LiverDefense: Using A Tower Defense Game As A Customisable Research Tool

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***Abstract*—In this paper, we present LiverDefense - an educational Tower Defense game illustrating the basic functions of the human liver. LiverDefense serves as an easy-to-use evaluation tool for psychological game-related research since it can be customised with regard to its degree of difficulty. Furthermore, Likert scale questionnaires can be displayed throughout the game and relevant game events can be logged. All customisation is performed via human-readable XML files, abolishing the need for programming proficiency. LiverDefense has been successfully used in a user study focused on exploring the effect of perceived control over gameplay on players' emotions. We report on the analysis of this study with regard to enjoyment and frustration and the resulting insights on LiverDefense's usefulness as a customisable research tool.**

I. Introduction

Serious games as introduced by Clark C. Abt in 1968 [1] are games that are not primarily focused on providing a form of entertainment [2]. Instead, many of them aim to utilise the human drive to play as a way to teach facts, instill knowledge or train skills as demonstrated in various game studies [3], [4]. Prensky [5] found that contemporary young learners respond well to more interactive methods like serious games as they tend to find traditional learning media boring and insufficient for their needs. Mangold [6] states that virtual media are potentially useful tools to address the so-called *millenial generation*'s issues of engagement and (inter-)active learning. However, educational games need to follow certain design rules in order to be engaging as well as efficient with regard to teaching. Malone, for instance, developed a framework to promote intrinsic motivation in instructional games [7]. He suggests a number of aspects important to this goal, among them the following: Clear and meaningful goals, performance feedback, varying difficulty, support of fantasy, and adequate complexity to promote curiosity. While simply adhering to these design aspects is no guarantee for creating a motivating serious game [8], it can at least be a valuable step in the right direction.

Tower Defense games are a very successful genre of video games that employ these aspects already in a non-serious field of application. In this genre, the player's objective is to defend a given asset, e.g. a castle. The asset is assaulted by enemies, usually along a given path. In order to prevent them from reaching the castle, the user may place defensive units, so-called towers, along the path. The player takes damage for every enemy unit that reaches the end of the path. The goal is to survive as many enemy waves as possible while these become more and more menacing. Due to cost and placement issues, strategic planning is required. Furthermore, each type of enemy may require its own type of tower to be dealt with. For more information on the genre, refer to Avery et al. [9]. They conducted a comprehensive analysis of the Tower Defense genre, its history, and its applicability for computational intelligence research.

Since Tower Defense games inherently comply with Malone's goals for successful educational games as stated above, the genre harbours a lot of potential to serve as basis for effective serious games. To explore this possibility, we developed LiverDefense, a Tower Defense game in the biological-medical context. We intend LiverDefense to serve as an easily customisable platform for psychological studies in the field of game research. Thus, we decided to focus on customisability with regard to game difficulty, and providing researchers with the opportunity to comfortably add, edit, and display questionnaires during the game.

We also report on a study where LiverDefense's customisation capabilities were successfully used to research the effect of varying degrees of difficulty on player's perceived control and emotions during play.

The rest of the paper is organised as follows. We provide a review of related literature relevant to our approach. Subsequently, we present the concept and implementation details of our game LiverDefense and highlight the customisable features. Finally, we report on a first study that successfully used LiverDefense as an evaluation tool.

II. Related Work

Sawyer [10] reports on the general applicability of games in the health sector and presents a number of possible application areas. Wattanasoontorn et al. [11] reviewed 108 academic and commercial serious games for health and developed four criteria for classification: main purpose, targeted health care phase, intended target group, and game technology. They performed a detailed classification of all 108 games and found a high degree of diversity in the field. McCallum [12] reports in more detail on the research challenges for serious health games, such as measuring effects due to varying game experience for players, the necessary quality of health games to be engaging, and the effect of extrinsic versus intrinsic motivators. Papastergiou [13] reviewed thirty-four articles with regard to the usefulness of video games in health education and found them to have many potential benefits, among them the

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ability to engage students. Her findings indicate however that empirical evidence pertaining to the educational effectiveness of health-related video games is still sparse. Baranowski et al. [14] conducted a survey on twenty-seven articles regarding health-related behavior change and found that video games can indeed have a positive influence. However, they conclude that more research is needed on the optimal use of game elements such as interactivity to promote beneficial changes.

With regard to the application of Tower Defense games in the health sector, we found the following projects particularly interesting. Thompson developed Food Fight, a diabetes-related tower defense game [15]. The game aims to teach players the necessary balance of a healthy diet and steady exercise with regard to diabetes management. Various foods embody the incoming enemies, while the player has to place *diet* and *exercise* towers. Motivation is used as the game's currency. In a novel approach, diet towers do not destroy enemies. Instead, they symbolise the dietary choices of the player and influence the types of incoming food. For instance, placing a carbohydrate diet tower results in less sugar-rich foods, i.e. enemies, entering the playing field. However, the healthier the diet, the more motivation it costs to uphold. Motivation can only be regained by using exercise towers to destroy the approaching enemies. To promote beneficial self-care behaviour, players are encouraged to keep their virtual blood sugar at a stable and healthy level. Hence, points are awarded for keeping a horizontal blood sugar meter close to the optimal middle value.

Bassilious et al. [16] focused on diabetes and the Tower Defense genre as well. They developed the game *Power Defense* to teach diabetes type 1 patients the numeracy skills needed for insulin management. The focus of the game lies on experiential learning. They chose to use primarily implicit teaching methods by employing the metaphor of an unstable power plant to symbolise the body's blood sugar level. Players learn the necessary calculations by deciding in real time how much additional energy (e.g. food) may enter the facility to prevent power failure and how much coolant (e.g. insulin) is necessary to avoid a blowup. In addition, explicit methods like diabetes-related quizzes are used to convey and manifest knowledge. Bassilious performed an evaluation of PowerDefense with 44 adolescent participants [17], but did not find any positive effects regarding diabetes management. He does however list numerous limitations of the study himself which might have prevented him from discovering the desired effects.

Clements et al. [18] developed a game that allows players to experience the workings of the human immune system first-hand. They chose the genre of Tower Defense as they found its mechanics most suitable to illustrate the underlying principles of immune response. The goal of the game was to prevent the infection of healthy cells. To achieve this, players could specialize generic immune system cells to defend against pathogens entering the blood stream. Clements et al. chose a two-dimensional approach and cartoon-like animations to award the game a fanciful atmosphere while still retaining biological accuracy as much as possible. This game was designed according to Malone's recommendations [7] for use in an actual teaching environment; however, Clements et al. do not report on any findings pertaining to the reception and efficiency of their approach.

Avery et al. researched Tower Defense games with regard to their usefulness for computational intelligence research [9]. They found the genre particularly suitable to serve as a test-bed for game-related research due to its easily implemented and easy-to-understand mechanics, its applicability to various domains, and its inherently challenging and addictive nature.

Regarding a game's difficulty, Clements et al. emphasise the need for adjustability thereof to keep the game interesting and engaging for all manner of players [18]. Charles and Black, who conducted research related to player-centered game design, found that the difficulty of a game influences its perceived entertainment value [19] and is thus worth looking into concerning its motivational and emotional impact. Based on this, van Lankveld et al. researched the affective impact of various difficulty settings [20] based on Rauterberg's incongruity theory [21]. This theory is similar to Csikszentmihalyi's concept of "flow" [22] in that it states that the difference between the context complexity (e.g. the difficulty of the game) and the system complexity (e.g. the skills and knowledge of the player) influences the player's affective state: If the game is too difficult, the player will be frustrated; if the game is too simple, the player will be bored. Only the right amount of challenge ("slightly positive incongruity") will bring the player pleasure and keep them in the flow. Van Lankveld et al. were able to support these hypothesised effects to some extent. Please refer to [20] for more details.

While there are many frameworks that define evaluation criteria for serious games [23], [24], they mostly focus on analysing games outside of the playing experience. Liu and Ding [25] have developed an evaluation component for in-game analysis, however it is integrated into their own game engine and can only be modified via script programming.

The above-mentioned works show the applicability of Tower Defense games in the biological-medical context, and as a research tool. With LiverDefense, we intend to provide an easily customisable tool from this domain which can be employed by researchers without programming knowledge.

III. Design Considerations

Due to the inherent conceptual similarities between liver metabolism (neutralizing harmful or waste materials) and the principles of Tower Defense (neutralize assaulting enemies), we chose the basic functions of the human liver as a content domain for the learning matter of the game.

In accordance with Thompson [15], Bassilious et al. [16], and Clements et al. [18], we employed a real-time instead of a turn-based approach to keep in touch with the biological reality and provide an engaging challenge for the player.

As the related work indicates that difficulty is an important aspect in creating successful games, we chose this as a point of focus for LiverDefense. The potential to influence affective states makes game difficulty an interesting element of research for psychological studies. However, many researchers in this field are not proficient programmers. For this reason, LiverDefense is intended to allow for the manual customisation of difficulty in order to induce affective states such as frustration, boredom, and pleasure as needed by the researcher. Since questionnaires are a common tool in psychological research, LiverDefense should be able to add and display them in the game, and provide capabilities for easy editing.

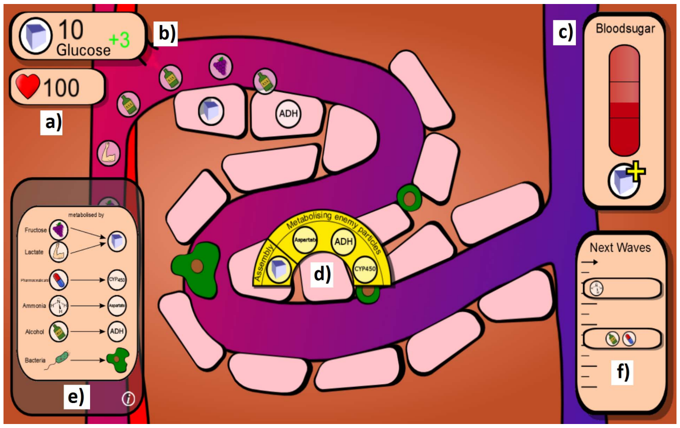

Fig. 1. Screenshot of the LiverDefense playing field and interface, showing a) current health points, b) current glucose balance, c) current blood sugar level, d) the build menu to specialise liver cells, e) the info box for mouse-over help, and f) the next wave preview

Fig. 2. Screenshot of a displayed Likert scale questionnaire (translated from German); the blood sugar management is disabled for the time of the inquiry.

IV. LiverDefense

A. Biology Basics and Learning Matter

LiverDefense aims to convey basic human liver functionalities to players with little or no previous knowledge in this area. The human liver detoxifies biological waste materials like alcohol, ammonia, and pharmaceuticals in the bloodstream by the use of specific enzymes (e.g. alcohol dehydrogenase/ADH, aspartate transaminase and cytochrome P450) [26]–[29]. The liver also has the ability to drain glucose from the bloodstream and store it in the form of glycogen [26]. Furthermore, bacteria are destroyed inside the liver tissue by a layer of macrophagic Kupffer cells lining the bloodstream [30].

B. Necessary Simplifications

The biological context is complex and requires a lot of prerequisite knowledge to be fully grasped. However, to provide a smooth introduction and enhance the playability with regard to a Tower Defense game, we decided to simplify several aspects. Instead of confronting the player with an entire liver system to manage, one singular bloodstream was chosen as basis for the game's playing field to reduce the cognitive demand. We also reduced the number of waste materials metabolised by the liver to alcohol, ammonia, and pharmaceuticals. These materials capitalise on a certain familiarity on part of the player and are representative of the liver's functions. The large and complex urea cycle, which deals with the metabolism of nitrogen, is thereby reduced to a single representative reaction, i.e. neutralising ammonia. In this manner, the player is not overwhelmed and fluid gameplay is ensured. Glycogen synthesis, too, is simplified. Glycogen itself is not introduced in the game mechanics, so that glucose functions as the game's sole currency for income as well as expenses. Instead of confronting the player with the entire glycogen synthesis, we decided to opt for an approach where glucose is simply built from fructose and lactate.

Actual liver cells are capable of several concurring functions. In the spirit of Tower Defense game mechanics, however, we employed generic cells that can be specialized for one specific function to serve as "towers". Cells may thus occupy only one function at any given time.

Another simplification concerns the distribution and behaviour of Kupffer cells. Contrary to the actual situation wherein Kupffer cells line the entire bloodstream within the liver tissue, we decided to provide the player with at most three distinct Kupffer cells. This improves the clarity of the playing field design. Additionally, this approach makes it possible to treat Kupffer cells as towers as well.

With regard to blood sugar management, we chose to present generic negative effects for both exceeding and undershooting the ideal level. Insulin is not mentioned nor is more insight provided into the real-life effects of dangerously high or low blood sugar so that the player will not be diverted from the main task of protecting the liver.

C. Game Elements & Mechanics

The application of the Tower Defense genre to the simplified learning matter presented above results in a set of game elements and mechanics which are described in the following. The developed game interface can be seen in Figure 1. In the case of LiverDefense, the "castle" that the player is given to protect with their "towers" is the liver, and, as a result, the entire body's health. To reflect this in the game mechanic, the player is given 100 health points (see Fig.1, a). Once all health points are lost, the player is presented with a death screen.

As stated above, a singular bloodstream constitutes the path along which the enemy units advance to attack the liver. In accordance with the biological context, these enemy units are alcohol, ammonia, pharmaceuticals, and bacteria. All of these vary in damage potential, and approach in waves of varying composition. Interspersed with these are fructose and lactate particles which can be used to build glucose. Glucose serves as the in-game currency (see Fig.1, b) and is needed to specialize liver cells. As an additional challenge, the user also has to spend glucose to keep the ever-decreasing blood sugar level within acceptable minimal and maximal bounds (see Fig.1, c). To gain glucose and defend against adversarial particles, the player has to specialize the generic liver cells (*hepatocytes*) bordering on the bloodstream. Generic liver cells are specialized into one of the following cell types: glucose hepatocyte (*assemble glucose*), aspartate hepatocyte (*neutralises ammonia*), ADH hepatocyte (*neutralises alcohol*), and CYP450 hepatocyte (*neutralises pharmaceuticals*). A liver cell can be

```xml
<liverDefense>
    <settings>
        <initialGlucose>25</initialGlucose>
        <timeBetweenWaves>15</timeBetweenWaves>
        <timeBetweenParticles>1.5</timeBetweenParticles>

        <particle>
            <damagePotentialAlcohol>1</damagePotentialAlcohol>
            <!-- ... -->
        </particle>

        <hepatocyte>
            <costAdh>5</costAdh>
            <!-- ... -->
            <durationTime>3</durationTime>
            <regenerationTime>10</regenerationTime>
        </hepatocyte>
        <!-- ... -->
    </settings>
    <waves>
        <wave>
            <displayQuestionnaire>true</displayQuestionnaire>
            <elements>
                <element>Lactate</element>
                <element>Alcohol</element>
                <element>Alcohol</element>
                <element>Alcohol</element>
                <element>Fructose</element>
                <!-- -->
            </elements>
        </wave>
        <!-- -->
    </waves>
</liverDefense>
```

Fig. 3. An abbreviated difficulty settings XML file specifiying the various game element parameters (translated from German)

specialized by assigning one of the functions via the build menu (see Fig.1, d).

In order to defend against bacteria, Kupffer cells are necessary. Therefore, the player is provided with three dedicated building spots. Building Kupffer cells is more expensive than specializing cells; however, they are not subject to the same limitations. Specialized liver cells can only ever deal with one of their assigned waste materials at once. This is realised via a "metabolism duration". The cell will only concern itself with the next enemy after this time has passed. To make things more interesting and give the player the potential for more flexibility, specialized cells will also revert back to their generic state after a certain number of enemy encounters. After a short "regeneration time", the player can specialize the cell again according to their strategic considerations. This mechanism is a simplified representation of the death and regeneration of real liver tissue.

An introductory tutorial preceeding the actual game is used to teach the player the basic gameplay and, as such, the basic functions of the human liver. The tutorial design briefly introduces each piece of information (e.g. "*ADH hepatocytes metabolise alcohol.*"), and then instructs the player to perform the corresponding function (in this case: "*Build an ADH hepatocyte to defend against incoming alcohol particles.*"). Players can then take their time to perform the task; the tutorial only progresses after they have finished. All information on game element characteristics (e.g. function, damage potential, building costs, building hotkey etc.) can later be retrieved via mouse-over pop ups on the respective elements during gameplay. An infographic regarding which hepatocytes metabolise which particles can be retrieved via mouse-over on the info box shown in Fig.1, e.

Further assisstance is provided via a wave preview window (see Fig.1, f). Here, players can see which enemy particle

```xml
<questionnaire>
    <item1>Currently, I feel joy.</item1>
    <item2>Currently, I feel bored.</item2>
    <item3>Currently, I feel frustrated.</item3>
    <item4>Currently, I feel angry.</item4>
    <item5>Currently, I feel in control of the game.</item5>
</questionnaire>
```

Fig. 4. A LiverDefense XML file specifiying the employed questionnaire items (translated from German)

types will be included in the next wave and when it will arrive. Neither explicit numbers of enemy particles nor the occurence and numbers of potential fructose/lactate particles are revealed. This helps players with their strategic decisions without telling them what to plan for exactly. In between waves, players have a short time of respite to regroup and reinforce their defenses for the next assault. Since the player cannot collect more glucose in these intervals, the decrease of the blood sugar level is stopped until the next wave arrives.

D. Customisable Features

As stated before, being able to customise the difficulty of an interactive experience is potentially beneficial for psychological studies. LiverDefense employs an XML approach to support the editing of a number of relevant parameters. General parameters (such as initial glucose balance, time between particles, time between waves, damage potential of particles, and drop rate of the blood sugar level), as well as cell-specific parameters (e.g. building costs, metabolism duration, and regeneration time) may be specified as XML parameters of the given elements. The number and composition of waves can be specified as well. With this, it is not only possible to influence the current run of the game; settings can also be saved as complete XML files and be reused or shared. An abridged sample XML file is provided in Figure 3.

In order to support the use of common research methods, LiverDefense enables researchers to add, edit, and display 7-point Likert scale [31] questionnaires. The questionnaire items can be easily specified in an XML file as well, and edited or exchanged as needed. The questionnaires can be displayed throughout the duration of the game, i.e., after every wave. To support the display of questionnaires during waves seemed unnecessary since it would disrupt the flow of the game and potentially annoy participants independent of actual gameplay. Due to layout constraints, each questionnaire frame in LiverDefense is limited to five items. A screenshot of a questionnaire presented in the game can be seen in Figure 2. See Figure 4 for the corresponding XML file. To further supplement questionnaire-based evaluations with game-related data, LiverDefense also provides a CSV-formatted log file which can be imported easily into tools like Microsoft Excel [32] or IBM SPSS [33]. It contains the following values: current timestamp, current action (beginning of new wave or questionnaire display), current questionnaire answers (99 if no questionnaire was displayed, otherwise the chosen Likert scale value), current health points, current glucose balance, death counter, info box counter (e.g. how often players referred to the in-game help), and, once at the beginning, the level of difficulty as indicated by the name of the corresponding XML file. An example can be seen in Figure 5.

Time	Action	Emotion item 1	Emotion item 2	Emotion item 3	Emotion item 4	Emotion item 5	Lives	Glucose	Deaths	Info counter	Difficulty = normal
4/1/2015 2:37:50 PM	Emotiontask 0	5	1	0	0	6	100	25	0	0	
4/1/2015 2:37:53 PM	Spawning wave 0	99	99	99	99	99	100	25	0	0	
4/1/2015 2:38:20 PM	Spawning wave 1	99	99	99	99	99	100	9	0	0	
4/1/2015 2:38:50 PM	Spawning wave 2	99	99	99	99	99	100	9	0	0	
4/1/2015 2:39:23 PM	Spawning wave 3	99	99	99	99	99	98	5	0	0	
4/1/2015 2:39:56 PM	Spawning wave 4	99	99	99	99	99	98	10	0	0	
4/1/2015 2:41:18 PM	Emotiontask 1	5	0	0	0	6	95	4	0	0	
4/1/2015 2:41:30 PM	Spawning wave 5	99	99	99	99	99	95	4	0	0	
4/1/2015 2:42:11 PM	Spawning wave 6	99	99	99	99	99	95	9	0	0	
4/1/2015 2:42:51 PM	Spawning wave 7	99	99	99	99	99	95	18	0	0	
4/1/2015 2:44:18 PM	Emotiontask 2	1	5	2	0	0	39	40	0	0	
4/1/2015 2:44:30 PM	Spawning wave 8	99	99	99	99	99	39	40	0	0	
4/1/2015 2:45:08 PM	Player died	99	99	99	99	99	0	50	1	0	
4/1/2015 2:45:19 PM	Spawning wave 9	99	99	99	99	99	100	75	1	0	
4/1/2015 2:47:10 PM	Emotiontask 3	2	0	0	0	6	94	40	1	1	

Fig. 5. An exemplary LiverDefense log file, pertaining to the study design as detailed in Section V (Evaluation); imported into Excel.

Log files are named according to the player name / participant ID that is entered at the start of the game. They are never overwritten, instead all data pertaining to the same ID is accumulated in one file and saved for subsequent analysis.

E. Comparison with Malone's Goals

A comparison of Liver Defense with Malone's goals for successful educational games [7] yields the following results.

Clear and meaningful goals are provided courtesy of the easily understandable game mechanics of the Tower Defense genre. Due to the implicit character of the employed experience-based teaching method, the player is presented solely with the game-related goal of surviving the enemy attacks. Aside from the relative single-mindedness of the defense task, clear and meaningful goals are further emphasised by the distinct display of health points (see Fig. 1, a). The goal is meaningful in that players are given an asset to protect with which they can identify to some extent, i.e. the human liver. The identification is further supplemented by the death screen which says "Your liver is being regenerated. You will be revived in x seconds.".

The display of health points additionally functions as constant *performance feedback* for the player. Whenever enemies reach the end of the path and damage is taken, the display flashes in alarming red. While this does not mean instant defeat, it indicates that the player needs to revise his or her strategy. The same concept is applied to the blood sugar level (see Fig. 1, c), which starts flashing red whenever it falls below or exceeds the optimal bracket.

LiverDefense supports *varying degrees of difficulty* in that several parameters such as initial glucose balance, time between enemy particles, enemy wave composition, and many more can be adjusted.

Fantasy in the game is supported by presenting the player with a playing field that mimicks the inside of the human body on a scale not normally accessible. The fantastic character of the experience is further aided by the employment of cartoon-like graphics. However, in accordance with Clements et al. [18], a substantial degree of realism is retained to ensure basic biological accuracy.

LiverDefense's *complexity* is comprised of various elements. Time is one factor, as well as the necessary development of strategies to achieve the game's goal. *Curiosity and exploration* are promoted via the various tower and enemy types, i.e. liver cells and adverse particles respectively. Players are pointed to an illustration detailing all tower-enemy mappings (see Fig.1, e) in the tutorial, however the tutorial exercises only cover part of that information actively. Thus, players are prompted to explore the remaining combinations during gameplay.

As shown, LiverDefense adheres to the basic principles of Malone's theory. While not being conclusive, this is at least indicative of LiverDefense incorporating the necessary features to provide an engaging experience for learners.

LiverDefense was used successfully as a research tool in a psychological study. The setup and results of the study are as follows.

V. Evaluation

With regard to the tremendous popularity of developing and using games for educational purposes, most explanations regarding why games determine students' emotions in terms of their positive as well as negative valence, refer to their interactive nature originating from the control provided by the game in connection with students' perceived control over gameplay [5]–[7], [34]–[36]. Being in control over gameplay is regarded as enjoyable [37], while a lack of control appears to support frustration [36], [38].

However, it has not yet been fully investigated in what manner external game events (e.g. variation in the degree of difficulty) influence the perception of control, and how the different control perceptions interact with emotions during gameplay. Investigating these emotions in more detail is important as they are deemed to influence engagement and learning in educational settings [39]–[41]. While positive emotions should facilitate performance, negative emotions should be detrimental thereto.
Thus, the aim of this study was to explore whether the extent of perceived control over gameplay (manipulated by varying the degree of difficulty) affects positive and negative emotions while learning with LiverDefense. While a broader range of emotions was investigated in this study, we will focus on the analysis of enjoyment and frustration in the testing conditions, as these serve as examples for positive and negative emotions. In the following, we report on the method and outcome of our study.

TABLE I. MEANS (STANDARD DEVIATIONS) OF PERCEIVED CONTROL AND EMOTIONS, REPRESENTED PER CONDITION

	High control condition (n = 39) (easy difficulty)	*Moderate control condition* (n = 41) (normal difficulty)	*Low control condition (n = 41)* (hard difficulty)
Perceived Control	5.22 (1.41)	4.36 (1.17)	4.02 (1.25)
Enjoyment	4.26 (1.53)	4.29 (1.34)	4.10 (1.21)
Frustration	1.84 (1.21)	2.81 (1.35)	3.35 (1.44)

A. Method

1) Participants: The sample of this study consists of bachelor and master students in the fields of psychology, computer science, economy, biology, and medicine from Ulm University (Germany). Students were recruited via an email that was sent to all students of the university, and an announcement on the university's Facebook page. In sum, one hundred and twenty-one students participated in this experiment. Their age range varied between 18 and 38, with the mean age equal to 22.89 years (*SD* = 3.01). 54.8% of the participants were female and 45.2% were male. Regarding frequency of play, 26.8% reported that they play games every day, and a further 30.1% said they played games up to once a week.

2) Material: LiverDefense was employed as a research tool to elaborate the link between varying levels of difficulty and learners' perception of control, as well as their emotions during play. The highly specific learning matter, e.g. the basic functions of the human liver, made sure that we could acquire a large pool of participants with equally minimal knowledge in the field. Via extensive pre-testing, three difficulty XML files (easy, normal, and hard) were prepared to induce *high*, *moderate*, and *low perceived control* in the intended target group. Easy difficulty made sure the player could survive waves most of the time, even without strategic planning. Normal difficulty required some strategy, yet players would generally still be able to survive the required amount of time. Hard difficulty, however, bombarded the player with a quick succession of enemy particles and shortened the supply of available glucose significantly via the demands of a rapidly sinking blood sugar level. This condition ensured that players would frequently be overrun by enemy particles. The corresponding parameter details for the three difficulty settings were as follows:

Easy:
- initial glucose balance: 35
- time between particles: 2.0
- blood sugar decrease per second: 0.2

Normal:
- initial glucose balance: 25
- time between particles: 1.5
- blood sugar decrease per second: 0.35

Hard:
- initial glucose balance: 20
- time between particles: 1.0
- blood sugar decrease per second: 0.5

Additionally, from easy to hard there were more enemy particles and comparatively less resources to assemble glucose. Time between waves and particle damage were however the same for all three settings. To guarantee equal playing time for all participants, we employed a respawn mechanism not usually found in Tower Defense games. For this purpose, upon losing all health points during a wave, the player was presented with a death screen, after which they could continue to fight the next wave with a set of new resources.
Questionnaires, detailed in the next paragraph, were presented to the participants after the end of each three minute round. Overall, the participants played three rounds each.

3) Measures:
Perceived control: To examine whether the manipulation of control via LiverDefense's three difficulty settings was effective, students' perceived control was investigated once before the game, and at the end of each of the three rounds. Students were requested to indicate how they had experienced being in control of gameplay on a 7-point Likert scale ranging from 1 (= very little) to 7 (= very much).

Emotions: For measuring enjoyment and frustration, students responded on how much of each of the emotions they experienced before and at three points during gameplay; the responses were given on a 7-point Likert scale ranging from 1 (= very little) to 7 (= very much).

4) Procedure: The experiment was conducted in a university computer lab. All participants were randomly assigned to one of the three game versions (easy, normal, and hard difficulty), with each version representing one of the manipulation conditions of control in the experiment: *high control condition* (n = 39), *moderate control condition* (n = 41), and *low control condition* (n = 41). There was no significant difference between the three conditions regarding participant gender (male = 18, female = 21 for the *high control condition*; male = 20, female = 21 for the *moderate control condition*; and male = 18, female = 23 for the *low control condition*).
In the beginning, all participants were introduced to the game elements and mechanics by playing the introductory tutorial previously described. After playing the tutorial, participants completed a questionnaire with respect to their perceived sense of control and emotions; these baseline ratings were used as covariates. Afterwards, participants were invited to play three rounds of LiverDefense, constituting approximately ten minutes and ten to eleven waves depending on the difficulty setting. After each round, perceived control and emotions were measured as described above. During gameplay, participants worked on an individual basis on a computer. They could interact via keyboard and mouse.

B. Results

1) Differences in Perceived Control: First, we investigated whether the manipulation of the game regarding the players' sense of control took effect as intended. For this, we averaged the ratings of control perception over the three rounds of play. A one-way ANCOVA was carried out to discover the differences between conditions with the experienced sense of being in control as the dependent variable, the game conditions as the independent variable, and the sense of control measured before starting the game as the covariate. The means for all three game conditions are summarized in Table I.

The covariate – the perception of control after the tutorial and before starting the three rounds of gameplay – was significantly related to the perception of control during gameplay: $F(1{,}115) = 50.70$, $p < .001$, $\eta^2 = .30$. There was also a significant effect of the game conditions on the perception of control after controlling for the covariate: $F(2{,}115) = 12.26$, $p < .001$, $\eta^2 = .17$.

Bonferroni corrected *post hoc* comparisons revealed that participants in the *high control condition* displayed a higher sense of control than participants in the *moderate* ($p = .002$) and *low control condition* ($p < .001$). Furthermore, there was a significant difference between participants in the *moderate* and *low control condition* ($p = .047$), indicating a higher degree of control perception for the moderate condition. These results demonstrate that the manipulation of the perception of control via the three difficulty settings *easy*, *normal* and *hard* was successful.

2) Differences in Emotions: Next, we explored how participants in the different game conditions differed in their experienced extent of enjoyment and frustration. For both, a one-way ANCOVA using each emotion as the dependent variable, game conditions as the independent variable, and the measured emotions after playing the tutorial and before gameplay as the covariate was performed. Due to missing data the degrees of freedom differed between single procedures. Results showed that the covariate was significantly related to enjoyment ($F(1{,}115) = 114.13$, $p < .001$, $\eta^2 = .49$) and to frustration ($F(1{,}115) = 59.97$, $p < .001$, $\eta^2 = .34$). Also, the game condition had a significant effect on participants' enjoyment ($F(2{,}115) = 3.56$, $p = .03$, $\eta^2 = .05$), and frustration ($\mathrm{F}(2{,}115) = 21.55$, $p < .001$, $\eta^2 = .27$).

For enjoyment, Bonferroni corrected *post hoc* comparisons demonstrate that participants in the *high control condition* reported higher enjoyment, and differed significantly from participants in the *low control condition* ($p = .03$). There was no significant difference between *high* and *moderate*, or *moderate* and *low control condition* ($p = .24$). As expected, frustration was rated lowest in the *high control condition* and was significantly different compared to *low* ($p < .001$) and *moderate control condition* ($p < .001$). Furthermore, significant differences also appeared for the comparison between *moderate* and *low control condition* ($p = .03$).

VI. Discussion

Analysis of the evaluation data shows that the intended variances in game difficulty, as regulated via the XML settings files *easy*, *normal* and *hard*, indeed led to varying levels of *high*, *moderate* and *low perceived control* in the participants.

Analysis regarding enjoyment and frustration indicates that LiverDefense is effective in inducing these emotion via its various difficulty settings in accordance with the theories of incongruity [21] and flow [22]. The lack of significance in cases where both enjoyment and the *moderate control condition* are concerned can be explained by the strategic demands of the game. The peculiarity of a participant's strategic abilities could, in the moderate condition, swing gameplay either way: Independent of the difficulty setting, particularly good or bad decisions could then make the gameplay situation easier or harder; and thus, more similar to one of the other conditions.

Overall, using LiverDefense as a research tool to induce various degrees of control via game difficulty and to collect player data was successful. However, the following limitations of using LiverDefense as an evaluation tool were discovered during this study. To create settings with varying levels of difficulty, extensive testing was required to explore suitable particle parameter values and wave configurations. In order for the settings to have any real-world relevance, they have to be tested by members of the intended target population outside the development team. This does however in turn reduce the pool of potential study participants. There are study contexts for which this can be a problem.

Furthermore, interface layout restrictions imposed restrictions on what kind of questionnaires could be used. Currently, LiverDefense only supports the display of five questionnaire items with answers on a 7-point Likert scale each per frame.

VII. Conclusion & Future Work

LiverDefense is an educational Tower Defense game aimed at teaching players the basic functions of the human liver while adhering to Malone's goals for successful serious games. LiverDefense can be adjusted in its difficulty and display 7-point Likert scale questionnaires throughout the game. Customisations regarding both the difficulty and the employed questionnaires can be done via easily-understandable, human-readable XML files. LiverDefense further supports research studies by saving relevant game events in log files distinguished by player ID. As such, LiverDefense is a useful evaluation tool and can be adapted by non-programmers to fit their needs.

LiverDefense has been successfully used in a psychological study concerning itself with the effects of perceived control on player emotions. Study results have shown that LiverDefense's difficulty can be effectively adjusted. Analysis indicates that this is potentially efficacious in inducing positive as well as negative emotions like enjoyment and frustration.

The next steps will focus on the remaining analysis of the conducted study, namely the effect of perceived control on the emotions boredom and anger, as well as learning outcome. This will provide further insights into the usefulness of games with adjustable difficulty as evaluation tools in serious games research.

To make LiverDefense applicable for more research scenarios, we will look into the possibility of supporting the queXML format for questionnaires [42]. This will free researchers from the limitation of 7-point Likert scale questionnaires and facilitate the integration of LiverDefense with other tools such as the web-based survey application LimeSurvey [43].

To address the underlying problem of creating suitable settings files however, more research needs to focus on which parameters of the employed game elements and which compositions of enemy waves have what kind of effect on the player's level of perceived control over gameplay. Instead of trial-and-error testing of various settings, this would provide researchers with design guidelines regarding game difficulty.

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