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The Virtual Runner Learning Game

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Abstract. A learning game has been developed which allows learners to study and learn about the significance of three important variables in human physiology (lactate, glycogen, and hydration) and their influence on sports performance during running. The player can control the speed of the runner, and as a consequence the resulting physiological processes are simulated in real-time. The performance degradation of the runner due to these processes requires that different strategies for pacing the running speed are applied by the player, depending on the total length of the run. The game has been positively evaluated in a real learning context of academic physiology teaching.

Keywords: human simulation, physiology, game-based learning, running, sports.

1 Introduction

Gamification is a concept which has in recent years been applied to many domains, for example in making social media more engaging [1] or even designing business software [2]. While there is often some confusion about the exact definition of *gamification* [3], it appears that one of the main driving forces which bring users to do certain things is *competitiveness*, and in a game-like setting users would try to get the best score by deeply engaging with the game. This is related to the concept of *persuasive design* which has been proposed by Fogg [4] and has found its way into learning and teaching [5]: for example, the EuroPLOT project has examined four case studies with applications of persuasive technology for educational contexts.

Physiological processes in the human body are a difficult subject to learn and to teach, and students often struggle to cope with and understand the complex interdependencies of large numbers of variables. Since the overall knowledge of human physiology nowadays is relatively well established, models have been developed to simulate human physiology by computing algorithms, e.g. [6], which can be used by learners to test how the human body reacts to changes in environmental factors or activities. These models alone are, however, often not persuasive enough for enticing students and learners to engage with. Therefore, we have developed a game around a simple simulation of physiologic processes, in which

the players can simulate activity and observe the effect of this activity on a set of physiological variables.

For our simulation, we have chosen the activity of running. The variables which we are simulating are the important physiological variables *lactate*, *glycogen*, and *hydration*. In this single-player game, the main task is to run a given distance in the shortest possible time. The player can hereby control the “effort” which the runner puts into the run. This effort translates into a running speed, but as the runner keeps running, the physiological processes limit the speed which the runner can achieve. This is reflected in the simple fact that for a short distance run, the runner needs to run as fast as possible, whereas for a long distance run, the runner needs to run at a slower, optimal pace which represents a speed which the runner can sustain for a long time. Through experimentation with the speed control, the learner can experience the different effect of running with various speeds. Also, at the end of each run, data of these three physiological variables are shown in 2D plots, which illustrate the influence which the running effort has on them.

An earlier version of the software [7] was developed using Macromedia Director and was tested with students in a trial, showing good results. The software has since then been replaced by a full 3D game with a graphical model of a runner and stadium environment. The software has been tested on two occasions with actual academic learners, students of Sports and Exercise Science at Leeds Metropolitan University. This paper provides a description of this learning game and some conclusions from the most recent evaluation of this software in an actual teaching class of 10 students. While this evaluation would need to be expanded to a larger number of learners, it provides some conclusive feedback and indicates the overall positive reception of this learning game.

2 Background and Related Work

The *Virtual Runner* learning game has employed the principle of interactive simulation with which learners can explore the effect of running speed on human physiology during running, and in turn observe the effect of these physiology processes on the attainable speed. The learning method is based on the general concept of gamification which in recent years has received increased attention as a means to convey this knowledge and information in a more intuitive way. There has been a lot of research conducted [8] which confirms the success of gamification and which has led to a deeper understanding of the involved learning design principles.

The simulation is centered on three physiological variables which are relevant during physical activity during sport and exercise: *lactate level*, *glycogen level*, and *hydration*. The following section describes the scientific background of these physiological processes which form the foundation of the simulation.

2.1 Physiology and Biochemistry during Physical Activity

During aerobic exercise several physiological processes interrelate to provide energy in the form of adenosine triphosphate (ATP) to the working muscles. Each contraction

cycle of a muscle fibre requires the breakdown of ATP to energise repeated movement. In order to maintain repeated contractions a complex relationship of energy providing systems are implemented to replenish ATP from the body's fuel stores, namely carbohydrate (as glycogen and circulating glucose) and fat stores [9].

Three major pathways operate synergistically which provide this energy from carbohydrate sources during exercise, the predominant fuel source above intensities of ~ 60% of an individual's aerobic capacity [10]. The balance of these pathways is determined entirely by the intensity of exercise, where endurance events rely on an intricate balance between these three systems, with oxygen dependent oxidative phosphorylation predominating. However, if exercise becomes shorter in duration with a need for more speed and power, such as sprinting, this pathway cannot maintain ATP re-synthesis at a high enough rate. In order for this to occur, 2 non-oxygen dependent pathways exist, the ATP-CP (creatine phosphate) system, which can provide energy for about 10 seconds of maximal effort, and the glycolytic system (glycolysis), able to provide approximately 2-3 minutes of energy provision at very high intensity exercise.

Dietary carbohydrate, stored as glycogen in the body, provides the fuel for both glycolysis and oxidative phosphorylation, whereby it is ultimately broken down to glucose for use in these pathways. Glycogen stores are limited in the elite athlete to provide energy through glycolysis and oxidative phosphorylation for approximately 90-120 minutes of hard exercise. The level of glycogen stores will determine the maximum duration of carbohydrate fuelled endurance exercise, and will act as the main source of ATP re-synthesis in higher intensity and shorter endurance events. In the game, the simulation of the glycogen level is being modelled through a steady reduction of the glycogen reservoir, thereby reducing the glycogen store. This is specifically relevant for long-distance runs, where the glycogen level is significantly reduced during the running activity.

During high intensity exercise, the end product of glycolysis, pyruvate, is predominantly converted into lactate as oxygen availability is not high enough to maintain adequate ATP re-synthesis and demand by oxidative phosphorylation. The conversion of pyruvate to lactate is reversible, but only in the presence of oxygen. Only a limited production of lactate is possible before exercise can no longer be maintained. Therefore, lactate acts as an excellent indicator of exercise intensity and as a threat to exercise fatigue. The accumulation of lactate happens on a very short time scale and does immediately reduce the runner's capability to sustain running at maximum speed. In the game, this is modelled as an increase of the lactate level that is proportional to the running speed. After a certain threshold of lactate has been exceeded, the negative effect of lactate is influencing the maximum possible speed that the runner can achieve.

The human body is exceptionally adept at balancing the demands of exercise with fuel availability and fatigue being the key determinants of performance. We are by and large aerobic machines, capable of extremely long, sustained performances. However, our evolution has developed a 'sprint capacity' in order to engage a 'fight or flight' response to danger. Generally speaking, the sprints or higher intensity efforts are sustainable for a much shorter duration as lactate accumulates, indicating fatigue. When longer duration exercise is necessary, the sustainable intensity will be lower to enable the body to reach a state of exercising homeostasis, or steady state

exercise that balances the production and disposal of energy producing by-products. The exercising body is not only affected by the forced rate of lactate production, it is also limited by the quantity of glycogen available in liver and muscle. In addition the production of heat during exercise is controlled by sweating to maintain body temperature but at the cost of some dehydration.

Hydration in humans is generally well regulated at rest, however when homeostasis is disturbed by exercise a series of complex mechanisms are utilised in an attempt to maintain fluid balance. Dehydration is not uncommon in runners, particularly those in long distance events and even more so during exercise in the heat. It is generally accepted that dehydration as little as 2% of body weight can impair exercise performance. Not only can dehydration lead to a performance deficit in runners, but hyperhydration can also have an ergolytic effect due to hyponatremia [11]. Although dehydration generally has a negative effect on running performance, some marathon runners can still perform well in a dehydrated state with over 2% loss of body weight. During exercise, hydration is an acute matter rather than chronic, as it would usually be in clinical situations. In the game, the hydration is simulated as a loss of liquid during long-term distance running. The reduced hydration has a negative influence on the possible running speed, reducing the maximum speed that can be reached. The simulation also allows the gamer to refill the hydration level by simulating that an amount of liquid is taken in.

These are the relatively complex processes which a learner of sports physiology needs to learn. The game that we have developed is targeted to making such learning easier and more intuitive than conventional learning from a textbook. Learners need in particular to learn that an equilibrium needs to be chosen in which the lactate production is compensated by an equivalent lactate disposal which also occurs during physical activity.

The simulation of these processes in the game is implemented as follows: the three variables lactate level, glycogen level, and hydration are set to initial values (which the user can set). As default, glycogen and hydration are set to 100%, lactate to 1 mmol/L, so as to provide ideal starting conditions. For experimentation with non-ideal initial conditions, these values can also be set to other values. When the player starts the game and makes the runner run at a certain speed, these variables are being updated in regular time intervals (1/10 second), taking into account the established relations between the current running speed and the history of this particular run. This is where the overall simulation becomes non-linear: the state that is comprised of those three variables has an influence on the possible maximum speed that can be achieved. The player can try to run at 100% effort, but this maximum speed cannot be achieved by the runner at specific states during the run, as any disadvantageous state reduces the possible speed.

2.2 Gamification

The use of game play in learning and the success of this approach in terms of improved engagement of the learners have been documented in numerous publications (e.g. [12]). One of the main factors in this success is the high motivation of players when they play a game [13], fueled by the element of competition [14]:

learners are willing to put more effort into an activity if the reward is to be better than other competitors.

Another element of game-based learning is the constructivist learning approach [15] which is inherently present in a simulation, where players/learners can experiment with the simulation, try out a variety of options, and build the knowledge of the domain to be learned about. Such a simulation is also a safe way of exceeding possible boundaries (of safety) which cannot be exceeded in a real experiment. Such simulation and experimentation leads to a richer experience of the subject to be learned.

In this game, the player is taking the role of a single runner, trying to achieve the best running time for a given run distance. The means for achieving this are choosing the optimal speed and effort, which influence the three simulated variables in such a way that their effect on reducing the running speed is minimized.

3 The Game

In the learning game *Virtual Runner*, we have implemented the above mentioned principles of simulation and game play, and have linked it to a set of lesson plans which we have prepared in order to achieve given learning outcomes. This allows the game to be used in an educational context within a curriculum and a set of learning objectives.

3.1 Technical Background and Design

The learning game has been developed for Windows. It has been tested running on Windows XP, Windows 7, and Windows 8. It was written in C# and requires the Microsoft .NET 4.0 framework [16] and the Microsoft XNA framework [17] (for the 3D graphics). An installer will provide automatic installation of these components.

The graphical user interface (GUI) is using mouse input to select menu items for configuration and operating the game. Configuration data are stored in XML files, which also can be edited offline during the debug phase of the software development.

The running simulation itself runs at a rate of 10 Hz, to provide real-time update of the lactate level, glycogen level, and hydration level. For long-distance runs (Marathon), the simulation is sped up to faster than real-time to avoid the long waiting time to complete the run.

The 3D models for the runner and the stadium were purchased and were then modified in 3D StudioMax. The animation of the runner is controlled as a function of the running speed. The runner is following the trajectory of the oval course in the stadium, and the player cannot control the running direction. This was made so that the interaction by the player is as simple as possible. The viewpoint of the virtual camera is behind the runner, directly following him, so that the player has the runner in constant view. The interaction of the player is kept to a minimum, so as to avoid distractions and focus on the main objective, which is to find the optimum speed profile for the running pace.

The game is a single-player game, in which the player tries to optimize the running times of the controlled runner. Direct competition is currently not implemented, but may be in the future, through networking with several instances of the software. What is possible in this version is to define several individual runners and run them consecutively. They would show up in the common running score board, and a competitive play would allow to compare the results directly in this board.

3.2 Playing the Running Game

The game is designed as a single-person game, in which the player has to control the running speed of the sole game character, the *Virtual Runner*, to obtain fastest running times at given distances. The achieved running times are kept in a scoreboard, and several users on the same computer can run the game by keeping individual profiles in the software.

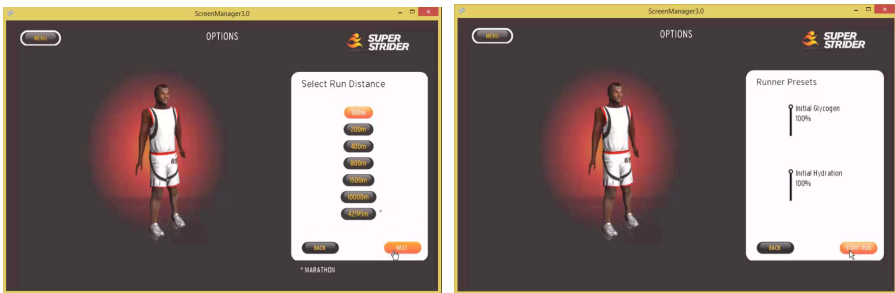


Fig. 1. Configuration of the Virtual Runner at startup. Left: selecting the distance. Right: choosing initial levels of glycogen and hydration.



Fig. 2. The main 3D running view of the game. The *central widget* shows lactate level and speed, and the yellow lever on the centre-right side can be moved with the mouse to control the runner's speed.

After configuring the runner (weight, age, gender), the user can select a given distance (see Fig. 1, left) and initial hydration and glycogen levels (see Fig. 1, right) before starting the run. Currently there is only the visual representation of a male runner present, but we plan to provide a choice of a female runner as well.

The widget to control the runner's speed is a yellow lever which the player needs to move upwards to set the user's running speed. This in some way is a metaphor of a ship's speed control. The position of this lever does not directly indicate the actual speed, but the "intended" speed and hereby the "effort" with which the runner tries to run. If the lever is placed at the top level, the maximum possible speed is run, but that speed will then get reduced to the "attainable speed" which is limited through the boundary conditions of the physiologic parameters. This widget also indicates actual speed through a blue indicator on the right side next to the speed lever. At the left side, the lactate level is shown in orange (see Fig. 2). In an earlier stage of the development we did consider to employ a keyboard-based speed control, in which the player would need to press alternating keys, simulating the running movement of the legs. We have, however, abandoned this idea because the physical activity by the player would distract from the observation of the physiological processes. Instead, the smooth operation with a lever was chosen, because this needs not constantly to be moved and can be left at a fixed setting, allowing the player to observe the levels of lactate, glycogen and hydration.

After the run has been completed, the screen shows the final state of the simulation with the levels of lactate, glycogen and hydration. In addition, the running time is shown as well as average speed and final speed (Fig. 3). The user then can see graphical plots of these data over time or distance (Fig. 4).



Fig. 3. Results after a completed run. The table shows levels and running data (right). Also the top scores for the specific running distance are shown (left).

3.3 Learning Outcomes

This game is designed to achieve the following learning outcomes:

- Understand the influence of lactate level, glycogen level, and hydration on running performance.
- Understand that different running strategies are necessary for achieving best running times in different running distances.

Short-distance runs are basically run at full speed, without regard of the simulation of the physiology parameters. It can be seen that an untrained person will build up higher levels of lactate which then in turn limit the performance of the runner, leading to longer running times.

During longer-distance runs, the runner need to take into consideration the lactate level, and therefore needs to reduce the speed in order to prevent build-up of the performance-limiting lactate.

For a Marathon run, there are then additional constraints due to reducing levels of glycogen and hydration. The runner can replenish the fluid levels by drinking water when the low hydration level becomes limiting to the runner's performance.

The graphical plots allow the player to review the run and the strategy by looking at the levels over time or distance and can draw conclusions for the optimal strategy (Fig. 4).

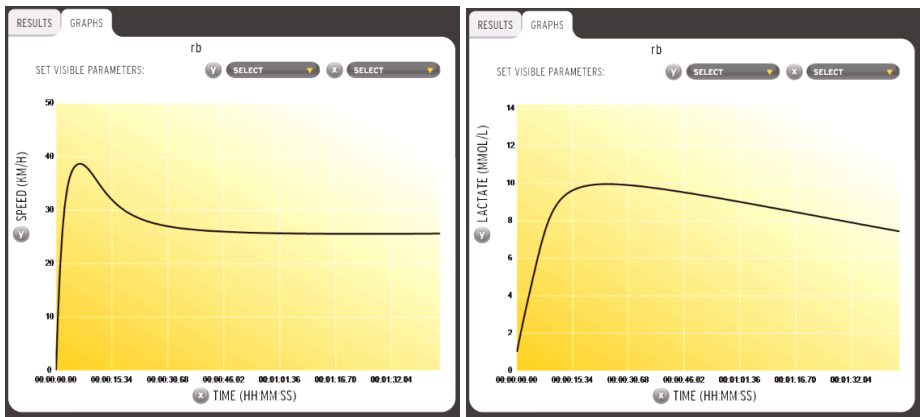


Fig. 4. Graphical plot of a trained athlete's running speed (left) and corresponding lactate level (right) over time.

4 Evaluation

A first evaluation of the *Virtual Runner* game was conducted in February 2012 with 8 students. The purpose of that evaluation was to determine if the user interface was appropriate and if the users would accept such a software in principle. The feedback from this earlier evaluation was then used to guide the development of the final version of the software and to improve certain interface aspects.

In November 2013 a second evaluation was done in a Nutrition Applied Practice class of 10 MSc students of Sport and Exercise Science. We prepared a tutorial from our lessons plans, which we had devised earlier as means of using the game in an educational context. The students were presented with the software on laptop computers, and after a short introduction, they could then operate the game, sharing one laptop computer among two students. The students were given the specific challenge to simulate running a distance of 800m and to observe the lactate level for various running speed profiles. At the end of the tutorial each student filled out a questionnaire with 7 questions. While these 10 students do not represent a sample that can be generalized over a wide population, it can give an indication of the use in the educational context for which this learning software was developed.

When asked to determine the best method of learning about human physiology among the options; game simulation software, traditional lecture, and a blended learning approach which would combine both, all the respondents agreed that the blended approach would work best.

Two of the ten students claimed that they did not learn anything new by using this game, as they already knew about the lactate influence on performance. But 80% of the students did learn something new by using this game. In particular, 7 of these 8 students did learn about the relationship between lactate and performance.

Only one of the 10 students was an occasional game player. The others never played games. This appeared to be a quite unusual situation, since we had expected that more students would be engaged with games. Yet none of them did have any difficulties playing the game and understanding the mechanics of operating it: all of them understood the operation of the game and the point of the simulation. One of the 10 students did state that the operation of the software (setting the speed) was somewhat unclear, but 90% of the students found the software clear and intuitive to use.

When the students were asked to answer four assessment quiz questions related to lactate, two of the questions were answered correctly by all of the students, and one correctly by 70% of them. The fourth question turned out to have been worded in a way that led to a misunderstanding, and was only answered correctly by 20%.

Overall, this evaluation indicates that this learning game has a positive reception by the learners, who indicated that they did indeed learn something through the engagement with this game.

5 Conclusion and Outlook

The evaluation of the *Virtual Runner* learning game has given us confidence that such a tool is very good for use in blended learning, and that also students who are not familiar with gaming can use such a learning software game easily. All of them were aware of the simulation nature of that game, and most of them did learn with this game in an intuitive way. Based on the feedback, some minor tweaks in the operation of the software will be implemented before further evaluation will take place.

The software is almost completed for final release, and we envision publication with learning material as part of a text book.

The simulation algorithm and the ability to predict lactate, glycogen and hydration can also be used in a mobile application which would take into account not the arbitrarily set speed, but the real speed of a runner. We have begun to develop such an application for a mobile smartphone which would then allow runners to monitor their physiological status in a live and real run.

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