maintain or decrease HRV, but to teach participants to control its rise and falls through various techniques, including breathing control but not at set paced. Thus, our study is not comparable with most other ones, given that we did not focus on breathing paces, but rather an array of techniques to teach the participant how to increase or decrease their HRV. These techniques are the voluntary production of apneas to suddenly increase cardiac variability [26], perform muscle movements to achieve a reduction in HRV (in line with Guidi et al [28]) or voluntary swallowing. This last strategy can produce changes in healthy people on some HRV parameters, like SDRR, LF, and HF power [42], and effortful swallowing increases LF power and the LF/HF ratio [43]. On a practical level, these strategies allow the player to move the character up and down the game screens because they provide rapid changes in cardiac variability.

Limitations and future directions

There are 3 main limitations of this study. The first one is the sample size in the pilot study. Even if the results show a significance in iHR mean (proportional to RR mean) and RMSSD, they should be considered preliminary. A second limitation is that participants were not monitored before and after the game, only during it. That means that the HRV indicators were collected as the game was being played, thus in an active state, and not in a resting situation. Our interest was to test whether there were changes in the HRV parameters and game performance at all, as a pilot study, but in future studies it would be interesting to observe the influence of our intervention on basal HRV.

Finally, most previous studies using techniques like HRVB include a type of sample with clinical patients, unlike the present one which was carried out in healthy university students. For instance, Siepman et al [44] compared the effects of HRVB in both healthy and depressed people, showing that the later had a greater significant improvement in HRV, compared to healthy volunteers. In the same line, Pyne et al [45] reported that HRVB training reduces symptoms of post-traumatic stress in older people only. These studies highlight that HRV parameters seem to be harder to alter with HRVB in healthy and younger people, than in older or clinical population, potentially explaining the results in the present work, with few to no significant changes in some HRV parameters. In the future, a higher sample size of healthy university students, or testing the Fitlab Game in a clinical population, could provide more consistent results. Finally, it would also be very interesting to provide new strategies for the voluntary control of HRV, perhaps further refining the ones we have already developed in this study. It would also be necessary to deepen the swallowing strategy, since

Yildiz and Doma [29,46] concluded that spontaneous saliva swallowing can change some short-term HRV parameters significantly even in healthy people.

Conclusion

The present study developed a serious game, named Fitlab Game, that teaches the user to self-regulate the instantaneous heart rate (iHR) using cardiac variability biofeedback. It also tested the developed game with participants in a pilot study. Overall, FitLab Game appears as a promising serious game due to its easy functionality, high engagement and enjoyability provided by the instantaneous feedback. The strategies learned by the experimental group to compete in the game, which included the voluntary production of apneas, muscle movements, and voluntary swallowing, improved the self-control of cardiac variability, and in turn may have enhanced performance. A significant reduction in cardiac variability observed in the experimental group, based on RR mean and RMSSD parameters, could explain the improvement in the management of arousal or activation compared with a control group. Thus, the application of specific strategies in the experimental group could have improved the self-regulation of heart variability, more than the simple practice of the game.

The usefulness of HRV as a health indicator is well known, and HRV biofeedback is considered an established intervention in clinical context. On this basis, learning simple and voluntary strategies through the developed serious game can aid to improve self-control and arousal management. Ultimately, with sufficient training, the game can become a relaxation technique for the general population or clinical populations, or, for example, an activation technique for athletes in certain situations.

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Conflicts of Interest

No conflicts of interest.

Abbreviations

ANS: autonomic nervous system
HF: high frequency
HR: heart rate
HRV: heart rate variability
HRVB: heart rate variability biofeedback
iHR: instantaneous heart rate
LE: low energy
LF: low frequency
MANOVA: multivariate analysis of variance
mHealth: mobile health

NS: nonsignificant difference
pNN50: percentage of consecutive RR intervals that differ more than 50ms between them.
PNS: parasympathetic nervous system
RMSSD: root mean square of differences between adjacent RR intervals
RR mean: average RR intervals
RSA: respiratory sinus arrhythmia
SDRR: Standard deviation of RR intervals.
SNS: sympathetic nervous system

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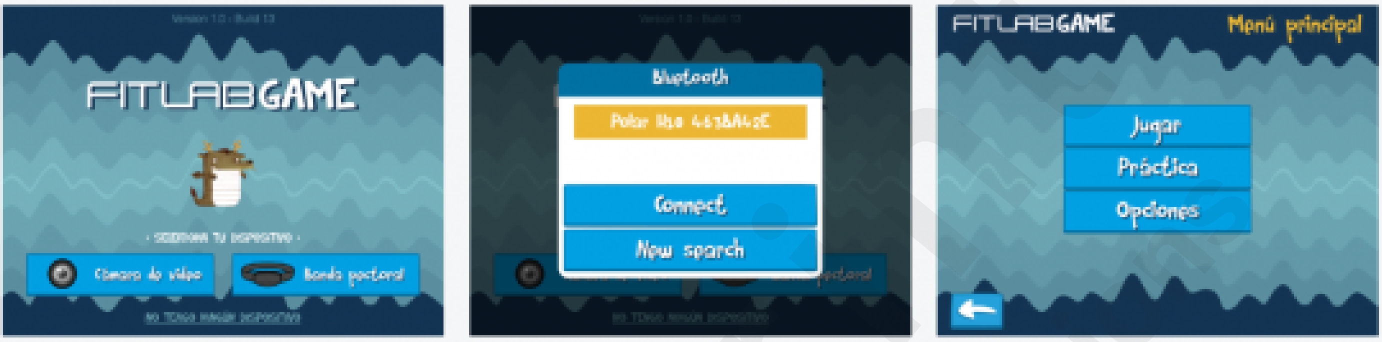
Supplementary Files

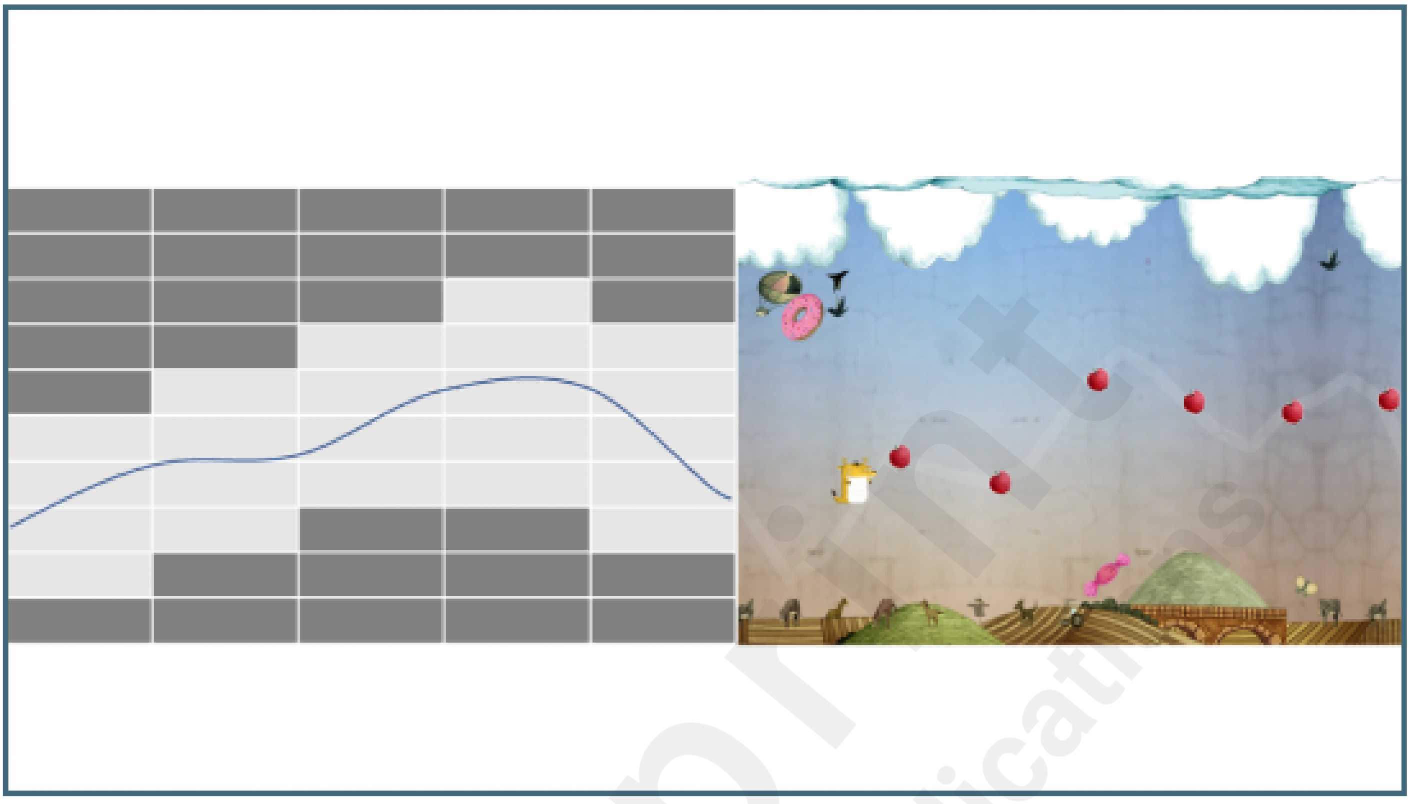
Figures

Screenshots of the game’s menus. Game’s transition from the Main screen to the screen that appears when you select “Banda pectoral” (“Chest Band”), and which allows to connect a heart rate sensor to the game. On the right, the third menu where the player can select “Jugar” (“Play”) to play.

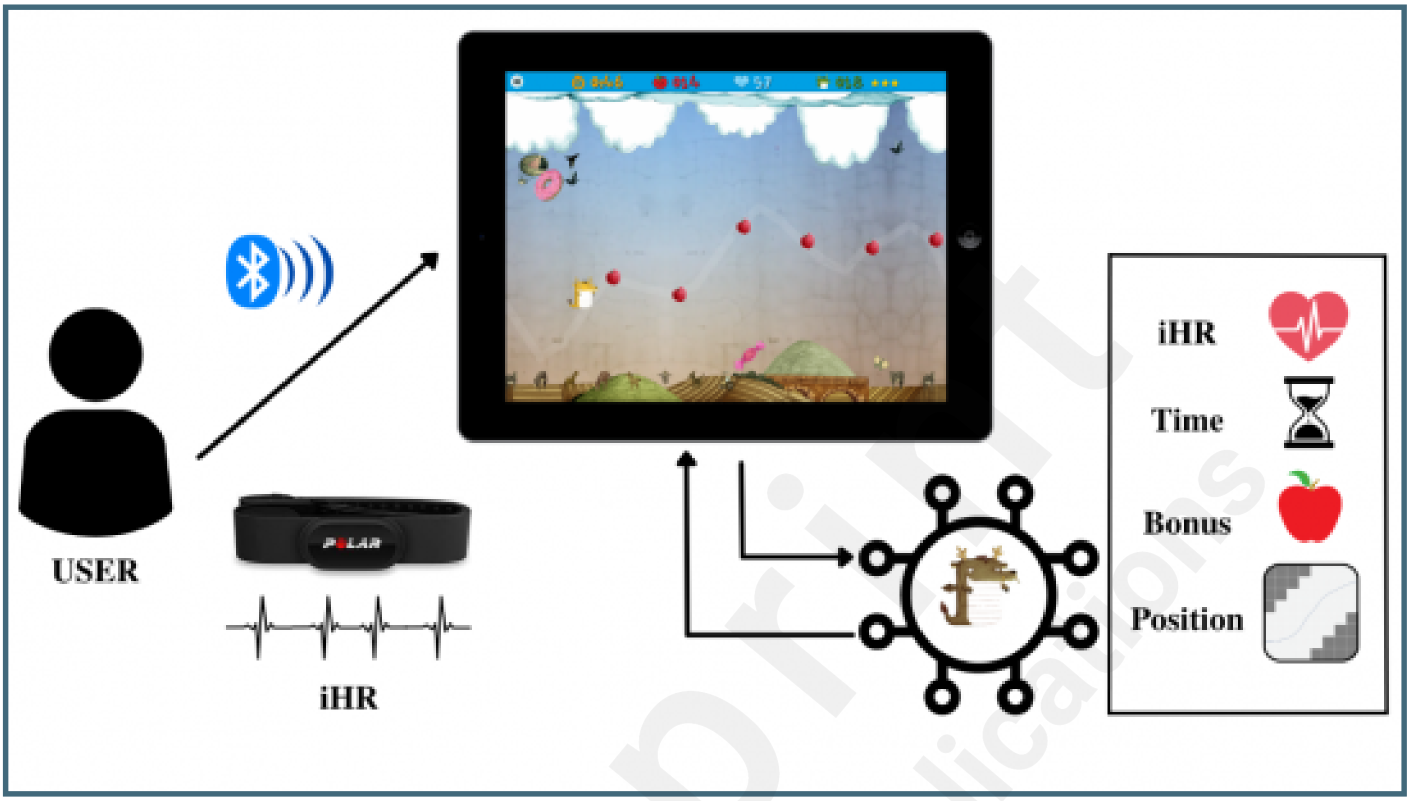


Screenshots of worlds and scenarios of the game: “Campo" (“Rural area”), “Mar” (“Sea”) and “Espacio" (“Space”).

Example of wave based on an instantaneous heart rate (iHR) curve from a particular RR interval serie.



Game flow representation. iHR: instantaneous heart rate from RR intervals.



Example of screens of the game that participants played. Testing consisted in three parts (Part 1: Baseline Phase; Part 2: Practice Phase; Part 3: Test Phase).

Mean, Confidence Interval 95% and distribution of RR mean and RMSSD, when comparing Baseline and Test situations in the Experimental and Control groups.