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Framework for personalized and adaptive game-based training programs in health sport

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Abstract This paper describes an interdisciplinary approach towards a framework for personalized, game-based training programs for elderly and handicapped people. Adaptation and personalization are proposed as a way to increase the physiological training effects of game-based training programs (exergames). Hereby, the diversity of users and a broad range of physiological handicaps are considered. The framework is based on scientific training programs enhanced by technical methods and concepts for personalized exergames. This includes an authoring environment (StoryTec) which supports game designers and domain experts (sport scientists, medical doctors, therapists, etc.) in the development process and the (personalized) configuration of such exergames. Two prototypically implemented applications (ErgoActive and BalanceFit) demonstrate the usability and adaptation of the underlying training and game concepts for different user groups and provide indicators of the effectiveness and efficiency of the generic framework for particular user groups. For instance, ErgoActive is applicable for people of all ages and both trained and untrained users by being able to provide personalized training levels to improve endurance. Similarly, BalanceFit is useful both for wheelchair and walking frame users in order to maintain and possibly even increase their balance, strength and muscular coordination.

Keywords Serious Games · Health · Exergames · Training · Personalization · Adaptation · Sensors

1 Introduction

The lack of physical activity and its consequences are well-documented worldwide phenomena: Half of the ten most serious diseases are either caused by a lack of exercise, or can be

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alleviated by sufficient exercise [31]. In the European Union, 60 % of the inhabitants rarely or never do sports and the inclination to work out tends to decrease uniformly with age. Only 22 % of the population above 70 is still sportive [31], which means doing sufficient exercising (at least 30 min on 5 days a week or vigorous-intensity aerobic activity on 3 days a week [9]). This is caused by a limited mobility, gait impairments or other reasons hindering to engage in physical activity. Due to these facts and emphasized by the demographic development, the need for appropriate training programs and technologies to preserve mobility and enhance physical health is obvious. Successful commercial movement and reaction games (exergames) such as Wii Fit, originally developed for pure entertainment, are promising motivational instruments also in movement therapy and rehabilitation, or as a training option in senior homes [11].

However, scientific studies show measurable effects of exergames [5], so they can be a successful approach to improve peoples' health status. Further studies show that the effectiveness (e.g. in terms of short-term energy expenditure or long term training effects) of commercial entertainment games as training tool is lower than the impact of classic training [13]. A major drawback of commercial exergames is that they are not optimized for specific target user groups, purposes and corresponding training programs. Furthermore, they do not adequately consider individual preferences or needs such as the vital state of the players or patients [7]. Domain experts such as medical doctors, therapists or scientists in sports and health underline the potential of game-based approaches (primarily for their benefits in terms of motivation) on the one hand and simultaneously postulate the need for scientifically grounded, personalized training plans and programs for specific purposes and targeted user groups on the other hand. Therefore, appropriate tools and user interfaces enabling experts (e.g. therapists) to author and configure the programs 'on the fly' in daily practice would be extremely helpful.

Serious Games or Games for Health unify these potentials and requirements of entertainment features and solid, scientific grounded applications and programs in the health (care) domain. Well-known studies by Baranowski and Kato [1, 12] have proven the positive effects of Serious Games in terms of behavioral changes in nutrition and therapy of cancer, respectively. For the latter purpose, the video game Re-Mission was created to support the therapy of children who suffer from cancer. In a randomized, controlled study with 375 participants, Kato et al. proved that playing Re-Mission significantly increases the success of regular therapy.

The authors of this paper have been inspired by these best-practice examples and focused on the development of a conceptual framework and prototypes for goal-oriented, game-based and personalized training programs (exergames). In addition to the interdisciplinary work among computer scientists and sport scientists, relevant domain know-how from medical doctors as well as expertise in evaluation methodologies by psychologists, among others for the determination of game experience [6, 8], complements this work. First practical results include the prototypically implemented exergames ErgoActive and BalanceFit. Whereas ErgoActive is used as game-based approach for cardio training, BalanceFit focuses on balance, strength and coordination training. Both exergames allow the adaptation of gameplay and game properties in order to in- or decrease the cognitive or physical challenge that the games pose to their players. These adaptations can be made dependent both on the vital state of the player (e.g., her heart rate) or with respect to the needs of target user groups (that share specific characteristics).

The subsequent Section 2 describes the proposed adaptation framework based on the requirements from the field of sport science elaborated in Section 3. We propose the combination of these well accepted training principles with game-based training systems such as exergames as one possibility to increase the effectiveness of game-based training systems. The necessary adaptation concepts, sensors and adaptation models are described in Section 4. By using the previously developed authoring tool for configuration (Section 5), two application examples have been implemented and evaluated in Section 6. The paper is concluded by a short summary and outlook (Section 7).

2 Conceptual framework

ErgoActive and BalanceFit are embedded within a generic framework for the usage of serious games for sports and health in prevention and rehabilitation (see Fig. 1).

Basically, the components of the conceptual framework can be divided into three groups:

- The game engine, sensors and the repository (with the game itself, user profiles, training programs and other data) are necessary and mandatory to run personalized, adaptive exergames that consider the vital state and other characteristics of players.
- The authoring tool and the configuration component facilitate the creation and personalization of the exergames. Especially easy access to configuration tools is crucial for the acceptance of such approaches by therapists (not the least due to their limited time available for individual patients or training groups).
- The context framework and the user portal represent further optional components, which are dedicated to extensions of the system and to particular business models, e.g. the inclusion of a service provider or a health insurance company.

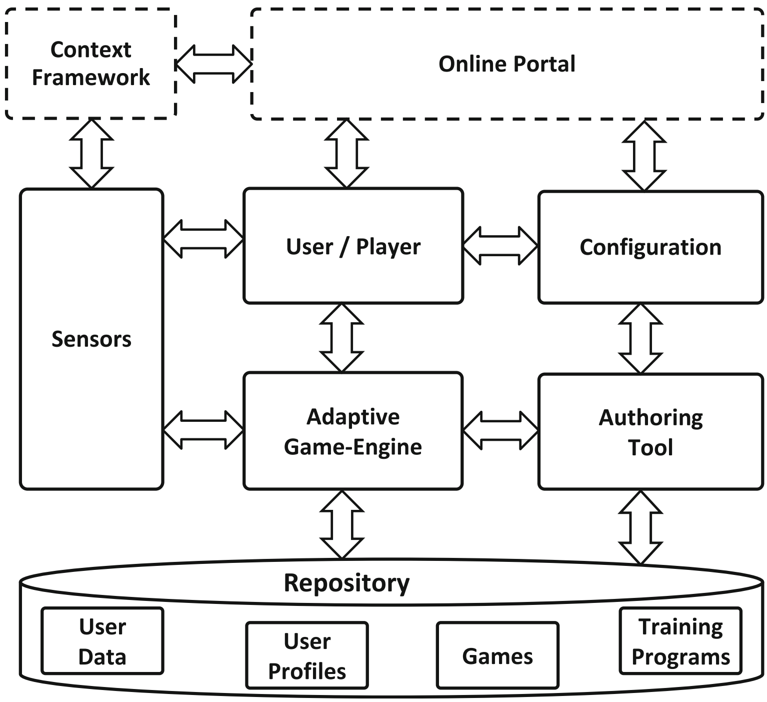

Fig. 1 Framework for adaptive Serious Games for Health

The overall concept of the framework is modular and envisions a maximum of flexibility in terms of extensibility and the combination of different games with sensor technology and methods and concepts for adaptation and personalization. The games are collected within a repository and are classified with respect to their training goals (e.g., to increase the player's sense of balance, her muscular strength, or her overall endurance) and to the type of game (e.g. 2D vs. 3D, action game vs. jump & run, etc.) according to a defined metadata format [6]. The games can be composed and preconfigured using the authoring tool StoryTec [16, 17], which has been developed and refined during the recent years by the Serious Gaming group of the Multimedia Communications Lab at the Technische Universität Darmstadt (see also www.storytec.de). The games (or more specifically, the game engine) can be supported by (a set of) hardware sensors, which will then influence the gameplay accordingly. Selecting appropriate existing sensors or developing custom sensors for a specific application are challenging tasks and not addressed in this publication. We assume that for most applications, the specifications of single sensors have a significant impact on the games but that the type of sensor/controllers can be changed as long as it meets the specifications. E.g., different controllers are usable in applications for personal computers if they comply with the Human Interface Device (HID) profile. For instance, the application ErgoActive can be played with ergometers from different vendors (it currently supports two different vendors) as well as with different ergometer types (the game can be played with cycling ergometers as well as with elliptical trainers).

The Adaptive Game Engine (AGE) makes up the core of the system and is responsible for the adaptive control of the games in real-time during play. The games themselves might be understood as frame games [26], i.e. small (game) units with a specific game concept and game design. The configuration of the games contains game assets and game parameters and therefore defines the look and feel as well as the difficulty level of a concrete game. E.g., ErgoActive as well as BalanceFit both offer different designs depending on the selected set of assets. The AGE serves as a runtime environment for games and creates a concrete instance of a game by applying the personalized configuration to a universal frame game. Furthermore, the AGE is responsible for all I/O-related tasks, i.e., to provide a user interface and to establish the connection to the used hardware sensors in the framework. For instance, the functionality of the AGE in the context of the three frame games of the ErgoActive training system is described as follows:

The games of the ErgoActive system can be controlled either by an ergometer bike, a treadmill, or an elliptical trainer. The AGE provides an interface suited for all of the three controllers. If the training goal is "cardio training", all devices can be connected to the game engine and all devices can be used to play the ErgoVideo application. If parameters are part of the training plan that differ from the two universal parameters 'training time' and 'heart rate', it is important to distinguish between the used devices. Cycling, for instance, requires less energy than running at the same speed. By taking into account the information about the used device, comparability can be achieved among different devices or different movement types. As illustrated, the training load for a defined task depends on the choice of the training device. Otherwise, by adapting the training exercise, we can establish the same training load on each device. A second aspect considers possible disabilities of the user. Therefore a specification of the movements, e.g. which limbs are used in the training, and in which range of movement, ist needed. A third aspect concerns the specification of the reaction and game control (possibilities) of the devices. For the game LetterBird (former name PigeonHunt) it is necessary to change the control parameters. E.g. either speed, cadence, or power can be used to control the "altitude" of the bird, whose task is to collect letters. While the cycling ergometer easily allows this control, this is more difficult with the elliptical trainer and even more with a treadmill.

In the ideal case, the users do not require special prerequisites to be able to play the exergames. The selection which exergames are suggested to a player as training games depends on the player's abilities, skills, and constitution (her vital status). The challenge of modeling a player's properties and attributes is not within the focus of this paper, but an intriguing problem and open to further research.

3 Requirements for the adaptation and personalization of training programs

Sport science, and training science in particular, emphasizes the fact that training, being systematic and planned interventions and measures to yield long-term influences on human performance and its components, has to take into consideration the condition of the individual trainee. Therefore, several general principles have been established [30]:

- The principle of individualized training loads
- The principle of age- and development-dependent training loads
- The principle of progression of training loads

So, in order to ensure individual and adaptive training, numerous characteristics of the trainee have to be considered, e.g., age, gender, motivation, goals, needs, health level, risk factors, performance level, and individual options depending on job and family situation. Taking the example of prevention, training should be adapted to different target groups and their specific characteristics like hypertension, obesity. Respective research shows that long-term effects can only be established using a holistic approach that takes into consideration social, psychological, and physiological conditions.

Furthermore, only by applying appropriate training loads adequate adaptations can be established. Five features characterize the training load in a specific training domain like endurance, resistance or strength training:

- Intensity of training stimulus
- Duration of training stimulus
- Volume of training
- Density of training
- Frequency of training

These features allow an individualized regulation of training load. Intensity of training, e.g., can be determined by means of relative, person-related measures like relative heart rate. Depending on the particular training domain, several training methods have been established representing a specific structure of the load characteristics.

Because all the parameters currently used for the control of training show a considerable inter-individual variability, it is not possible to give exact prescriptions or recommendations being generally valid for every user. Rather, individualized and adaptive control of training must be an iterative process including a continuous cycle of planning, execution, documentation/measurement, and analysis. This means a successful training approach can be planned before the start of an intervention program based on training principles and personal parameters, but throughout the training process, it needs to be adjusted to comply with requirements derived from the training history. To comply with this conclusion, ErgoActive allows the manual definition of manually created personalized training plans (exertion, cadence) and BalanceFit allows the manual adjustment of different training and control parameters (sensitivity, acceleration).

3.1 Training programs—basic assumptions and building blocks

Physical training has significant benefits for health (see Table 1): Physical activity has positive effects on cardiovascular, metabolic, immune, muscle-skeleton, and psychic systems. Therefore, training programs in health-oriented sport (HOS) rely on four columns of physical fitness: endurance, strength, flexibility, and coordination [4, 20]. Of course, the enhancement of physical resources is just one out of six core aims of health sport [3]. In order to be successful, HOS programs require a holistic approach that integrates social, psychological, and physiological elements.

Depending on the specific conditions of the particular target group, the four columns are emphasized differently (see Table 2). Programs dedicated to fighting obesity, e.g., focus on issues of energy expenditure, whereas programs dedicated to the prevention of low back pain focus on the strength of muscles stabilizing posture. In principle, HOS programs should always include all four components in order to ensure a broad impact on the subject's overall health.

Unfortunately, there is no scientific evidence for unequivocal prescriptions of quality and quantity. Numerous programs exist that are neither comparable nor compatible. Because there is no agreement concerning adequate programs for specific target groups in HOS, the components are discussed separately. Here, we focus on endurance and coordination training.

3.2 Endurance training

Physical inactivity and its consequences (e.g., obesity and hypertension) are among the most serious threats to health and well-being. Fall prevention is another important area of prevention, particularly for elder people. Besides control of nutrition and drug consumption, performing an adequate, continuous, and enduring program for physical activity is an important thing to do.

Table 1 Evidence for the impact of physical activity on health conditions (adapted from [21])

Condition	Number of studies	Impact and effect type		
Total mortality	+++	↓↓↓	+++	high
Coronary heart disease	+++	↓↓↓	++	medium
Apoplexy	++	↓	+	small
Hypertension	++	↓↓		
Diabetes Mellitus Type II	++	↓↓	↓↓↓	high
Breast and colon cancer	++	↓↓	↓↓	medium
Other cancer diseases	+	↓ ↔	↓	small
Osteoarthritis	+	↓		
Lower back pain	++	↓	↓	decr. risk
Osteoporosis	++	↓	↔	no effect
Anxiety/Depression	++	↓↓	↑	incr. risk
Obesity	+	↓		

Table 2 Target groups and training structure in health-oriented sport

Target group	Endurance	Strength	Flexibility	Coordination
Obesity	+++	+	+	+++
Hypertension	+++	+	+	+
Diabetes	+++	+	+	+
Fall prevention	+	++	++	+++
Osteoporosis	+	++	+	+
Low back pain	+	+++	++	++

+ low importance; ++ moderate importance; +++ high importance

One goal of these activities is to raise the energy expenditure above a minimum of 600 to 800 kcal per week, with on optimum of about 3.000 kcal per week [28]. For cardio training it is important to offer training loads activating the cardio-vascular and cardio-respiratory system. Two training methods are of specific importance [30]:

- Continuous method
- Interval method

The continuous methods are characterized by a moderate to vigorous intensity, comparatively long durations (up to multiple hours), high volume and high density (no interruption). These methods aim at enhancing basic aerobic capacity, i.e., adaptations of the cardio-vascular and cardio-pulmonary system (increased economy, oxygen uptake, respiratory capacity) as well as the aerobic metabolism (glucose and fat metabolism). There are several variants of the continuous method like intensive versus extensive methods and constant versus varying loads (e.g., speed-play). In order to achieve a broad spectrum of adaptations and to avoid monotony of cardio training, the program should apply a mixture of the above-mentioned variants.

The characteristic of the interval methods is the application of incomplete rest intervals between the exercise bouts. During this incomplete rest (“rewarding rest”), the heart rate (abbr. HR) drops exponentially while cardiac output is still high. Therefore, interval methods are appropriate for adaptations of the heart (hypertrophy and dilatation). Depending on the various variants (intensive versus extensive intensity, short-term versus long-term intervals), further adaptations of aerobic and anaerobic metabolism and other systems are supported. Particularly the extensive interval method enhances cardio-vascular and cardio-respiratory functions. Depending on the given conditions of the respective target groups, continuous and interval methods need to be combined in a specific way to ensure optimal adaptations.

Another important issue mentioned above is the control of the training load. In cardio training, the relative heart rate or relative oxygen uptake can be used. Relative HR means that the individual response to the training load (e.g., running speed or resistance of the cycle ergometer) is related to the individual maximum HR (abbr. HRmax). HRmax depends on both age and gender. HRmax can be determined either by specific maximum exercise tests, or by equations. In this regard, the most widely used equation [22] is:

$$HRmax = 220 - age$$

However, this equation is lacking precision and has not been scientifically validated. Therefore, research has looked for alternatives [22, 29]. Based on a meta-analysis, Tanaka, Monahan, and Seal propose different equations depending on gender and physical activity [29]. Because a regression analysis did not confirm gender and physical activity differences, the authors suggest the following equation:

$$HRmax = 208 - 0.7 * age$$

The validity of this equation was confirmed by a laboratory study. However, residual variance of HRmax values points to the fact that further individual factors have to be taken into account to ensure adequately individualized training loads using HRmax. Further physiological measures for the control of intensity are oxygen uptake, heart rate variability, and blood lactate. Because the respective parameters represent specific subsystems of the human organism, they are usually combined to convey a full picture of human performance.

Another parameter for individualized training load is the RPE (short for "rating of perceived exertion" [2]). RPE reflects the subjective evaluation of exertion integrating peripheral and central control processes [15]. RPE has proved to be a valid load parameter for preventive training [10].

Exergames provide the perfect setting for dynamic control of training load in order to perform endurance training using a continuous or interval load structure and to ensure optimal adaptations:

- A first option is to plan a specific load structure in advance by prescribing a fixed training protocol including continuous or interval methods. This protocol is transformed to a specific sequence of demands in the game.
- By monitoring, e.g., HR during gaming, physical demands can be adapted online based on the individual load dynamics. If HR increases, for example, during a constant-load continuous program, the game control device can reduce the physical demands of the game to ensure appropriate load.
- Furthermore, the trainee or the supervisor can intervene by changing the game demands if the training load exceeds the predetermined limits.

Despite the belief from the field of sport science that the sense of balance is necessary for coordination, generally accepted training models do not exist for sense of balance training. Due to the generic nature of coordinative abilities numerous principles and guidelines for coordination training have been proposed:

- Variable tasks
- Variable requirements (e.g., speed and precision)
- Variable performance conditions (situation, complexity, load etc.)
- Variable information conditions (vision, audition, proprioception)

A basic formula proposed by Roth [23] suggests that a combination of simple motor skills and variable information demands and/or performance conditions should be presented.

Again, exergames offer unique opportunities for variable and adaptive sense of balance training. Existing studies on the impact of exergames on the sense of balance [5] show that commercially available exergames have the potential to enhance balance skills. The study of Kliem and Wiemeyer [13] shows that game effects can transfer to both static and dynamic balance skills.

4 Adaptation and personalization of Exergames

A state-of-the-art research in sport sciences reveals a demand for answers to the question, how exergames can motivate the user to behave in a way that this activity complies to the identified training principles, as meeting these training principles would be a fundamental step towards achieving a high training effect. The interaction therefore must match the skill level of the individual user in order to provide the adequate training stimuli which will trigger the physical adaptation process of the player's body. Since the personal skill level differs among players, the interaction, which is a substantial part of the gameplay, needs do be individualized for every single player. The framework sketched out in Fig. 1 includes technical components required for the adaptation and personalization of exergames as well as a component that might allow improvements of the adaptation process. The proposed framework does not include concepts or approaches for the adaptation and personalization process, but describes the context for the development of such approaches. This allows the further adaptation of basic models which focus on only one relevant domain. E.g., the Gameflow concept [27] is an approach that focuses only on game experience and different health recommendations. [9] focus only on the health/sports domain. The Dual Flow Model [24, 25] is an attempt to bring together psychological and physiological requirements and proposes that exergames need to be both attractive and effective. This leads to the question of how attractivity and effectivity can be achieved at the same time. Since there exist similar constructs (i.e. challenge, performance, load) in both domains (user/game experience research and sport science), this raises the question of how game experience and physical activity actually influence one another. We assume that the sensors and actuators used will influence the user experience as well as the training, while the training and the user experience influence each other (see Fig. 2). For both domains, the used hardware and sensors play an important role. Thus, the topic sensorics has to be considered briefly although the development/selection of sensors is not a focus of this publication. Sensors allow the measurement and, if required, the recording of performance parameters. This option already finds wide application in professional sports training. Coaches record the heart rates of athletes during their trainings or use high-speed cameras to capture their movements in order to be able to analyze and eventually optimize these, such as the feet ground contact times of sprinters. The technology used in these application areas is very

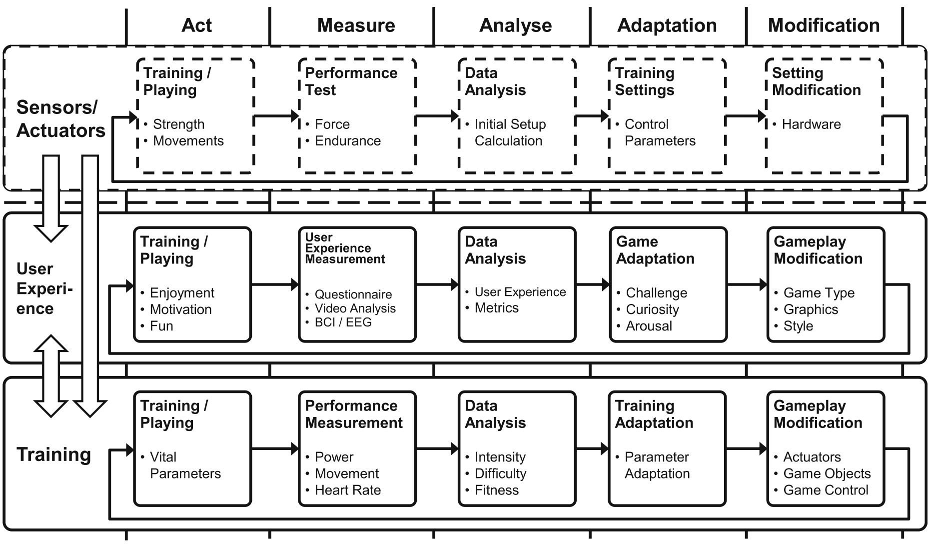

Fig. 2 Adaptation layers—sensors/actuator (constitutional adapation), user experience and training

powerful, but also complex and highly expensive. In contrary, for the use in playful training scenarios the hardware must be low cost, but this is not the only requirement.

To embed movement information in real-time in a game and in order to provide a precise movement control and feedback, the used sensors need to work with high accuracy, low delay and a sufficiently high sampling rate. Depending on the training goals, sensors and actuators applied in professional sports or amateur sports can be used (cycling ergometer, chest belt). The proposed model for the use of sensors for the adaptation of exergames to a specific use (training goal) consists of three layers: "Constitutional Adaption", "User Experience Adaptation" and "Physiological Adaptation". These layers need to be considered separately, but they are interdependent. The term 'adaptation' describes the process of modifying a system in order to make it fulfill a specified goal. The term 'personalization' is used if this adaptation takes into account individual attributes of multiple users. Figure 2 sketches the interdependencies between the different layers and within them.

4.1 Constitutional adaptation

Constitutional Adaptation (Fig. 2—Sensors/Actuators) describes the adaptation of exergames to the physical constitution of the player. This includes the player's stature, her physical limitations and partly performance describing parameters such as maximum force. The goal of the Constitutional Adaptation is to adapt the entire system to the physical characteristics of the player. This, for example, would allow the usage of the same game for both children and young adults (small people) as well as for full grown adults. The adaptation of the hardware means adjusting the hardware to the body size, which may be achieved using the existing hardware (e.g., by adjusting the saddle height on a cycling ergometer) or by having to exchange the existing hardware in part or even completely (such as providing a smaller bike children). The Constitutional Adaptation layer therefore enforces a modular hardware construction which allows the extension and modification of the hardware. Not only the hardware, but also the minimum and maximum performance parameters play an important role if the system is supposed to be suited for different user types. Children, adults and seniors may vary strongly in their maximum performance. An electromagnetic brake as it is used in ergometer cycles needs to brake and measure the power at different performance levels with high precision. Training with low performance and at a low cadence must offer the same control precision as training with high cadence and high performance. The adaptation control itself is realized by the AGE, which alters the relation between sensor inputs, game objects and corresponding feedback.

The Constitutional Adaptation layer also includes the accessibility aspects. The utilization of a game for a broad range of users, including physically and/or cognitively disabled people, can be realized by different types of feedback (visual, auditory, haptic adaptation). Accessibility is not necessarily a hardware-related issue. For example, changing contrast, colors, and sprite size can assist people with amblyopia. People with perceptional impairments may need a higher delay and decelerated reactions of the game. For the game BalanceFit, which is described in detail in Section 6.2, the sensitivity of the force sensors of the balance board and the virtual weight of the ball can be adjusted. In this way, the game can be played irrespectively of the maximum forces of the player. This allows wheelchair drivers, people with gait impairment and perfectly healthy people to play at their personal performance limit, which is most challenging and which allows the highest training load.

The parameters relevant for the Constitutional Adaptation (such as a player's size, weight or endurance) can either be measured to allow a very precise adaptation, or simply guessed by an experienced therapist. An automatic calculation of the values based on statistic formulas which take into account, e.g., age, size, gender, fitness, and fitness level of the player is considered as impossible in the field of rehabilitation, because usually, the differences between two individuals are too big and as such, individual adjustment will be required in any way. In the field of prevention, there are guidelines for standard training plans which can be followed if the maximum heart rate has been determined and if a heart rate sensor is used.

4.2 User experience adaptation

The User Experience (UX) Adaptation layer describes the adaptation of a game according to the personal preferences of a player and according to the increasing skills of a player. The UX Adaptation takes into account different UX attributes, such as immersion or arousal. An automatic measurement of user experience through sensors is challenging and a current research issue. An adaptation is possible by incorporating the user in the adaptation process. This is possible by using questionnaires, as it has already been done for multiplayer online games [8].

The first step in the UX adaptation process is the selection of an appropriate game from a set of games which meet the specified training goal. The selection can be determined based on a matching of specified characteristics (game type, style) or by trying out all available games for a short period of time. The definition and matching of such characteristics is a challenging task in UX research [19].

The exemplary exergame ErgoActive, which is explained in detail in Section 6.1, includes three different mini-games with the same training goal, but conceptually different gameplays. The three games provide differents levels of reality, interactions and cognitive tasks (single task/dual task) as well as different designs (realistic vs. comic). Practical experiences let assume individual preferences of players who chose one of the games as their favorite.

A precise analysis and differentiation of the UX relevant attributes is suggested. To assess "fun", a video analysis (facial expression analysis) can be used, for the UX aspect of "perceived challenge" the gained points per time unit can be taken into account, but this is not necessarily corresponding to the actual challenge level experienced by the player. Based on the measurements or on user ratings (perceived User Experience) another game can be suggested or the game can be adapted in a previously defined manner. BalanceFit, e.g., allows modifying the amount of game objects or obstacles in order to adjust the (cognitive) challenge. Additionally, one or more game objects can be added to increase the player's curiosity. A second option is to modify biomechanical parameters (resistance, sway area) in order to adjust the physical challenge. Modifying the physical challenge also affects the perceived/ cognitive challenge.

4.3 Training adaptation

The Training Adaptation layer enables the adaptation of the game to the requirements posed by sport science. This layer consists of two adaptation loops, a short-term loop (real-time, during the runtime of a game) and a long-term loop (adaptation between two training sessions). While the requirements posed by sport science have been described in Section 3, the technical issues (realization and options) of adaptation by using sensor-measured vital parameters are the subject of this section. Sensors in exergames measure kinematics and kinetics of individual limbs or the entire body. This data is annotated in relation to the behavior of virtual objects inside a game. The behavior of virtual objects in a game can be used to communicate different types of feedback (visual, auditory, haptic) about body movements to a player. The Training Adaptation can be done by the modification of parameter values, more specifically by changing the relations between game objects and therefore their behavior. These parameters are called Training Control parameters.

An example for such a parameter in the mini-game LetterBird (Section 6.1), which is part of the ErgoActive game compilation, is the average speed of the player (or, more specifically, of the ergometer pedals). Alternative parameters may include the cadence, the interval size (maximal and minimal value of both parameters), and the mechanical resistance of the ergo bike.

The average speed (or cadence) defines—together with the resistance (at the same gameplay)—the player's performance (measured in watts), which is needed to play the game successfully, e.g., to "catch" a letter. The intensity and the time (duration of playing) define the amount of work (Joule), which is equivalent to the training load.

The second example, BalanceFit, provides the two training control parameters sensitivity and difficulty. In the prototype BalanceFit (see Section 6.2) the training control parameters are sensitivity and difficulty, whereby difficulty is composed of the number of balls and the number of obstacles. Sensitivity is the transformation factor between measured force and virtual movement (rotation, translation) of the game objects. Depending on the sensitivity value, more or less force (and therefore strength) is needed to move the object over a definite distance. Thus, the player has to move in a bigger (or smaller) area of sway. The difficulty is a parameter for the control skills (coordination, reaction) of the player. Another control parameter for training control having strong impact on UX is the delay of the control. Increasing the delay makes the game harder to play and decreases the user rating for "control" in the UX questionnaire.

5 Authoring tool and development process

The proposed concept to support the authoring process in health games and exergames allows adjusting a game to the individual needs of each player or trainee. It supports and simplifies the collaboration of different user groups who take part in the development process [18] and was already successfully use the research project Motivotion60+ [14].

The development of a new game starts with a specification of requirements and exercises suited for reaching a specific training goal. This should be done by domain experts settled in the field of sport science or medical science. Together with game designers, concepts for a playful realization of the goal-oriented exergames are conceptualized. In the case of the BalanceFit prototype, this has resulted in an exergame which uses force measurements to allow the user to control the game objects by varying the center of pressure. This small game is created as a scene template. A scene template contains all necessary objects of a scene, already preconfigured according to the game concept and the game design. Domain experts and IT specialists (familiar with the StoryTec authoring tool; see Fig. 3) integrate domain knowledge and configure the appropriate scene templates. The sport medicine experts define, e.g., foot position, arm angles, the number of repetitions or the duration of training games. This way the respective games can be configured by therapists or supervisors in a valuable and scientifically founded range.

The particular experts work within StoryTec at different views of the same game and its structure (see Fig. 3). These views are called "templates". By using their respective view, design experts can modify the design without changing the gameplay while sports experts can configure the game but do not need to deal with design issues. Furthermore, none of the domain experts needs programming skills.

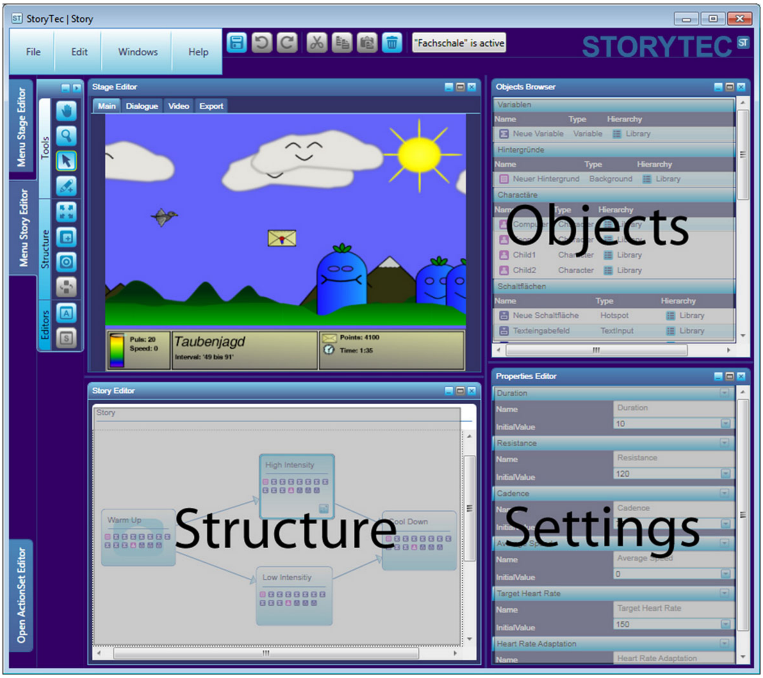

Fig. 3 Authoring tool StoryTec

The template concept allows a simplified and accelerated development process, but also provides access to the full flexibility and functionality of the authoring tool. Since the complexity of such a system increases exponentially with the increasing functionality, a stage-less system has been developed which allows the activation or deactivation of single features for each targeted user group. Thus, StoryTec is able to provide the necessary features without being overloaded. For the creation of the games, after the overall training goal of the games was clear (cardio training/fall prevention), we first identified possible exercises (movements, postures) and afterwards selected the appropriate hardware. The creation of the gameplay and the game content was a creative phase and needed several iterations between domain experts (sports scientist, caregivers).

6 Application examples and evaluation

To allow for the precise measurement of different operationalizations of existing constructs and approaches, the two exemplary applications BalanceFit and ErgoActive were developed. In order to comply with the assumptions and models described in the Sections 2 and 3, both applications are based on a technical architecture called StoryTecRT (Fig. 4), which allows the dynamic adaptation of the games while they are being played. For example, this includes the possibility to exchange textures and therefore to modify the look and feel of the game without changing the core gameplay mechanics. By changing only some assets such as graphics and sounds, the operationalization of positive and negative feedback can be changed easily. This provides the opportunity to evaluate the effects of different operationalizations of single constructs.

The reasonable adjustment of the training load is a challenging problem. From the sports science comes the requirement to allow for an adjustment of the training load in a wide range, as pointed out in Section 3, because the training load is directly correlated to the training effect (among other aspects). On the opposite, a high training load can also increase the difficulty level. This could lead to a situation where the player feels that she cannot cope with game's demands, which is likely to decrease the overall game experience. Therefore, we chose to evaluate the acceptance and game experience of games developed based on our approaches first. Afterwards, we can use these findings as a baseline for future measurements with different concept and methodologies for the adaptation and personalization of the training load in these games. Because of that, the measurement of the heart rate, energy expenditure, or other parameters for the training load have no relevance in the first evaluation. E.g., technically the prototype ErgoActive allows to increase the mechanical resistance of the ergometer to up to 800 W, which is a far too high value for all but the very well trained. Increasing the resistance to such a high value nevertheless will probably result in a player's refusal to play the game in the first place. Consequently, we rather set the resistance as described in Section 6.1.

6.1 ErgoActive

ErgoActive is an exergame and as such an example of a serious games for sports and health. As described before, ErgoActive consists of a set of three different frame games for interactive cardio training. The fundamental goal of ErgoActive is the provision of scientifically and medically grounded exergames, which do not only control and log the vital status of the player, but which also motivate physical activity in a playful way. Each of the three applications realizes the adaptation of the previously described training control parameters with different gameplays and different levels of interaction or interactivity.

All three games can be played with a cycling ergometer as well as with an elliptical trainer or a treadmill. In the simplest case, a video of a recorded track is played according to the cycling speed of a player. The video was recorded on a regular outdoor bike track and is played according to the speed or cadence the user is cycling at. This way, the user can cycle along real-world tracks such as "L'Alpe d'Huez" which she could not cycle in reality (because of low fitness, vision or balance impairment, or simply due to the lack of time to travel to the real world location). The virtual track is correlated to geographic information so that the resistance of the ergometer is adjusted accordingly to the track (e.g., slope), which conveys a realistic feeling. This virtual video cycling has a realistic look, since it is based on video recordings and has no game elements such as scoring or challenge. The duration, performance, speed, and cadence are measured and used to control the speed of the video, but they do not need to be controlled by the player in order to gain points.

Two additional applications are both games which use external sensors to control the gameplay and provide a feedback about vital parameters. The concept of the game LetterBird (Fig. 5, bottom right) is based on the translation of vital parameters into the gameplay. The game is a side-scroller game and features a bird with the task of collecting (flying) letters. The measured vital parameter, speed, cadence or performance, controls the height of the bird. By changing this parameter, i.e., if the user

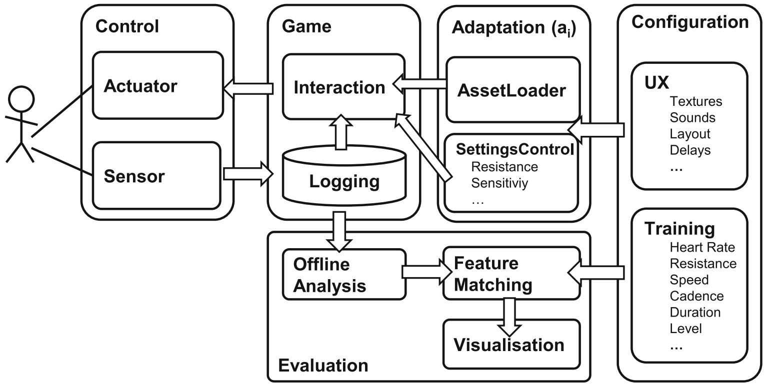

Fig. 4 StoryTecRT, evaluation framework for exergames

cycles slower or faster, she can adjust the altitude of the bird and collect the letters to earn points. If the user stops cycling or if she decreases the speed too much, the bird will fall down and the game ends. This way, the user needs to keep the vital parameter in a predefined range which lets him control his vital parameters seamlessly during playing the game and thus play with defined vital parameter values. By adjusting the target ranges, e.g. adjusting the desired average speed to 20 km/h or 40 km/h, or by changing the mechanical resistance of the ergometer, the prescribed values for the vital parameters can be controlled by the game. This mechanism is the key to allow a game-based training at parameter values previously defined by therapists.

The mini-game ErgoBalance (Fig. 5, bottom left) uses a similar way of vital parameter feedback but in contrast to the LetterBird game, the player has not the task to adjust her cycling speed (or a vital parameter) but to keep it at a defined value. If the desired value is reached, a clown, balancing on a ball, stands upright. If the parameter value is too low, the clown falls to the left; if the parameter value is too high, the clown falls to the right. In contrast to LetterBird, the goal of the game, i.e., the way how points can be achieved, consists of two parts. Keeping the vital parameter at a concrete value is necessary to keep the game going, but earning points requires hitting balloons which fall down with the mouse cursor.

The evaluation of ErgoActive was performed in a fitness studio. The sample contains n=48 participants (age: 14–64 years, M=31.69, SD=14.82, gender distribution: 70.8 % male & 29.2 % female). As a first step, the participants were asked to fill out a questionnaire in order to get information about their gender, age, TV/video game consumption habits, and the average amount of their weekly sport activities (in minutes). Additionally, the participants were asked to make an assumption about their overall fitness level by selecting one of five grades (very good, good, average, sufficient, poor).

The used hardware was a cycling ergometer, type Daum 8008 TRS 3, which was connected via Bluetooth with a serial port adapter. The ergometer was adjusted to the height of each person, more specific to the length of their legs, tested for a short time and adjusted again until the setup was optimal in the participants' opinion (Constitutional Adaptation).

For the initial setup of the training configuration the resistance was adjusted in 5 steps from 60 to 140 Watt according to the personal fitness rating of the participants.

The approach of User Experience Adaptation was evaluated by a comparison of the three conceptually different Mini-games. The participants played all three games, one after another and rated them afterwards with respect to several predefined criteria by filling out a questionnaire. The most significant result is that motivation is higher when playing LetterBird and ErgoBalance compared to VirtualVideo (Friedman test: $\chi^2=10.02$, $p<0.01$) (Fig. 6). The rating of the games concerning short-term and long-term motivation depends on the game and correlates with the personal fitness rating. The non-interactive application VirtualVideo is rated differently by male and female participants. However, 3 (games)×2 (gender) ANOVAs reveal significant ($p<0.01$) gender effects only for exertion games was realized within subjects. The female participants rated the games more exhausting than the male participants (Table 3), this implies that gender is a relevant parameter for the calculation of power/resistance and needs to be respected in future adaptation and personalization approaches.

No correlation was found between assessment of the games and times the participants watch TV or use PC per day. The judgement is significantly related to the fitness level of the participants ($r=-0.30$; $2p=0.036$). Most participant (83.3 %) stated that they would like to play the games again. More than three fourths (77.1 %) would

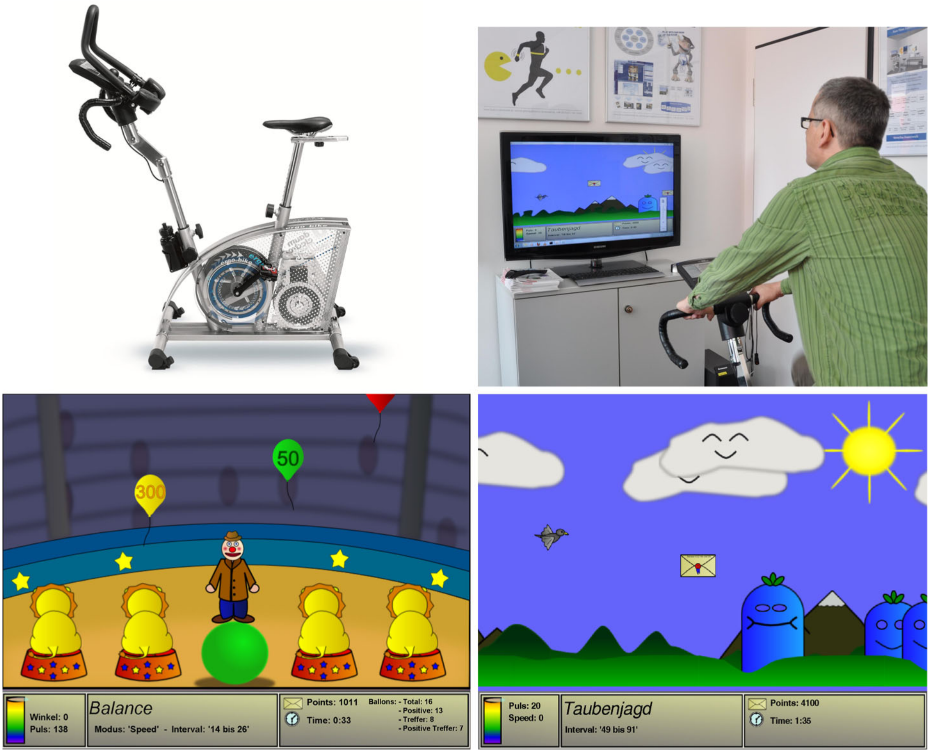

Fig. 5 (from *left to right*, *top row* first) Daum 8008 TRS 3 ergometer cycle, user playing ErgoActive, screenshot of ErgoBalance, screenshot of LetterBird

Table 3 Details for the gender-dependent rating of the perceived exertion

Game	Gender	Mean	SD	*N*
LetterBird	Male	4.12	0.946	34
	Female	3.92	1.326	14
	Total	3.88	1.123	48
ErgoBalance	Male	4.09	0.996	34
	Female	3.29	0.994	14
	Total	3.85	1.052	48
ErgoVideo	Male	3.62	1.256	34
	Female	2.79	1.251	14
	Total	3.38	1.299	48

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 home. The results show, that the developed system was well accepted by the user. This means that adaptation technology does not lead to non-motivating games in general. Both game-based applications are more motivating than the virtual video cycling (Fig. 5). However, since both applications differ in more than one parameter (realism, interactivity, feedback, challenge), due to the problem of confounding variables the evaluation could not identify the impact of

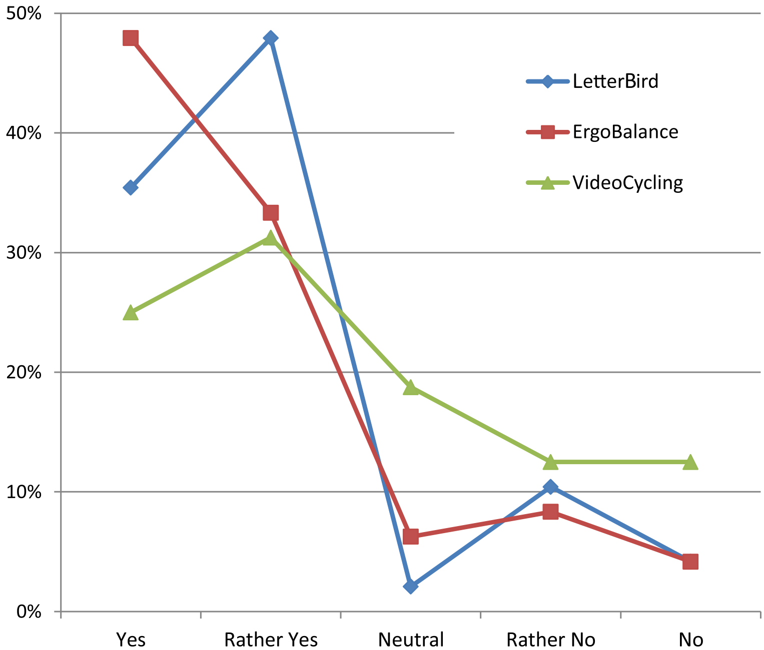

Fig. 6 Percentage of answers to the question "does this game motivate you?"—both games, are more motivating than the virtual video cycling

single parameters on motivation. The gender effects indicate that the gender is a relevant parameter for adaptation and personalization of (perceived) exertion.

6.2 BalanceFit

BalanceFit is a system to support playful training of strength, coordination and balance with the overall aim of fall prevention. The system is intended to improve the players' abilities to lower the risk of falls.

Decreasing strength and balance are, among others, main reasons for falls of older persons. These abilities are trained in the seniors' home only rarely. The seniors' home offers gymnastics and bowling but to allow participating of all inhabitants, these events take place while sitting on chairs in order not to exclude wheelchair drivers or seniors with gait impairments.

Thus, one requirement for the developed training concept was that it includes all inhabitants, irrespective of their constitution, fitness level or physical or cognitive impairments. In order to achieve a broad acceptance of the developed game it should be very motivating. Therefore it includes game-based incentives. Additionally, the game should be biography-oriented, should allow a high grade of recognition and should be simple and understandable in order to provide a low entry barrier, both physical and cognitive.

To allow an adequate training load according to the skill level of the players, which increases during the training progress, the system needs to support a broad range of difficulty levels. The training progress needs to be measurable in order to show a) the effectiveness of the training system (lowering the risk of falls), b) to document the training success for single users and c) to increase the motivation by empowering the self-efficiency to the players.

The developed game should be seamlessly integrated in the care concepts of the seniors' and nursing home. For that, it needs to be simple to manage (that it can be handled by all employees).

The hardware consists of a special frame integrating a force plate with four pressure sensors. It allows a stable stand and a safe training also for people with gait or balance impairments (Fig. 7).

Fig. 7 Woman during the evaluation at the seniors' home (left) and stability frame for secure training

A preliminary evaluation took place in a seniors' home: The participants were acquired from the inhabitants of the seniors' home: 6 seniors (age=59 to 76 years, M=76.00, SD=14.11; 1 male) and 9 pupils (age: 16 to 18 years, M=16.76, SD=0.71; 7 males). The seniors strongly differed in constitution and fitness level. Some were able to walk without help, some needed a walking frame and some others were wheelchair drivers. All participants were able to play the games independently from their disabilities. This indicates that the game provides a sufficient Constitutional Adaptation, even for the seniors with strong gait impairments. All participants accepted the games as an appropriate kind of training. After playing the game in a group the seniors filled a questionnaire containing 23 questions derived from the German translation of the Game Experience Questionnaire [19]. A few seniors asked for a competition mode and wanted to play the games frequently (each day/week). Seniors (M=3.91, SD=0.54) rated the game to be more ($t_{(12)}$=3.12; p<0.05) immersive then pupils (M=3.02, SD=0.50) and seniors (M=1.10, SD=0.15) experienced less ($t_{(12)}$=4.90; p<0.05) negative affect than pupils (M=2.04, SD=0.41). Interestingly, seniors (M=1.20, SD=0.45) rated the game more easy ($t_{(12)}$=2.338; p<0.05) to master, than pupils (M=1.78, SD=0.44). The results show that the game's Constitutional Adaptation (the sensitivity of the board) enabled both user groups, to play the game independently from their personal constitution. Although the games were created especially for seniors—the gameplay (balancing a ball) was chosen to be biography-oriented—it is quite surprising that seniors rated the game easier to master and that seniors had less negative affects than younger participants. One reason might be, that the seniors never played video games before and therefore do not have experiences with commercial games and therefore do not compare this game with other professional games.

7 Conclusion and discussion

In this paper we propose a framework for the development and use of personalized and adaptive game-based training programs in health sport. The approach allows the inclusion of experts from different domains. In contrast to existing approaches the framework allows the creation and configuration of scientifically founded games for different training goals and the configuration of personalized training plans. More specifically, the framework allows the separation between three adaptation layers and identifies the corresponding adaptation parameters.

Altogether, the framework enables the creation and (adaptive) control of personal, game-based and technology-enhanced training programs for different training goals and user groups.

First evaluation results show that serious (health) games for cardio training as well as for balance training are accepted by a broad range of users. Especially for elderly people the social aspects of training in groups plays an important role. To allow the usage of the games by a broad range of end users with different skills and fitness levels, the proposed adaptation concept provides a promising solution.

The long-term training effects and long-term motivational effects have not yet been investigated in this research. At least first evaluation studies in terms of tests of acceptance and qualitative feedback (questionnaires and interviews) suggest a potential for enhanced long-term motivation. However, this hypothesis has to be empirically evaluated and proven in the next step by comprehensive long-term studies with end users and dedicated end user groups. Hereby, experts from the medical domain and physical therapy as well as psychologists provide valuable support for the scientifically well founded conceptualization, execution and analysis of evaluation studies.

In addition, further research will be conducted to develop models for the identification of relations and effects of single adaptation parameters. An additional goal is the integration of fine-grained concepts for the automatic adaptation and the measurement of their effects.

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