Work Hard, Play Hard: How Linking Rewards in Games to Prior Exercise Performance Improves Motivation and Exercise Intensity

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Abstract

The concept of providing power-ups and other rewards to players in sedentary gaming sessions based on prior engagement in beneficial activities, such as exercising, has recently been explored under the term pervasive accumulated context exergames (PACE). Such games have less special requirements and may appeal to a broader audience than regular exergames. However, so far, little is known about the motivational potential and the impact on the targeted beneficial outcomes. To advance research on the potential of asynchronously linking physical exercises to games, we provide a discussion of related work and present a design space for further systematic exploration. Additionally, we present a study which indicates that linked rewards in gaming after an exercise session can lead to motivational benefits and to increased physical activity, when compared to playing a game that does not include such explicitly linked rewards after an exercise session.

Keywords: Exergames, Games for Health, Activity Tracking, Quantified Self, Player Experience, Motivation, Fitness

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1. Introduction

Sedentary behavior and a lack of physical activity are major causes of health issues [1]. Motion-based games can be engaging and offer a host of tangible benefits in this regard. Be it as exergames, with a focus on fitness and joy in play and motion [2, 3], or as games for health with a focus on medical applications [4, 5], for example in the support of physiotherapy and rehabilitation [6, 7]. The benefits can be summarized as offering (1) motivation, (2) guidance for motion executions, and (3) objective analysis. However, these games have special requirements, such as specific sensors and devices, a suitable computing platform (e.g. console), space for moving around, time for setup and calibration, etc. that exceed the usual requirements for video games and are not always easy to meet. As noted by Stanley et al. [8], many of these requirements stem from the direct link of performing an exercise activity whilst playing a game. Social requirements, such as the willingness to expose ones physical abilities or even simply the willingness and ability to be physically active in the way required by a given exergame are further limiting factors. Notably, many current-generation consumer exergame systems face limited long-term adherence. This can likely be attributed to a mixture of novelty effects wearing off and users reaching the limits of the content provided in the games. Additionally, the dominant - and arguably for many preferred - style of playing video games is still playing while seated at a desk or on a couch. These challenges, together with the parallel growth of mobile connected consumer sensor devices (smartphones, fitness bands, smartwatches, glasses, etc.) and the emerging fitness tracking and quantified-self markets, form the basis for *pervasive accumulated context exergames* (PACE) [9, 8, 10].

PACE (cf. Figure 1 for a conceptual visualization) are an alternative approach to exergames where exercises can be performed at a different time than the actual gameplay while both activities are still linked with an overarching *action-reward structure*. For example: performing an afternoon run can be tracked, counting steps with an accelerometer and the step-count can later be

Figure 1: Data from tracked exercises provide the basis for rewards in pervasive accumulated context exergames; PACE are played asynchronously from the exercising and are controlled by standard input devices.

translated into a boost to the speed of ones avatar in a sedentary game. Despite being patently promising, the concept is relatively novel and while related research has found indications that the concept is meaningful to players [10], the impact of design choices such as the impact of activity-related rewards in the game on player experience and exercise performance to the best of our knowledge have not yet been studied in a controlled comparative manner.

In this paper we structure game design choices that require consideration when developing PACE as a form of *asynchronous exergames*. After presenting a sample PACE system we report results from a pre-study on the question whether the concept is perceived as meaningful, as well as results from a study which compared the impact on motivation and exercise performance when *playing a game that included rewards that were explicitly linked to the performance in prior exercise sessions* with the impact on motivation and exercise performance when *playing a game following an exercise session that did not include explicitly linked rewards*. This study addresses the research question whether designing in-game rewards that are explicitly linked to the prior activity provides benefits compared to simply providing ready-made games without further adjustments, i.e. using the games as a form of bulk reward instead of presenting scaled relative rewards in the game.

In the broader context of game user research and HCI this research contributes to the areas of serious games and gamification [11], since PACE can be expanded to activities beyond exercising, such as education [12], household chores, completing tasks at work, and so on.

2. Background

2.1. Exergames & Challenges

Exercising as an element of playing video games has been explored since the appearance of specialized peripherals (e.g. dance-mats). Recent advances in multi-purpose tracking devices, such as the EyeToy, Wii-Mote, Kinect [13], or player tracking for room-scale virtual reality, have given rise to an explosion of new developments ranging from pure entertainment to ambitious serious applications. Related work reports clear evidence for benefits with various target groups, such as obese children / adolescents [14], older adults [15], physiotherapy and rehabilitation patients [7], people living with Cerebral Palsy [16], Parkinsons disease [17], depression [18], and many more. Despite the positive outlook, such motion-based games face challenges that arguably limit the sustained adoption and success. A number of these challenges have been noted by Stanley et. al [8]. We propose an extended selection and a structure including the following three classes:

Technical Challenges - which include necessary specific equipment such as input-output / sensor devices that bring costs and a set of conditions for working properly [13]. The same applies for the gaming platform, which needs to function well together with the input-output / sensor device and in many cases should support various sizes and types of displays.

Environmental Challenges - Space [9] is required to perform motions and also to provide a properly sized display. Motion-based games often require extra time for setup, and they also require extended periods of frequent use integrated into day-to-day activities and the respective environments, due to the nature of the adaptation of the human body to fitness workouts and the fact that persuasion (or behavior change) is often an incremental process [19].

Social Challenges - in many settings, the motion-based nature of exergames leads to differences regarding social aspects of the interaction when compared to traditional video games. For instance, when others are present, body-related self-consciousness may play a notable role [20]. This has been observed and studied in relation to exergames by Mueller et al. [21], who discuss resulting balancing needs. The requirements for the design of games for health by Yim and Graham [22] also relate to this challenge for multiplayer and bystander situations, going so far as to suggest hiding players fitness levels and to avoid systemic barriers to grouping. Lastly, the sustained success and dominance of sedentary gaming indicates that – in many gameplay situations – players rather enjoy a classic video gaming session on the couch or at their desk.

2.2. Fitness Trackers & Quantified Self

The development of new motion-based game enabling devices is related to the development of increasingly small and affordable tracking devices. Activity trackers are now common mainstream consumer products. Fitness bands, rings, necklaces, watches, and also regular smartphones can feature multiple sensors that facilitate the recording of physical traces of various kinds of activities [23]. This is one aspect of the developments in the larger scheme of the *Internet of Things* [24] termed *quantified-self*, or *lived informatics* [25]. Earlier studies on comparatively simple digitally supported feedback mechanisms in combination with digital tracking devices (e.g. PDA + heart rate belt [26]) show great promise in fostering exercise experience and adherence [27]. Omnipresent yet unobtrusive devices provide great potential for reflective learning [28] and can support persuasive approaches [29], since they are in many cases not encumbered by the *environmental challenges* noted for exergames. Online platforms are currently built primarily for data presentation and information visualization, although some platforms also include gamification elements (such as badges and rewards) and social features. Patient-driven health care with quantified self-tracking is a looming trend [30]. While most studies in this area have focused on the effect of data tracking / quantified self without the impact of additional motivation through linked games, first connections between activity trackers and exergames have been implemented [31], especially with smartphones as trackers (cf. *World of Workout* [32]). The focus of PACE, however, lies on the motivational potential of combining real gameplay mechanics and spare-time activities that are rewarding in and of themselves, as opposed to simply interacting with performance visualization and analysis interfaces that may feature added gamification elements.

2.3. Pervasive Accumulated Context Exergames

Stanley et al. [9, 8, 10] provide a comprehensive overview of related work on PACE, spanning from *(Multiplayer) Mobile Mixed Reality Games* (such as *Pokémon GO*), over *Freegaming* [33], rewarding (playful) visualizations (such as *Ubifit Garden* [34]), and mainstream commercial PACEs (e.g. *Foursquare* or *Run-Zombies*, which offer asynchronous rewards, although the gameplay is still synchronous), to scientific explorations such as *Neat-O games* [9]. The *Neat-O games* are one of the first explicit explorations of the PACE space and the accompanying study recorded first indications of resulting improved activity, albeit not in a robust experimental setting [35]. Stanley et al. also present design considerations with a focus on game design aspects that result from the PACE concept when applied to complex games and report on a study with a complex PACE featuring a modification of the game *Neverwinter Nights 2* [8]. In their example, active behavior prior to a gaming session was rewarded with tweaks to an in-game companion (pet), showing a rather deep and complex integration with exercise elements. Stanley et al. found no significant differences between different feedback groups when comparing different reminder strategies regarding the physical performance while exercising and no interactions of player type. They reason that they might have "stretched Huizingas magic circle to the breaking point", meaning that the mapping from activity to in-game effects might not have been direct enough and that the results did not become apparent immediately. In an earlier study they reported on indications that behavior can be changed with the PACE approach [10]. However, a controlled laboratory study regarding the impact of linked game rewards within the PACE approach on motivation and exercise performance has not yet been reported.

2.4. Extrinsic and Intrinsic Motivation

It can be argued that offering either sessions of game play "as-is" or sessions of game play with specifically linked power-ups as rewards for prior "serious" activity, such as physical exercising, presents a form of extrinsic motivation that does not only fall short of the potential of deeply integrating exercising into the gameplay, as would be the case with regular exergames, but that might also present the danger of undermining any intrinsic motivation [36]. However, findings reported based on games that were played asynchronously but linked to prior educational activities have shown improvements in performance [12], hinting at the presence of buffer effects, such as a potential internalization of the extrinsic motivation, which would mean that the rewards are not perceived as controlling behavior [36].

3. Modeling Dimensions for PACE Design

In the following we introduce modeling dimensions for structuring the design and discussion of PACE. The dimensions were derived from related work, as discussed below, in combination with recurrent analysis of the iterative PACE development process that led to the system described in section 5. It can be said that typical contemporary exergames are *linked* with exercising in a *synchronous* manner. A player observes a display device and the body is (partially) observed by a sensor device. Movement translates into game control. We refer to these games as (*synchronous*) exergames and argue that the link does not have to be direct in all aspects.

3.1. PACE as Asynchronous Exergames

As an alternative to the metaphor of *pervasive accumulated context*, PACE can also be described as *asynchronous exergames*, meaning games that have a rewarding *link* between a game and some exercise(s), although exercising and playing *do not happen at the same time*. Since exercise and gaming are temporally uncoupled, both the exercise portion and the game design can vary much more independently than in synchronous exergames. Movements do not need to translate directly into game actions. Exercising can – in principle – be performed anywhere and at any time, depending much more on players personal preferences. This allows designers to avoid some of the challenges related to the *time* aspect of the *environmental challenges* that can occur with synchronous exergames. Asynchronicity also brings the potential of easing the challenges around *space* requirements, since exercising can be done elsewhere. *Technical challenges* can be eased because designers are free to include a wide variety of sensing / tracking techniques in their concepts [37] that do not need to function as direct game-controllers. Lastly, *social challenges* can be eased, e.g. by performing the exercises individually in separate places, whilst still playing together in a later game session, or vice versa. The central question with these potential advantages is *whether the intended motivational effects and behavioral / functional improvements occur*. If posed in relation to the effects known from synchronous exergames, the question more specifically would be *to which extent the effects bridge the disjunction between gameplay and exercising*. This question is not only rooted in considerations about reasons for the lack of effects in the latest study by Stanley et. al [8], it is also rooted in psychological findings about motivation and the distance of rewards. Postponing immediate gratification while persisting in goal-directed behavior for the sake of later outcomes is a necessary skill for effective functioning as a human being [38] and yet discounting future outcomes due to their delayed availability underpins much of human decision making [39]. Furthermore, task interest is known to interact with effects of delayed rewards on motivation [40]. Given a low task interest, more immediate rewards have been connected to more intrinsic motivation, although a high task interest may still trump those improvements even without any or with distant rewards. These findings can be connected to the aforementioned effect of external rewards undermining intrinsic motivation, if the task / purpose is not internalized [36]. Other related work, however, suggests that the influence of temporal distance between exercise and remote feedback on motivation is negligible and comparable to supervised exercise sessions [41].

Altogether, the psychological evidence marks no clear suggestion; the desired effects may or may not occur depending on the nature and perception of the rewards. Related work does suggest that a detailed consideration of the manipulated dimensions and the distance in relation to game design aspects (such as the general system setup, task importance, personal traits and circumstances, etc.) may play a decisive role. Further study is henceforth indicated.

3.2. Design Dimensions

PACE can be modeled or analyzed along a number of dimensions in contrast to regular exergames (cf. Table 1), allowing the formation of hypotheses about how far disjunction might affect the (desired) outcomes in order to support a structured approach to further explorations on PACE. We employed these dimensions to identify a promising combination of properties for further investigation below.

The *distance* aspects largely represent continuous dimensions. Determining the strength of motivational effects for certain ranges of distances marks a clear path for further explorations. The considerations on *social* and *platform aspects*, which are also implicitly discussed in recent work by Stanley et al. [9], represent more discrete choices that designers have to make during PACE design. An interesting lens including similar considerations is provided by the debate on slap-on elements vs. deep integration in the area of gamification [42].

In the following sections we present a system that we designed to be positioned on a level of the dimensions that tests for the presence of effects under notable distances, whilst adhering to the limitations imposed by a one-day laboratory study (fixed low temporal and spatial distance). The study provides an early sampling of the design dimensions, focusing on distances in a comparative manner.

Dimension	**Considerations**
temporal distance (TD)	*How long can the exercising be temporally disjunct from the gaming activity?* *Can reminders extend this range?* *Does the acceptable temporal distance vary relative to exercising / gaming duration?*
spatial distance (SPD)	*How far can the exercising be spatially away from the point of gaming?* *Is a rather close setup hindering?* *Are there interaction effects with TD?*
conceptual distance (CD)	*How much can the exercise differ from the game activities? More precisely: Does the concept work better when (e.g.) running is mapped to increased avatar speed / endurance as compared to running improving item spawn-rates or purely cosmetic aspects?* *Reward types: Do tangible game-mechanical rewards lead to better results than in-game achievements?* *How should the exercise volume and intensity be mapped to the extent and intensity of rewards received in the linked game?*
social aspects (SA)	*Will the expected increased intrinsic motivation and exercise effort be observable in single player games?* *Will the effects be observable in different types of multiplayer designs, such as competitive / cooperative multiplayer?* *Could a non-parallel exercising session ease social stress in gaming pairs with heterogeneous fitness levels?*
platform aspects (PA)	*Which types of trackers can function with which types of gaming systems?* *Which types of activities can function with which types of games?* *Can there be an interactive integration with an existing visualization and analysis interface for activity trackers?* *Can there be an interactive integration with existing cross-game reward and achievement systems?*

Table 1: Dimensions for structuring explorations on PACE.

4. Explorative Pre-Study

In order to explore the intuitive perception of the concept of PACE and to inform the design of our system, we conducted a pre-study with seven student subjects (3 female, 4 male) from Bremen, Germany who were introduced to the concept and then participated in a semi-structured interview lasting about 20 minutes. The script included both close-ended and open-ended questions. In addition to the participants thoughts about the connection of physical activities with games, we also collected biographical data, as well as information about physical activity and exercising behavior.

The average age of the participants was 26.6 years and they performed roughly one hour of medium to strong intensity exercising spread out over 2.5 sessions per week. Favorite sports include cycling, jogging, swimming, and yoga. Most participants indicated that they would *not be willing to do sports in which they have no interest in exchange for a reward in a linked exergame.* The participants prefer AAA quality games and six out of seven noted that they usually prefer (collaborative) multiplayer games. Compared to male participants, female participants reported more frequently to focus more on the appearance of characters and accessories in games as attractive reward types for the concept of PACE. Considerations by participants relating to such rewards included social context and psychological aspects, informing the above-mentioned categories. Since performing sports and gaming are not one-off events in the daily life of our subjects, *"how to motivate people to engage in both activities in a long run"* appears as an important issue to them. Participants noted that long-term reward mechanics should be introduced to the game in order to motivate people continuously. Moreover, they remarked that in-game rewards should not be achieved too easily. Thus, setting well-balanced minimum achievement thresholds for each reward is an important consideration. Participants noted that the type and the extent of the reward should be clearly communicated (e.g. before actual gameplay starts), instead of suddenly getting rewarded during play. Some participants suggested that the game mechanical rewards should be controllable, meaning that players should be able to decide when to use a reward (e.g. as a power-up). In addition, the participants' utterances suggested that social context is another dimension of game rewards. All of them like to share their achievements in both physical activities and game play with families, friends, and in other social communities. Such reward sharing mechanics not only help them to feel that they gain reputation, but can also increase social connectedness, which might, in turn motivate further exercising. These interviews informed the generation of the above-mentioned design dimensions as well as the design process for the PACE system that is described in the following section.

5. The Tune PACE System

To avoid substantial learning periods, and to support a clearly visible mapping between exercise performance and power-ups as in-game rewards, we aimed to create a PACE with a game and linked exercises that are easy to learn, accessible, and easy to perform in a lab setting. We thus opted for the straightforward combination of *stationary cycling* and a simple side-scrolling *platform game*.

Stationary cycling was chosen as an exercise since cycling is very popular, comparatively safe, known to be associated with positive effects on health, and since our pre-study informed us that all study participants were used to at least infrequent cycling. Furthermore, we aimed for a single-session study setup with controlled conditions and controlling the experience would have been much more difficult using outdoor activities. Tracking exertion and exercise effort can be done reliably when exercising on a stationary bicycle. The ergometer featured an LCD display showing real time data including *time*, *approximate energy expenditure* (in kilojoules), *distance* (km), *speed* (km/h) and *power* (watts). The seat height was adjusted for each participant. While cycling, the participants *heart rate* (HR) was tracked with a belt that was linked to a mobile device (display out of sight).

A side-scrolling platform (*jump'n'run*) game was developed for the study

Figure 2: Screenshot of the game Tune.

to assure full control over all aspects of the software. We designed a PACE version *with linked rewards* and a version of the game *without linked rewards* that otherwise remained the same. The game features *time* and *health* as the two major resources and contains a classic selection of *obstacles* (walls, gaps, moving / elevated platforms, disappearing floor, gaps for sliding) and *enemies* (approaching rockets, creeping alien snails, an alien in a UFO that trails the player to enforce moving forwards for better experimental comparability). The game mechanics are thus closely aligned with classic jump'n'run games, such as *Super Mario*, differing merely in the selection of obstacles and distinct player actions (aside from regular movements, such as jumping and running). The game also features a badge as an additional cosmetic reward for the exercise effort and a display of the remaining power-up called *super run time* (SRT). A selection of these game elements can be seen in Figure 2. The game was designed to be played with a gamepad controller (optimized for an MS XBOX 360 controller), using the directional pad for moving the player character left and right, while employing one button for jumping actions, one for crouching, one for sliding, as well as a trigger button for controlling the speedup function. In order to assure comparability across subjects, the game was designed to avoid complete failure: Contact with enemies hurts the player, but does not kill the player character (however, the scoring system still rewards players for avoiding collisions with enemies). Falling down from a platform or loosing health results

Figure 3: Top: Screenshot of the award screen for the *linked condition*, presenting information on the achieved badges and SRT.
Bottom: Screenshot of the award screen for the *unlinked condition*, presenting an exercise summary and placebo badge.

in the player being reset in place. This takes a few seconds, inducing a penalty on the time resource. Hence, the best play strategy would still be combining continuous forward movement with maximum feasible speedup, while employing dexterous jumping actions to avoid enemies and obstacles, or to scale obstacles as fast as possible. For the study detailed below, a tutorial level with a duration of roughly 2 minutes was designed, together with a gameplay level that takes 2 to 3 minutes to complete.

An exercise performance summary is presented to the players at the beginning of a round. In the *linked* case, the screen includes a notification on the amount of seconds of SRT and the level of the badge reward earned by the effort in the prior exercising session (cf. Figure 3, top). The screen for the *unlinked* condition only contains a summary of the exercise performance together with a plain badge (cf. Figure 3, bottom). After completing a level, a summary of the score is presented (time used and remaining health) together with scores from

Figure 4: Badges according to burnt kJ in the linked condition.

previous rounds (if applicable).

5.1. Linking Rewards to Exercise Performance

The exercise performance was calculated after each exercise session. A second pre-study with 20 participants in which we compared the impact of either (1) *a badge reward* or a (2) *game mechanical* (speed-up) reward following a within-subjects design had shown no clear significant differences between conditions with regard to game user experience or exercise performance. Therefore we adopted a combined game mechanical (low CD) and badge reward (larger CD) for the linked PACE condition in the main study, in order to establish a clear, permanently visible, and possibly motivating link between players exercise performances and the game. Pretests with the stationary bicycle had shown that very low intensity cycling for five minutes on average resulted in approx. 40kJ of energy expenditure, while high intensity cycling burned approx. 120kJ. Based on this data, we established a linear mapping between energy expenditure and reward. The badge reward for the linked group featured five levels (cf. Figure 4).

Reward Mechanic Adjustments. We originally chose an increased speed as the game mechanical reward, since it is has a *low CD* to the endurance training activity of cycling. The player actions for the game were running (forwards and backwards), jumping, sticky-jumping up walls, and sliding. A speed boost was designed to affect all of these actions, making them more powerful in theory. The forty trials of the second pre-study mentioned above included this increasing maximum speed for the game character. The outcomes indicated that the

$$x := energy expended[kJ], f(x) := SuperRunTime[s]$$

$$f(x) = \begin{cases} 5 & , \quad x \leq 40 \\ 5 + \left(\frac{x-40}{5.4}\right) & , \quad 40 < x < 175 \\ 30 & , \quad x \geq 175 \end{cases} \tag{1}$$

$$Note : 5.4 = \frac{(175 - 40)}{(30 - 5)}$$

Figure 5: Equation for the amount of *super run time*.

theoretical advantage did not always lead to improved performance and subjectively reported enjoyment, possibly because increased speed requires increased dexterity and timing, if all obstacles are to be passed smoothly. Since the game reward should grant reliably positive experiences, we adjusted our choice to a player-controlled boost (or power-up) with a fuel/active-time resource which was then provided as a reward in an amount corresponding to the exercise performance. Thus, players were able to use the speed and invulnerability boost in places where it was helpful. To assure availability of this mechanic for at least a short while, we set the minimum available SRT to be five seconds. After balancing tests we determined the useful upper limit for the SRT resource to amount to 30 seconds. Tests with extreme intensity cycling had shown a top value of 175 kilojoules. Given these boundaries, the available SRT for each player was calculated as follows:

The midpoint of this linear mapping interval (17.5s) was used as the fixed amount of SRT for the unlinked condition so that differences in game experience and performance cannot be attributed to the mere presence or absence of SRT.

6. Study of the Impact of Linked Rewards

A comparative study was set up in order to determine whether the PACE with linked rewards can lead to measurably improved motivation and an increase in exercise performance in comparison to exercising and playing a game without a direct link. We hypothesize that (H1) *an explicit link between the prior activity*

Figure 6: Setup with exercise (left) and gaming (right) station.

and the gaming through adjusted in-game rewards can improve motivation and exercise performance. The system was set up for a fixed position in the design space for PACE that intends (based on prior experience, our pre-studies, and on related literature) to provide a high likelihood for motivation effects, namely: a close CD between exercise (cycling) and game reward (SRT + cycling-related badge), a close TD with a salient reminder (splash screen and permanently visible effects), a close SPD (an exercise bicycle in a separate lab section), and single player (to exclude the impact of social aspects), as well as using familiar platform elements. The study setup and methods were tested in two separate pilot runs with an expert and a convenient subject prior to settling on the exact procedure (with minor adjustments) as described in the following subsections.

6.1. Setup

Figure 6 illustrates the study setup. The stationary bicycle was located in a separate area of the room with no direct line of sight to the gaming station. The gaming setup consisted of a laptop with a 27” screen, speakers, a Microsoft XBOX360 gamepad and a separate survey laptop. Not pictured is a cool-down area where participants were seated for a cool-down period after each exercising session and watched a video of a fireplace on a laptop for controlled distraction.

6.2. Measures

A number of models exist for explaining motivational effects and impact on behavioral change. *Self-determination theory* [43] and *self-efficacy* [44, 45] have been shown to be useful frameworks both in the context of exercise motivation and gameplay motivation. Our study thus builds on these constructs for the psychometric analysis.

A broad selection of measures was taken in order to facilitate a reliable triangulation of the expected effects. Next to the main endpoints related to exercise performance with measures of *heart rate* (bpm; measured with the HR belt), *energy burned* (kilojoules) and *distance traveled* (km; both measured by the ergometer), this included pre- and post-session measurements with psychometric instruments, a demographic questionnaire, a post-study interview, and game performance data. The demographic questionnaire included items on gaming and exercising habits, items about play style, and a short form of the *International Physical Activity Questionnaire* (IPAQ) [46]. A *Locus of Causality for Exercise* (LCE) questionnaire was administered before and after the intervention. Three custom items were included to capture the experience after each round of exercising (EX1: emph"Please rate how much effort you put into this exercise session." [0–100 scale], EX2: *"Please rate how well you think you did in this exercise session."* [0–100 scale], EX3: *"I enjoyed this exercise session."* [*strongly disagree (1) – strongly agree (7)* Likert scale]). After each round of gaming, the participants responded to two custom game experience items (GE1: *"I enjoyed this game session."*, GE2: *"Playing the game motivates me to perform exercises."* [both 7pt Likert scales]), to an *Intrinsic Motivation Inventory* (IMI) [47] and to the autonomy and presence items of the *Player Experience of Needs Satisfaction* (PENS) [48] questionnaire. After the intervention, *self-efficacy* [45] was captured with a custom *sports self–efficacy* (SPSE) questionnaire (constructed following Bandura [49]; cf. Table 2). The data collection was augmented with an observation protocol to capture notable / irregular behavior, utterances, and technical difficulties that might occur.

6.3. Procedure

The study followed a between-group setup with sessions consisting of three identical trials to allow the participants to become accustomed with the rela-

SPSE	Statement to express agreement with (7pt. Likert scale):
Q1	*"Due to todays cycling, I will exercise more in next few days."*
Q2	*"Due to today's game play, I will exercise more in next few days."*
Q3	*"I would exercise more, if my exercise effort would lead to achievements in my favorite games."*
Q4	*"I would exercise more, if my exercise effort would give me a game play advantage in my favorite games."*
Q5	*"If I do a good job in the game, I will exercise more in next few days."*

Table 2: Questions relating to self-efficacy.

tionship between exercising and gameplay / rewards. After an informed consent procedure the participants played the tutorial level (showing all types of movements, obstacles, enemies, the SRT mechanic, and the scoring). Participants were given the chance to request further information, or a prolonged learning period. This was not made use of. Following the subsequent completion of the pre-study questionnaire, participants began the first trial. Each trial consisted of an exercise block, a rest period, and a gameplay block. Each exercise block included 5 minutes of cycling (1 min. warm-up, 3.5 min. full intensity, 30s cool down). Participants in the linked group were made aware that there would be a connection between their performance and the game and that *"the better [their] performance, the higher level of a reward [they'd] get"*. Participants in the unlinked group were instructed to start cycling like they were exercising to be sporty. Participants in both groups were aware that they would play a game after exercising. Each exercise block ended with a short questionnaire. In order to build up some temporal distance and to allow all subjects to focus on the gameplay sessions and to be able to control the game with adequate dexterity, a two minute rest period was inserted, separating the exercising and gameplay blocks. For the rest period the participants were asked to sit on a chair and watch a video clip of a fireplace to avoid uncontrolled distractions. Each gameplay block consisted of one level with approximately 2–3 minutes of playtime. Durations were chosen as a compromise between a notable game experience and a reasonable total duration of the study of 60–70 minutes per participant.

Each gameplay block was closed by a questionnaire. The only differences between trials for the participants of the two treatment groups were the wording of the instructions prior to exercising and gameplay, the exercise performance summary screens, and the rewards in terms of badge level and amount of SRT. Upon completing all trials the subjects responded to a final questionnaire and participated an interview to gather potentially unanticipated reactions.

6.4. Participants

20 participants were recruited for the study without monetary compensation (10 female and 10 male univ. students; age 20-36; M = 26.45, SD = 3.53). They had diverse cultural backgrounds including European (13, including German, Swedish, Portuguese, Luxembourgish and Russian), Asian (6, including Chinese and Indian) and American (1, Chilean) roots. They came from a diverse range of fields including natural/social sciences, engineering, computer science, art, language, business and pharmacy. Participants were randomly assigned to the groups with equal gender splits.

6.5. Results & Analysis

In addition to descriptive statistics we report Welch Two Sample t-tests with prior Levene's tests for the equality of variances and adjusted assumptions if needed for contrasts between the two treatment groups. We report largely on the t-tests, since the primary research interest was in contrasting the two groups. Trials within each condition group did not constitute different treatments so t-tests were performed on means of means from all trials. One-way repeated measures ANOVA for analyses of per-trial data were employed for confirmation together with non-parametric validations of the results (Mann-Whitney's U tests instead of unpaired t-tests and Friedman tests for within-subjects factors instead of one-way RM ANOVA) in case our participants might not have perceived the Likert scales as interval, finding all reported between groups effects confirmed. Variances were winsorized (leveling outliers in the .2 quantiles to trim edge values) [50]. We also report Cohen's d / η^2 effect size estimates.

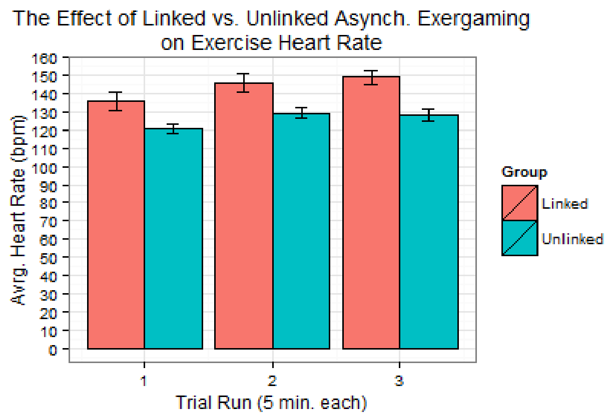

Figure 7: Heart rate by group and for each trial. Error bars indicate standard error.

trial	group	Energy expenditure (kJ) mean (SD)	Distance (km) mean (SD)
1	linked	108.44 (21.03)	2.13 (0.31)
1	unlinked	95.82 (12.46)	1.91 (0.21)
2	linked	112.08 (15.04)	2.18 (0.21)
2	unlinked	99.44 (17.81)	1.99 (0.27)
3	linked	116.22 (6.87)	2.23 (0.1)
3	unlinked	98.76 (24.03)	1.96 (0.4)

Table 3: Kilojoules and distances for each group and trial.

Exercise Performance. The descriptive statistics show a notable difference in mean heart rate between the *linked* and the *unlinked* condition over all three trials (see Figure 7). A t-test contrasting the mean heart rate of both treatment groups marks those differences significant at the $\alpha = .05$ level (t(18)=3.24, p=.005, d=1.53, r=.61). The difference also appears to be increasing over the consecutive trials. Table 3 shows the remaining performance measures of *energy expenditure* and *distance*. While inferential statistics do not indicate statistical significance on both measures, the results can be interpreted as a trend and the descriptive statistics unequivocally show higher means for the linked condition.

Exercise & Game Experience. The *exercise experience* (EX) items on self-assessed exercise *effort*, *performance*, and *enjoyment* collected after each exercise block showed large variance and no significant differences between the treatment groups. The ratings on *effort* increased significantly (by ca. 10%) over time in both groups (F(2,36)=4.96, p=.012, η^2=.22), as did the self-assessed *performance* (F(2,36)=4.92, p=.013, η^2=.22). *Enjoyment* slightly increased over time and was overall positive (*linked:* M=5.67, SD=.44; *unlinked:* M=5.2, SD=.78).

The *game experience* item on *enjoyment* (GE1) did not show significant differences between the groups (*linked:* M=5.82, SD=.26; *unlinked:* M=5.93, SD=.34), but both means represent notably high scores on a 7 pt. Likert scale. There was a significant effect on the *motivation to perform exercises* (GE2) item (*linked:* M=4.49, SD=.71; *unlinked:* M=3.16, SD=.82; t(18)=3.89, p=.001, d=1.83, r=.68).

SDT Measures / Intrinsic Motivation. The IMI showed varying results on the four dimensions that were recorded (cf. Figure 8). There was a significant effect on *perceived competence* (Levene test sig., t(15.41)=3.6, p=.003, d=1.7, r=.65) between groups which is also visible in consistently increased competence measures over all trials under the *linked* condition as compared to the *unlinked* condition. There was another significant effect on the dimension of *tension/pressure*, this time with increased means under the *unlinked* condition (Levene test sig., t(12.4)=-2.93, p=.012, d=-1.67, r=.64). Both *effort/importance* and *interest/enjoyment* show high mean scores, but no sig. differences.

The PENS measures of *autonomy* (*linked:* M=3.18, SD=1.19; *unlinked:* M=3.97, SD=.75) and *presence* (*linked:* M=3.61, SD=.68; *unlinked:* M=3.64, SD=.96) showed no sig. differences.

Locus of Causality for Exercise. Contrasting the post-treatment minus pre-treatment differences of the LCE responses revealed a difference that can be interpreted as a trend (*linked:* M=.18, SD=.53; *unlinked:* M=-.23, SD=.47; Levenes test not sig.; t(18)=1.85, p=.081) with a positive development in the *linked* and a negative one in the *unlinked* group.

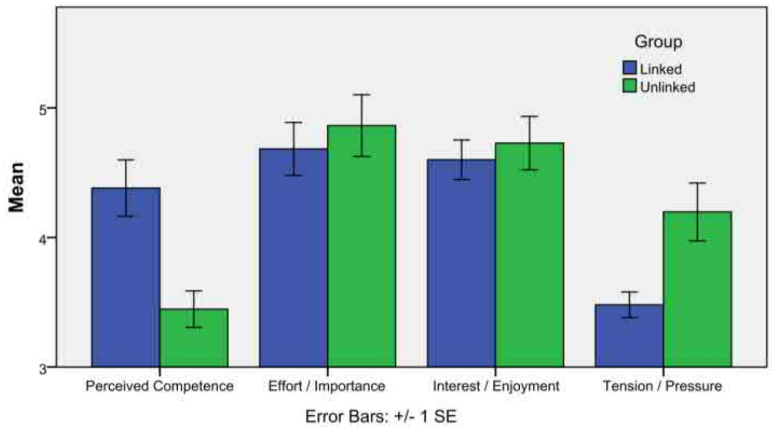

Figure 8: IMI measures relating to intrinsic motivation.

SPSE. The SPSE items on self-efficacy were analyzed separately since they were not designed to load a single construct. Participants appear to agree only slightly that they *will exercise more due to the cycling sessions* (*linked:* M=4.06, SD=1.85; *unlinked:* M=4.06, SD=.93) and there are differences in the extent to which they agree to the same statement with regard to the *gaming sessions* (*linked:* M=3.4, SD=2.17; *unlinked:* M=2.4, SD=1.35). Both items show large variances. The items Q3 (*linked:* M=4.6, SD=2.07; *unlinked:* M=3.46, SD=1.4) and Q4 (*linked:* M=5, SD=2.21; *unlinked:* M=3.36, SD=1.4), aiming at achievements or gameplay advantages as different motivators for increased exercise effort appear increased in the linked group. The participants do not appear to agree to Q5 (*linked:* M=2.86, SD=1.04; *unlinked:* M=2.4, SD=1.51). None of the items showed significant differences.

Contrasting *cycling* and *gaming* as factors for *increased exercising* yields a significant difference using a paired samples t-test (*cycling:* M=4.06, SD=1.42; *gaming:* M=2.9, SD=1.83; t(19)=2.861, p=.01). This difference appears to be stemming from the *unlinked* group, where the significant effect also exists (t(9)=2.72, p=.024) rather than the *linked* group, where there is no sig. difference (cf. Figure 9).

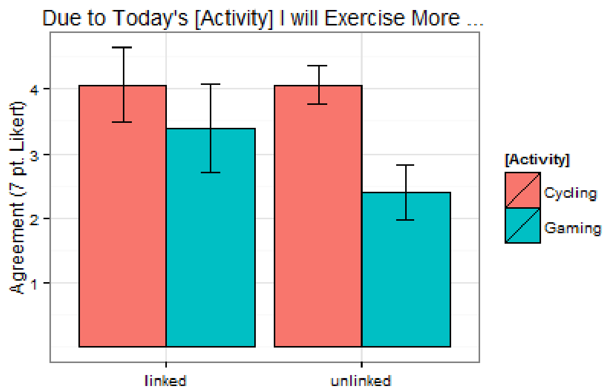

Figure 9: Means on influence of cycling and gaming on intended future exercising behavior. Error bars indicate standard error.

trial	group	Time (s) mean (SD)	Remaining HP mean (SD)
1	linked	122.58 (21.50)	683.26 (180.55)
1	unlinked	128.86 (29.73)	608 (206.79)
2	linked	107.04 (15.51)	862.4 (68.87)
2	unlinked	152.24 (47.96)	631.46 (267.29)
3	linked	105.86 (12.54)	838.84 (61.27)
3	unlinked	107.72 (17.45)	755.84 (149.19)

Table 4: Game time (lower is better) and remaining health points (higher is better) for each group and trial.

Game Performance. The game performance measures *time* and *remaining HP* both show significant learning effects over time (trial 1 to 3; using one-way RM ANOVA over both groups: *time:* F(2,38)=4.71, p=.015, η^2=.2; *remaining HP:* F(2,38)=5.34, p=.009, η^2=.22). T-tests show a sig. difference between groups with regard to overall mean *time* (Levene test sig., t(14.93)=-2.44, p=.028, d=-1.26, r=.53) and a trend with regard to *remaining HP* (Levene test sig., t(13.18)=1.97, p=.071, d=1.08382, r=.48).

Interviews. The interview contained four open-ended questions that were read out loud to each participant. Responding to the first item (*Do you like the idea: performing some exercises and then getting rewards according to your* *performance in the game later on?*), nine participants from the linked group stated that they liked the idea with reasons such as *"just like to get reward"*, *"its really motivating"*, and *"the better you exercised, the better you can beat the enemies"*. The only negative response was by a very sporty person, explaining that *"doing sport is for the real world, but not for the virtual world"*. Seven participants from the *unlinked* group explicitly stated that they had no idea about the mapping between the exercises and the rewards. Only one said that there might be a relationship (while there was none).

Six participants from the *linked* group agreed to the second interview question (*Do you think you would do more exercises in the future if you would continue playing this game, or similar kinds of "asynchronous exergames" (perhaps with a full commercial quality game)?*), whilst two disagreed with the explanation that *"instant feedback is better"* and another two did not answer directly, explaining that they do not play games regularly. In the unlinked group, six participants disagreed and only two explicitly agreed.

The third item faced the participants with the condition of the other group (*If the [linked: amount of boost you got was always the same, no matter how much you had exercised] / [unlinked: amount of boost was varied in connection to your former exercise performance], do you think that would have an impact on your motivation to perform better on exercising?*). All participants from the *linked* group agreed that there would be an impact reducing their motivation, explaining: *"I would lose motivation"*, and *"I would have no motivation and would not do more"*. Seven participants from the *unlinked* group agreed that there would be an impact on their motivation and only two disagreed, stating that they exercise for fun, not for a reward.

The last question addressed the issue of temporal distance (*Today we asked you to exercise and you got to play a game almost immediately afterwards. If you would exercise one day and then get to play a game on the day after, do you think that getting to play that game would have an impact on your motivation to exercise?*). Eight participants from the *linked* group agreed, explaining they would have *"the same motivation"* and would *"be long term motivated"*, while two disagreed, noting that *"human beings need to get a feeling of success immediately after something is done"*. In the *unlinked* condition, eight participants disagreed while one acknowledged that *"it would have very little impact"* and one added the condition *"unless playing with others"*. Two agreed, saying that *"it would be more interesting"* and that they would be *"a little bit more motivated"*.

7. Discussion

The results of our study indicate that there are differences in the *interaction experience*, *intrinsic motivation*, and *exercise performance* when using a PACE where rewarding game elements are *explicitly linked* to prior exercise performance as compared to a game where rewarding game elements are *not linked* to prior exercise performance, delivering empirical evidence from a comparative laboratory study for a central assumption in the concept of PACE. While *heart rate* can be influenced by a number of factors, the significantly increased heart rate in the *linked* condition ties in well with the trends in the remaining performance measures, the increased perceived *IMI competence* and the trend in the LCE. This observation is also supported by the GE2 item and statements in the interview, where more participants from the *linked* group favor the concept of PACE and believe that such games might increase their motivation to exercise in the future. We argue that the difference in HR even in the first trial run (prior to playing the game) can likely be explained by the promise of rewards in the following game session.

The overall experience of exercising and gaming in our study appears to be positive with high *EX* and *GE* and *IMI* rankings, as well as *valence* responses and positive comments in the interviews. The majority of measures show descriptive results that appear favorable to the linked condition, the flipped results in the IMI *tension-pressure* measure being an exception that may be related to the difficult role (arguably not a reliably linearly positive contribution [47]) of that construct as a factor of *intrinsic motivation*. The lack of effects on the

PENS dimensions of *autonomy* and *presence* are as expected, since they correspond mostly to game design aspects beyond the extent of badges and boosts. We believe that it is reasonable that the *competence* construct responds indirectly to real world achievements and thus to the game mechanical link.

Due to the study setup we cannot clearly separate the contributions of *being informed about a later reward* prior to the exercise session and of *receiving the reward* in the gaming session to the measured effects. An analysis separating trial one from trials two and three shows that both segments are significantly different between groups, which suggests that being informed in advance plays a considerable role, although a mixed contribution seems likely. A placebo study could be performed to explore this issue and deliver insights regarding the required accuracy of representing exercise effort in game rewards.

The SPSE items were only presented after the treatment and did not show clear differences between groups. Contrasting cycling and gaming as motivating factors resulted in a significant difference in the unlinked group. Here, cycling was attributed a clearly larger role, while this difference is not present in the linked group. This may be due to a perceptual change amongst the participants in the linked group, which would implicitly confirm a comparatively larger role of the linked PACE as a motivating factor for future exercises. Since we have no SPSE data from between trials, we can only suggest this as a hypothesis for future work.

Our summarized results support the hypothesis that PACE with linked rewards lead to an increase in exercise motivation and performance (H1). While game rewards can be interpreted as extrinsic motivation in relation to prior exercising, we still find some dimensions of intrinsic motivation measures increased. We thus assume that the linked rewards can support the internalization of gaming as a reward, conceivably through providing a more meaningful connection. Alternatively it could be hypothesized that the task-goal orientation is increased in the linked PACE session as the reward does not appear controlling. Either way, no notable undermining of intrinsic motivation occurred. We also did not find notable adverse effects of linking exercises that arguably lay outside the classic concept of the magic circle [51] of a game to elements inside the game, suggesting that its boundaries can encompass elements that are usually not associated with a sedentary game-world.

7.1. Limitations and Future Work

The goal of the study was to isolate immediate effects of providing linked versus unlinked rewards in a controlled lab environment. Future work should further sample and explore the design dimensions. Future studies should consider medium- and long-term behavior, both in the lab and also in the field (including more realistically situated setups where players determine exercising and play sessions on their own volition to validate the practical relevance of our findings), test how large the temporal distance can grow, and include either broader or more specific target groups, such as older adults (who may react differently to the concept, given – for example – an assumed lower affinity to fitness trackers). This could be of great importance as studies have shown that the acceptance of longer gratification delay correlates with cognitive and social competence [38]. Therefore, we would expect deviating reactions by target groups that do not respond well to gratification delay in general, or from target groups that are not inclined to respond positively to video game rewards, e.g., people opposed to computer games in general. Finally, other types of wearable devices and other types of exercises (e.g. not cardio-oriented), as well as the influence of production quality (e.g. full budget or AAA games versus indie level or academic games), need to be studied to gain a deeper understanding of design options and consequences.

8. Conclusion

In our study, we have shown that there appears to be a difference between the *interaction experience*, *intrinsic motivation*, and *exercise performance* when using a pervasive accumulated context exergame where rewarding game elements are explicitly *linked* to a prior exercise performance as compared to playing the same game when rewarding game elements are unrelated to prior exercise performance. The results of this paper contribute to the current state of the field in several important ways. First, we motivated our research and connected the approach to movements such as quantified-self and the growing variety of fitness trackers. We argued that it is important to understand how games, exercising, fitness trackers and quantified-self are potentially interlinked and can build synergies. To further the understanding in this area and facilitate systematic research we discussed and extended related work, laying out modeling dimensions for PACE. We then built on this discussion and produced a specific setup with a PACE that is different from existing work, mostly due to its focus on an unambiguous mapping between exercise performance and in-game rewards, in order to start exploring the modeling dimensions. We presented results from a comparative study in which we found that perceived *competence*, *heart rate* and *willingness to perform exercises*, all measures that can be related to intrinsic motivation, were increased when game rewards were linked to a prior physical exercise session.

We found convincing indications for benefits of linking games to physical exercises in an asynchronous manner. This finding is of interest compared to related work that could not isolate such benefits when employing the concept of PACE [9]. The comparison of these games to our game design and its respective design space support the assumption that games with very clear and apparent linked reward mechanics might provide stronger positive effects on motivation (likely with interaction effects depending on the target group) than more complex games. However, further studies are required to investigate this assumption. Our findings are also interesting with respect to the growing commercial market for fitness trackers, since they indicate that fitness trackers and games could be linked in many different ways and that – in addition to regular exergames, or adding game-like rewards without deeper game mechanics – there might be further beneficial ways of linking games to physical activities. Notably, asynchronous reward links can likely connect quite arbitrary activities to a game of personal choice or to different games depending on individual or producer preferences, instead of being limited to a specific exergame or gamification approach for a specific activity tracker. Given an open standard protocol for activity to reward links, a number of helpful pervasive accumulated context serious games can be envisioned.

9. Acknowledgments

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