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Adaptation Model for Indoor Exergames

Sandro Hardy, Stefan Göbel, Michael Gutjahr, Josef Wiemeyer, Ralf Steinmetz
Technische Universität Darmstadt

Abstract

In this paper we propose an approach towards adaptive long term motivating and physically demanding exergames for indoor training. Various previous approaches use ergometers (especially ergometer bikes) in interactive applications (mostly virtual cycling simulations) since decades, nevertheless exertainment applications for indoor training are not applied in a broad range. In this paper we present a structured analysis of existing commercial and scientific approaches towards interactive indoor training. On this basis a concept and model for adaptive exergames was developed. Exergames based on this concept are usable with different devices and provide adaptation possibilities for the psychological as well as the physiological needs and properties of different end users. In this way the proposed concept integrates the diverse dimensions of Sport, Game and Technology.

SERIOUS GAMES, GAMES FOR HEALTH, EXERGAMES, ADAPTATION, INDOOR CYCLING

Introduction

Lack of exercise is a global phenomenon (World Health Organization, 2010). Exergames, which promise to combine the motivational aspects (affects) of gaming and the effects of exercise on constitution and health became more and more popular in the recent years. With this development they became the focus of scientific studies. Various authors investigate the effects of playing exergames and analyze if exergames raise the human energy expenditure (EE) adequately (Baranowski et al., 2008; Wiemeyer, 2010) and if their effects are comparable with the effects of regular sports and exercises (Brumels, 2008; Kliem & Wiemeyer, 2010). Most studies concentrate on commercially available and popular exergames, such as Wii Fit or Dance Dance Revolution (DDR). The studies verify, that exergames raise the human EE significantly (short-term effects) and that playing these games can improve balance, reaction and coordination (Brumels, 2008; Kliem & Wiemeyer, 2010). Compared to regular sports and exercises the effects of those commercial exergames are low and do not always meet the minimum recommendations for physical activity.
The reasons for the different effectiveness of exergames and regular exercises with regard to physical training have rarely been investigated. Since the studied games have been developed with the focus on a maximum amount of entertainment and acceptable price of sale, it can be assumed that the sport and training science aspects played a secondary role in the design and development process of these games.

It thus remains an open question if it is possible to develop exergames that reach a similar long-term effectiveness as conventional training methods. If this is the case, these exergames should ideally be attractive and motivating for a long period of time. In order to achieve this goal, Exergames have to fulfil seamlessly multiple requirements from the different expert domains of Gaming, Sports and Technology as shown in Figure 1.

Exergames must be of a high quality from the playful perspective to be attractive, they need to be adaptive to provide a low barrier to entry for newcomers. At the same time they need to provide enough challenge and difficulties for more experienced users, otherwise they will loose their attractiveness and challenge after a very short period of time.

From the perspective of sport science the Exergames must pose an adequate load for optimal adaptation. If the load (particularly intensity, duration and density) is too high or too low adaptations will be suboptimal. In addition, overload may lead to over-reaching, over-training, or injuries. Therefore adaptation technologies for the training stimuli are required. The technologies have to combine, unite and match the sportive and playful aspects in a seamless way. It is not sufficient to add some playful elements to a regular training exercise, or vice versa, to add some exercise to a regular game.
Since exertion games, in contrast to regular computer games interact more with the human body the requirements concerning the used hardware and software are different. The hardware requires sensors to capture and measure human movements with sufficient accuracy and without bothering the player as well as actuators (Visualization, Hap tic, Force Feedback) to provide different kinds of feedback to the player

To fulfil all these requirements from the different domains Gaming, Sport and Technology and to seamlessly integrate those into Exergames it needs concepts and models to describe and analyse the impacts and influence of possible solutions for those requirements. The solutions for the requirements, as they are used in the expert domains alone can not be simply plugged together.

In the following sections we describe existing commercial and scientific approaches for the application field of indoor cardio training and analyse which aspects of the different domains they fulfil. Based on this analysis we build up a theoretical model, consisting of components, modules and interdependencies which play a role for the development of exergames. To evaluate this model we realized a prototype for the application example indoor cardio training. The prototype was evaluated in a study with *n*=48 participants which showed tendencies for the mode of operation of singular modules.

Related Work

For the playful realisation of indoor cardio training there already exist various approaches. The existing approaches realize a selection of aspects modules of the proposed model in different ways. Commercial applications for the field of indoor cardio training are mostly available as add-on to regular training ergometers, or as a combination of video games with special ergometers as game controllers. The existing scientific approaches mostly focus on the user experience of exergames (Thin, 2010).

The approaches can be classified with regard to the used hardware and the type of the interaction in the application (see Table 1). The hardware can be differentiated between stationary regular bikes equipped with a roller break to be used indoors (Tacx), regular cycling ergometers (Daum, Kettler), and special game controllers (XRBike, Cyberbike, Fisher-Price Game Bike). The regular bikes provide realistic haptics, look and feel, and realistic usage since they are equipped with brakes and gearings. The cycle ergometers are developed for indoor use only with adjustable resistance, but without brakes and gearing, they run more silent and have no possibilities for steering. The game controllers provide steering, sometimes also a brake but rarely digitally adjustable resistance, which is needed to adapt the training load to the fitness level of the player during gaming.

Table 1: Classification of different approaches for interactive cardio training.

	Bike	**Cycling-Ergometer**	**Game-Controller**
Game	VR Race (Tacx)	*ErgoActive*	XRBike, Fisher-Price Game-Bike, Cyberbike (BigBen)
Simulation (Video, 3D-Cycling)	VR-Trainer (Tacx)	Ergoplanet (Daum), Tour Concept (Kettler)	Puffer (ATARI)

Theoretical models for the effects of exergames base on the "Flow" theory (Csíkszentmihályi, 1975). Flow is the state between boredom and anxiety, it can be reached if an exercise is challenging, but not too difficult. The Gameflow (Sweetser and Wyeth, 2005) adapts the Flow Concept for Computer games (see Table 2).

Since Exergames combine computer games and exercises, they need to provide not only the adequate level of psycho-physical load. The Dual Flow Model (Sinclair, Hingston, Masek, 2007) adapts the Flow theory and accordingly the concept of Gameflow to exergames. Following the Dual Flow model the Flow in Exergames must be divided in Attractivenes (psychological Flow) and Effectiveness (physiological Flow). To match the Effectiveness, the physiological level of Flow or right level of exertion a system for heart rate adaptation (Sinclair, Hingston, & Masek, 2009) can be used.

Table 2: Comparison of Flow (Csikszentmihalyi, 1975) and Gameflow (Sweetser and Wyeth, 2005)

Flow (Csikszentmihalyi, 1975)	Gameflow (Sweetser and Wyeth, 2005)
Balance between perceived skills and perceived challenge (the activity is neither too easy nor too difficult).	Challenge - games should be sufficiently challenging and match the player's level of skill.
The merging of action and awareness.	Concentration - games should require concentration, and the player should be able to concentrate on the game.
Clear goals (expectations and rules are discernible and goals are attainable and align appropriately with one's skill set and abilities).	Player skills - games must support player skill development and mastery.
Unambiguous feedback (successes and failures in the course of the activity are apparent, so that behaviour can be adjusted as needed).	Feedback - players must receive appropriate feedback at appropriate times.

Concentrating and focusing, a high degree of concentration on a limited field of attention (a person engaged in the activity will have the opportunity to focus and to delve deeply into it).	Clear goals - games should provide the player with clear goals at appropriate times.
A sense of personal control over the situation or activity.	Control - players should feel a sense of control over their actions in the game.
A loss of the feeling of self-consciousness (no feelings of self- doubt or self-concern).	Immersion - players should experience deep but effortless involvement in the game.
Transformation of time (one's subjective experience of time is altered).	Social interaction - games should support and create opportunities for social interaction.
Auto telic experience (the activity is intrinsically rewarding - it is undertaken for its own sake).	

To verify, to extend and to understand the interaction between the components of the Flow, Gameflow and Dual Flow theory in exergames, and further on to try out different ways auf realizing these components it is necessary to develop exergames which provide different levels of adaptation. By adjusting single aspects and their influence on the complete system can be measured. Since the three concepts only deal with the "human" aspects and leave out technological influence the model needs to be extended.

Concept and Model

To investigate the effects and the interaction of individual parameters for the successful use of Exergames, it is necessary to identify them and to modify and adapt them independent of other influencing parameters. Besides the theoretical concepts described in the related work, the model presented here also contains aspects gained by explorative studies with different prototypes for exergaming (Göbel, Hardy, Wendel, Mehm, & Steinmetz, 2010).

As described in the introduction, aspects from the domains of Gaming, Sport and Technology are relevant for the development of exergames (Göbel, Hardy, Cha, El Saddik, & Steinmetz, 2011). Various aspects of the different domains influence each other and influence the Attractivenes, Effectiveness, Flow, User Experience and Gameflow Experience (Nacke, Drachen, & Göbel, 2010) of the games. To investigate the mode of operation of all these parameters need to be considered separately. Figure 1 shows the previously identified three domains (Göbel et. al., 2011) with a selection of examples for their constituent parts.

Figure 1: Relevant Domains for the Development of Exergames and their constituent parts

This model is now elaborated and improved. The aspects relevant to the development of exergames can therefore be identified as the application-specific “Hardware”, “Software”, and the human “Psychology” and “Physiology” as shown in Figure 2. Both cannot be considered separately, since they influence each other. The Software component and its modules “Gaming” and “Training” as well as the psychological component with its modules “Effectiveness” and “Attractiveness” can be modified during gaming, so they are classified as adaptive. The “Hardware” as well as the physiological characteristics of the player can not be influenced during gaming, so they are classified as static.

The Software can be a single game, a fixed or variable sequence of different minigames as well as training or gaming analyses, high score lists, training information or entertainment units. The content expression, such as training configuration or style can be determined at runtime. This way, by changing its content, the software can modify its effects on the player at runtime. This leads to different characteristics of the application with respect to the Flow, Gameflow, Dual Flow and User Experience. It can be assumed that this also leads to different psychological impacts on the player. For instance, different levels of immersion, fun, immersion, arousal and so on. By changing only one parameter, while measuring the effects to the player or in studies with several players and different setups while keeping all other parameters at a fixed level, the effects of single parameters can be quantified.

The whole Software of an Exergame is commonly called „Exergame“ or „Game“. If we consider adaptive exergaming, it is necessary to separate between at least two components in the application. In Figure 2 all for the parameters relevant to gameplay (everything which influences the Attractiveness), such as Game Concept, Game Logic, visualisation, design, and visual feedbacks must be considered separately from the sportive and training control elements (everything which influences the Effectiveness).
This does not mean that one side is more or less important than the other one – they can not compensate for each other – but to identify their impacts on the game they need to be adjusted and researched separately.

In which way the different aspects influence the psychological effects of the the application needs to be considered separately. The Flow aspect of challenge for example can be influenced by the cognitive (gameplay) challenge as well as the (physiological) training load. In cardio games, the training challenge is more or less physical exertion. I other scenarios, with coordinative elements, the physiological and cognitive challenge cannot be completely distinguished. To reach the "Flow" level both, gaming challenge and training challenge need to be balanced.

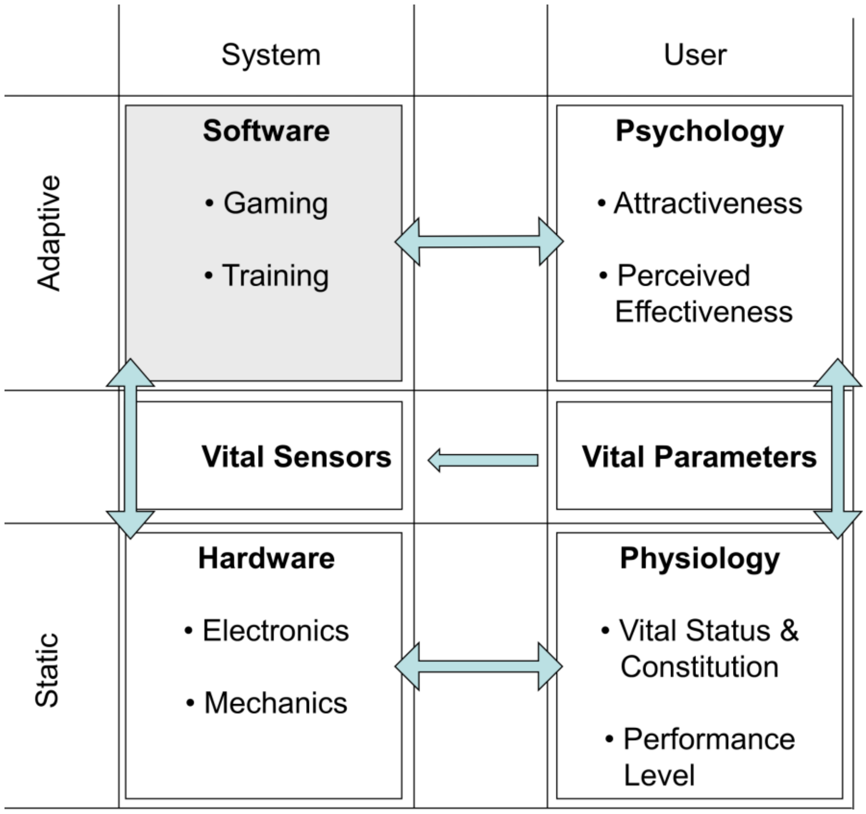

Figure 2: Refined Model of the relevant aspects for the development of Exergames

The "Training" module of the software component includes the relevant elements and functions for the adaptation of all parameters relevant to successful training. We assume that the control of these parameters directly influences the perceived Effectiveness of the player. The control itself follows guidelines of training in sport. To provide precise adaptation parameters the perceived exertion and vital parameters of the player play an important role. The perceived exertion is an indicator for the player's feeling, it includes daily variability in fitness, fatigue and pre-exhaustion. It must be collected by asking the user, which interrupts the game (Borg, 1998). A second basis for the training adaption is the vital state given by the vital parameters of the user. By the use of sensors this data can be accessed in real-time and therefore be used for real-time adaptation. In example, the resistance of an ergometer bike can be adjusted, so that the game is played at a predefined heart rate. One difficulty for the calculation of adequte training parameters is that the calculation base on the performance of the individual user. This needs to find ways to measure the fitness of the player in a safe way. The needed sensors as well as the actuators belong to the "Hardware" component. For the adaptation it is not relevant if the heart rate is measured by an ear clip, a finger tip or a chest belt. It is also not relevant for the adaptation if the resistance is controlled by a mechanic, magnetic or electronic brake as long as there is no undesired change or variability.

In contrast to classic video games, which are mostly controlled by mouse and keyboard, rarely by (force feedback) steering wheels, the used hardware plays an important role. While playing exergames the player interacts physically with the hardware. The mechanical elements (shape, haptics) of the hardware as well the electronic elements (sensors and actuators) define the possible usage of the device. All these elements are static during the play of a game, they cannot be adapted. This is similar to the constitution of the player, his size and abilities (very important in rehabilitation) do not change significantly during one playing session. So the hardware as well as the constitution of the player can be considered as consistent. The hardware can have changeable components, a controller in an exergame for rehabilitation for example may need different grab handles or the saddle and handle bar of an ergometer can be adjusted. Those mechanical changes are done before the play so they can be considered as static during the game. To ensure a valid comparison of games, those settings must not influence the game (a grab handle, saddle or handle bar must be adjusted in an adequate way before starting the game).

A further aspect of the hardware, which could be considered as dynamic part is for example the adjustable brake of an ergometer bike to change the resistance. This brake system is controlled by the “Training” module of the software, so the control and dynamic are part of the software. The fixed parameters such as maximum braking power, reaction time belong to the static specification of the hardware. Those specifications can play an important role. If they do not fit the needs of the game – for example if the brake is too weak – the “Training Control” cannot work properly and the “Effectiveness” can not be matched. The static parameters (mechanical, functional or haptic properties) of the hardware can also influence the User Experience of the whole system. A real bike provides a more realistic feeling than an cycle ergometer and in this way can impact the perceived immersion.

In sum all these factors play an important role for the User Experience. To reach a high degree of user experience, all factors have to be considered. For the quantification of the impact of adaptation methodologies and algorithms those factors need to be identical. For example to compare to different games they need to be evaluated with the same hardware to eliminate misleading influences.

Implementation

In order to evaluate the proposed model a prototype called *ErgoActive* was developed which implements three different concepts of gameplay (three types of Attractiveness) and provides the possibilities to adjust several parameters relevant for training (adaptive Effectiveness). The prototype has an interface (RS232, Bluetooth SPP) for different training devices, it can be used with a treadmill, an elliptical trainer or a cycle ergometer. All three minigames can be played with these three devices. For the evaluation the cycle ergometer was chosen.

In the minigame ”ErgoActive Video Cycling“ (ErgoVideo) a previously recorded video is played according to the speed of the player cycling on the ergometer. The faster the player cycles the faster the video plays, if the player stops cycling, the video will also stop. The recorded track includes GPS data such as position and height of the track. The height information is used so modify the resistance according to the inclination of the track, which should convey a realistic feeling. The application has no reactive elements. Since it is a video recording the quality of the visual appearance is very realistic. The user can choose between different tracks, recorded at different seasons and places (winter, summer, hills, and flat land). The initial resistance can be adjusted and if the inclination of the track is too high the player can reduce the resistance of the cycle ergometer manually. The Minigame ErgoVideo can be controlled via the mode speed, using cadence or heart rate as a control parameter is technically possible but note reasonable for the current gameplay.

Figure 2: The used ergometer-cycle (left) and a player playing Pigeon-Hunt (right)

The MiniGame ”Pigeon Hunt“ is a classical comic-style side-scroller game. It uses a definable input parameter such as speed or cadence (rpm) to control a flying bird. By changing the parameter, this means increasing or decreasing the cycling speed, the player controls the height of the bird. This way he can earn points by collecting letters which enter the screen from the right side. The faster the letters are, the more points the player will get. The players learn fast to get a feeling for the speed. Since there is a time delay between the changing speed and the reaction of the bird, collecting the letters is a challenging task. The resistance can either be adjusted manually or it can be automatically adjusted according to special training goals as described later.

The MiniGame ”Ergo Balance" is a combination of ”Shoot-Em-Up“ and ”Skill Game“. The screen shows a clown balancing on top of a ball. The player needs to keep the input parameter (heart rate, speed, cadence) at a fixed level in order to keep the clown balancing. If the player cycles too slowly, the clown will fall to the left side, if he cycles too fast, the clown will fall to the right side. At the same time the player has to click with a mouse at balloons falling down in order to gain points.

The Configuration-Interface provides access to the Training Control API (TCA) of all three minigames. Each Configuration can be saved with as a profile with a unique name. The parameter “mode” defines which sensor value is used to control the game. ErgoBalance allows for speed, cadence and heart rate as attributes for the control parameter mode. The game “Pigeon Hunt” allows speed and cadence as mode. Using the heart rate as control parameter is technically possible, but does not make sense according to the game concept and gameplay in the current version. The heart rate cannot be changed so quickly that it would be possible to collect the letters.

For each of the individual modes (heart rate, cadence, speed) the targeted average value as well a maximum and minimum value can be defined. The average value is the value which keeps the controlled game element at the "regular" position. For the Pigeon game the bird is flying in the middle, for the Balance game the Clown is standing upright if the average value is reached. The minimum and maximum values define the allowed interval, if the target value is out of the range, the bird dies and the clown falls down. The size of the interval defines the coordinative difficulty of the game. A smaller interval needs the player to be more precise. For the speed values from 20 to 35 km/h with a stepping of 5 km/h are allowed. The cadence can be set from 60 to 140 rpm in steps of 10 rpm. The target heart rate is allowed to set from 80 to 220.

Figure 3: Screenshots of the Minigames ErgoBalance (left) and Pidgeon Hunt (right)

The exertion of the games depends partially on the above mentioned control parameters. Furthermore the duration of the game and the resistance of the ergometer can be used to control the overall exertion. The duration can be set in steps of 1 minute from 1 to 60 minutes. The cycling power of the bike can be adjusted from 60 to 200 Watts. The resistance is adjusted dynamically and keeps the power depending on the current cadence, this allows following training guidelines nearly independently from the gameplay. Alternatively to these fixed setting a dynamic adaption algorithm allows playing at a specific heart rate for the defined amount of time, this mode is called heart rate adaptation. The desired heart rate range can be calculated automatically, corresponding to defined training goals.

$$h = p/100 * (220 - a)$$

With heart rate h, age a and the percent p of maximum heart rate (Robergs & Landwehr, 2002). The value p depends on the selected training goal. The concrete settings the parameters which control the training stimuli, depend on training guidelines set up by experts. The Training Control API provides only the control possibilities.

Evaluation

The evaluation was performed in a gym accompanied by a squash court. All participants took part voluntary and unpaid. The participants were informed about the general concept of interactive indoor cycling and that the study will be about their personal opinion of the games.

The sample contains n=48 participants (age 14-64 years, M=31.69 years, SD=14.82, gender distribution: 70.8% male, 29.2% female).

As a first step the participants filled out a questionnaire about gender, age, sportiness, TV watching and computer use per day and their estimated personal fitness level. As an indicator for sportiness and TV watching the participants were asked how many minutes per week they are engaged in sports and how many minutes they watch TV or use the PC.

Fitness level	Power (Watt)
Excellent	140
Good	120
Average	100
Sufficient	80
Poor	60

Figure 4: Setting of the Power/Resistance of the Cycling Ergometer depending on the Personal Fitness Rating

Furthermore the participants were asked to rate their own fitness level in 5 grades (1=excellent, 2=good, 3=average, 4=sufficient, 5=poor). Depending on this rating the power of the ergometer was set to a basis value of 100 Watts (equates to 3=average) +/- 20 Watts per level as shown in Figure 4, right table.

After these initial question the participants played each game (Pigeon Hunt, Ergo Balance, Virtual Video) and filled out the corresponding questions immediately after playing a game.

Figure 5 shows that motivation is higher when playing Pigeon Hunt and Ergo Balance compared to Virtual Video (Friedman test: $\chi^2 = 44.98$, p<.001).

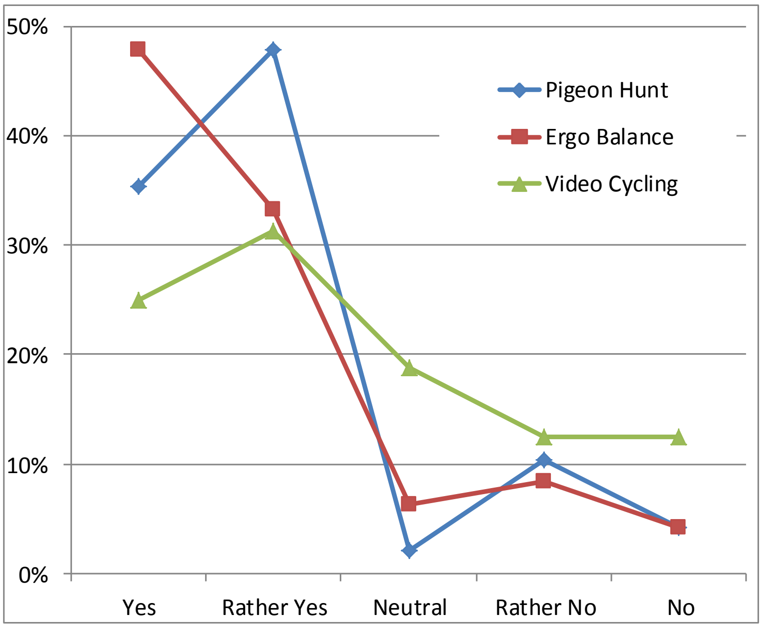

Figure 5: Answer to the Question "Does this game motivate you?" – Both Games, Pigeon Hunt and Ergo Balance, are more motivating than the Virtual Video Cycling

Figure 6 shows that Virtual Video is rated differently by male and female participants. However, 3 (games) x 2 (gender) ANOVAs reveal significant gender effects only for exertion. The female participants rated the games more exhausting than the male participants, this implies that the gender should be included in the calculation for the setting of their power/resistance.

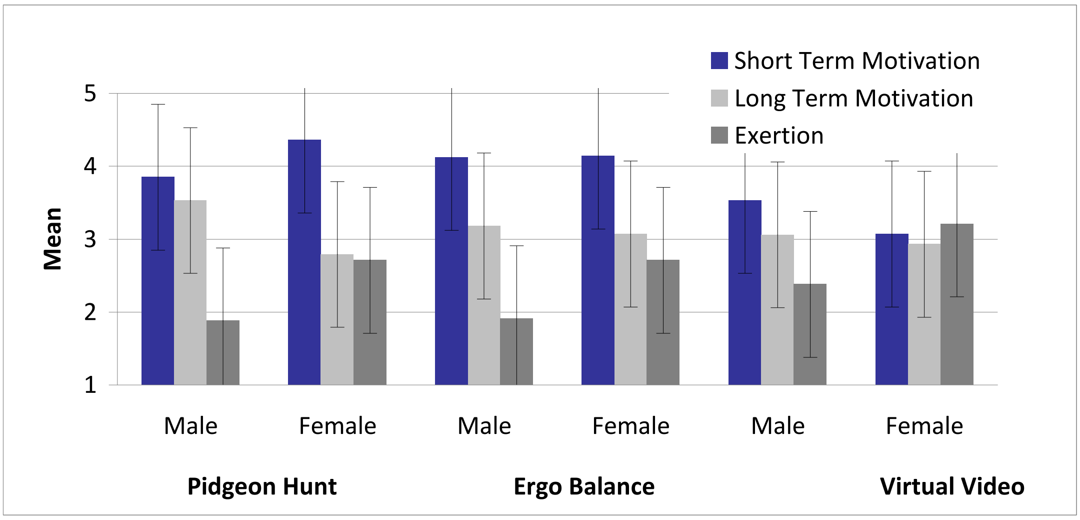

Figure 6: The Motivation, Long Term Motivation and perceived Exertion are rated differently, depending on the gender of the participants.

It was also calculated if the assessment of the games depends on the times the participants watch TV or use PC per day. This is not the case. The judgement is significantly related to the fitness level of the participants (r = -.30; $2p$ = .036).

Figure 7: Correlation between the Personal Fitness rating and the perceived motivation

As shown in Figure 7, people with a higher personal fitness rating find the applications more motivating than people with lower fitness rating. However, these differences are not significant.

Most people (83.3 %) answered that they would like to play the games again. More than three fourths (77.1 %) would prefer the games to the regular cardio training in the gym, but only a few (31.2 %) would buy such a system for the use at their homes.

Summary and Outlook

In this paper a model was presented which identifies the relevant components which are needed for the development of exergames. The model describes the interaction between these components and can be used as the theoretical basis for the design, implementation and quality assurance of exergames. Grounded on this model a prototype was implemented which contains all the components and elements of the presented model. The prototype has been evaluated with *n*=48 participants. The results are discussed in this paper. It was possible to identify differences in the impact of different configurations of the software component of the model as intended by the model. The different gameplays of the 3 implemented minigames yield different results concerning the player's motivation. The overall results depend on the gender of the participations and their estimated fitness. The implementation of the games was rated as motivating by the participants for both, the short and long term motivation.

The Training Control API allows adjusting the training load of the games (time, power, heart rate, speed, cadence), this way the prototype provides the ability to play at an arbitrary, user-defined level of exertion. It is reasonable but still an open question if this solution allows gaming at the same level of exertion as in a regular indoor training and if the EE is higher than during playing Wii Fit or Dance Dance Revolution.

The adaption of exergames in the dimensions of gaming and sport allows the creation of attractive and effective exergames for a broad range of end users. The adaptation provides a low level of entrance for newcomer as well as a high challenge for experienced users.

For the future various studies based on the model are planned. The results will show if the model can be validated and if the model needs further refinements. The planned improvements in additional prototypes will allow changing single elements in the software (designs, feedback) and will allow further investigation in the effects of different realizations of the identified elements. For example, some people asked if the speed is shown as a number during the game Ergo Balance - the study did not address the question how this would affect the overall motivation and if this is a subjective wish or a general improvement.

An already planned extension is to compare the effects of the visual representation (2D-comic-style, vs. 3D compared to autostereoscopic 3D displays) and its influence on the motivation and playability. The long term motivation was included in the study only as a value estimated by the users, long term studies together with gym will show if those estimations correspond to the real usage over a longer period of time.

A last but crucial issue is to show that the concept provides the opportunity for evidence-based successful training at all, this is planned to be tested in cooperation with experts from sport science and medicine.

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