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Ubiquitous Computing at its best: Serious exercise games for older adults in ambient assisted living environments – a technology acceptance perspective

Philipp Brauner[1,2,*], Andreas Holzinger[3,4], Martina Ziefle[1,2]

[1]Human-Computer Interaction Center (HCIC), RWTH Aachen University, Germany
[2]Chair for Communication Science, RWTH Aachen University, Germany
[3]Institute for Information Systems and Computer Media, Graz University of Technology, Austria
[4]Research Unit Human-Computer Interaction, Institute for Medical Informatics, Medical University Graz, Austria

Abstract

Ubiquitous computing and ambient assisted living environments offer promising solutions to meet the demographic change. An example are serious games for health care: Regular exercises mediated through games increase health, well-being, and autonomy of the residents whilst at the same time reducing the costs for caregiving. To understand which factors contribute to an increased acceptance of such exercise games in ambient assisted living environments, a prototypic game was evaluated with 32 younger and 32 older players. Game performance is influenced by age, need for achievement, and also gender. Acceptance and projected use are related to the believe in making the game a habit, current gaming frequency, and social influences. Notably, the game increased the perceived health of the subjects, which is an important issue. This article concludes with guidelines to successfully introduce serious exercise games into health care and future ideas to realize social inclusion in game design.

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1. Introduction

Western societies are facing an enormous demographic change [41]. The life expectancy is increasing through progress in medicine, nutrition, hygiene, and a time of peace and prosperity [59], however threatened by e.g. obesity [51], and unhealthy nutrition in western countries [3]. By contrast, the birthrate is declining since the 1960s. Current projections estimate that the rate of people 65 years and older will rise from 17% in 2008 to 30% in 2060 [27]. Also, the rate of people 80+ will rise from 5% to 14% in the same period.

This affects the social and welfare systems of western societies, as a shrinking workforce needs to support a growing number of beneficiaries. Today, one dependent elderly person is covered by 3.2 jobholders. This *old-age dependency ratio* is expected to dramatically decrease to 1:1.85 within the next 40 years [27]. The likelihood of chronic illnesses increases with age [31] and many people 80+ need special medical attention and support by others. This aggravates the development and increases the stress on health and welfare systems.

To maintain viable social systems that support elderly life with self-determination and dignity, new and innovative solutions must be developed. This work focuses on the idea of "prevention instead of treatment". Specifically, we want to understand how elderly people can be motivated to maintain or increase their physical fitness through regular exercises, as exercising has positive effects on health [43, 72, 67, 1] and also on mental well-being [53, 17, 35].

To address this question, this work combines three major research lines in the area of ubiquitous computing: Ambient Assisted Living (AAL), Serious

*Corresponding author. Email: philipp.brauner@rwth-aachen.de

Games for Health (specifically *Exercise Games* or *Exergames*), and technology acceptance research, that are presented in the following section.

2. Background

The following sections describes the three research domains combined in this work: Ubiquitous computing and ambient assisted living, serious games and serious games for health care and outlines technology acceptance research.

2.1. Ubiquitous computing, ambient assisted living

Already in 1991, Marc Weiser's vision of Ubiquitous Computing introduced the concept of "smart environments" in which information and communication technology is seamlessly integrated into the physical surrounding [69]. This early vision is closely related to the current discussion of "Internet of Things" (IOT) and Europe's concept of "Ambient Assisted living" (AAL). Smart health is the next big thing in the western countries and a necessity of the future [32].

Ambient Assisted Living strives to enhance the life quality, independence, and dignity of elderly, disabled, or chronically ill people through innovative, ubiquitous, and unobtrusive technology at home [42, 61, 76, 57, 62, 74]. Although such pervasive health care systems have large potential to provide patients with a new quality of (medical) home care [16, 15], fundamental questions regarding the behavior, communication and technology acceptance are not satisfactorily answered [49] and have enormous research potential [36]. Foremost, the social consequences of technology at home and the complexity to tailor the technology to the individual demands of the users is a crucial issue [44, 71] and the specific requirements of elderly are a critical factor for the success of ambient assistive living technologies [58, 54], e.g. usability engineering is a crucial factor [34, 37, 33].

Some visions of ubiquitous computing and ambient assisted living are slowly becoming reality: Smart homes that connect and orchestrate various devices inside a home and personal drones in the form of robot vacuum cleaners facilitate the day-to-day life of their users. Still, many ideas remain visions that cannot yet be realized in domestic environments. To understand the reception of these by potential users and to derive recommendations for researchers and practitioners, prototypic living labs are constructed that simulate the envisioned ideas.

One of these labs is RWTH Aachen University's Ambient Assisted Living Lab [75]. This prototypic living environment resembles a comfortable $25m^2$ living room with two couches and a coffee table. Various sensors are seamlessly integrated into this living room. For example, sensors in the floor detect movements and possible falls [47], an integrated scale measures a person's weight on his or her behalf, and an invisible infrared camera can detect a person's body temperature to signal possible illnesses [40]. A large multi-touch wall supports novel interaction techniques [30] and offers patients tele-medical consultation services, e.g., medical encounters with (tele-)doctors [8]. Figure 1a shows the living room and a video presenting the lab is available online[1].

2.2. Serious games and exercise games

According to a definition by Michael and Chen a "serious game is a game in which education (in its various forms) is the primary goal, rather than entertainment" [55]. Such games can have powerful effects, e.g. to stimulate motivation [20, 46, 56, 45].

From a psychological perspective, serious games build - amongst others - on the Premack principle [60]: The likelihood of an unlikely event (e.g., exercising) increases if it is coupled with a likely event (e.g., playing games [39]). First applications of computer-based serious games for health care, specifically for frail elderly people, have been presented as early as 1983 [70]. One prominent branch of serious games for health care are "exercise games" (a combination of the words "exercise" and "games") that are controlled by full body motions of the players [66]. They have recently gained new attention through the introduction of the Microsoft Kinect™ sensor as an inexpensive and easy to use gesture detection system, which produces 3D point cloud data and allows a lot of interesting research and worthwhile applications [38]. Rehabilitation of stroke patients [22, 48, 23], increasing maneuverability and strengthening the balance of the body of elderly [29, 25] and raising the motivation for exercising [11, 50] are just some examples of successful applications of serious games for health care.

2.3. Technology acceptance research

Technology acceptance research is based on Ajzen's and Fishbein's Theory of Reasoned Action (TRA) [21] and Theory of Planned Behavior (TPB) [2], both of which state that an individual's behavior is related to the intention to perform the behavior. This behavioral intention is governed by attitudes, subjective beliefs, and self-efficacy (in TPB) the individual has towards the behavior. Davis used this theory in the Technology Acceptance Model (TAM) to predict the later use of a business software (behavior) based on the intention to use the software (behavioral intention) [18]. In TAM, the usage intention is determined by perceived usefulness, perceived ease of use, and the attitude towards using the software. Intention to use and the later use of

[1] http://vimeo.com/31951636

the software were highly correlated, meaning that the model describes the factors influencing the adoption of a software as well as predicts future use of a software.

Davis' Technology Acceptance Model continually evolved to reflect different types of technology and software and to provide a finer grained set of explaining factors. In particular, the *Unified Theory of Acceptance and Use of Technology 2* (UTAUT2) [68] predicts the adoption of consumer technology. Here, the use is voluntary (in contrast, it is unusual that an employee decides on his own which office applications he or she uses) and besides the perceived usefulness, hedonic value and the price of the product play major roles in the adoption process. Specifically, UTAUT2 uses seven factors that influence the behavioral intention to use the software and the later adaption of a technology. These factors are presented in the following, as they are used in the subsequent user study: *Performance expectancy* refers to the perceived benefit of the given technology, e.g., if the user beliefs that she or he is able to achieve something desirable with the technology. *Effort expectancy* models the perceived effort for learning and using the technology. *Social influence* describes the influence of friends and family and the users' beliefs about their appraisement of using the technology. *Facilitating conditions* cover the help users may receive if they experience difficulties using the technology. *Hedonic motivation* relates to the fun the users experience while using the given technology. *Price value* describes the price-value tradeoff and models the users' beliefs if the perceived benefit is worth the monetary costs. *Habit* refers to the users' beliefs whether she or he would use the technology frequently and make using it a habit. In addition, these factors are moderated by the user factors age, gender, and experience. Despite its complexity, the UTAUT2 model is able to predict a fair amount of variance in behavioral intention ($\approx 74\%$) and later use ($\approx 54\%$) of a technology [68].

To understand if serious exergames would be accepted by elderly inhabitants of ambient assisted living environments and which factors are crucial for the adoption, we developed and evaluated a prototypic game. The following section describes the game, afterwards the experimental setup is described.

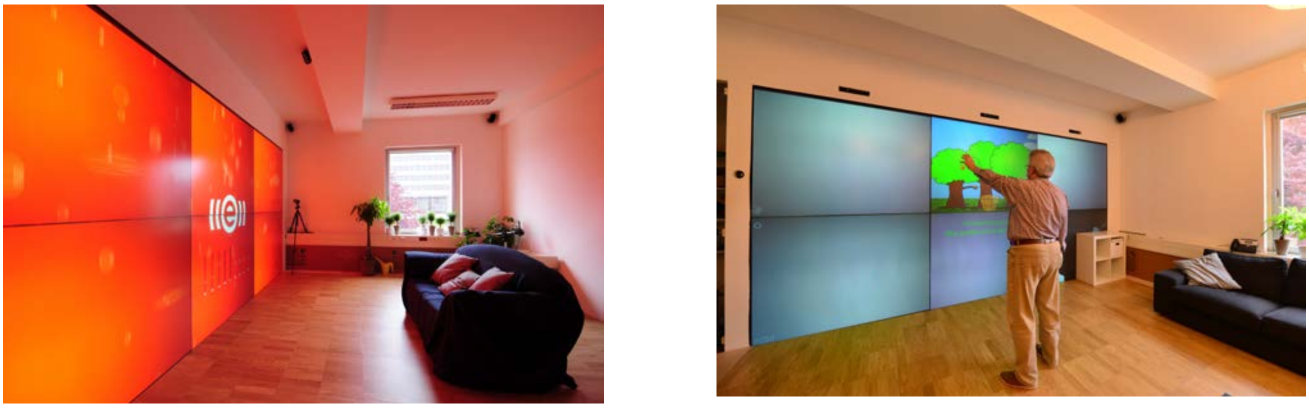
3. A serious exergame for ambient assisted living

To understand the personality factors contributing to acceptance of exergames in ambient assisted living environments, we developed the prototypic exergame "*Fitness Farm*". The game takes place in a virtual garden and the player's task is to collect different fruits within a specific time frame. The gardening scenario is based on one of DeShutter's and Vandenabeele's suggestions for meaningful play in elderly life [19]. The garden is presented on the large multi-touch wall in the living lab ($4.8 \times 2.4m^2$) and the players control the game using motion gestures that are detected by one of three Microsoft Kinect™ sensors. The game is conceptually similar to a game developed by Gao and Mandryk for promoting movement exercises at the workplace [24].

To address different exercises for strengthening different muscles, a set of movement gestures was developed. For example, apples need only to be touched briefly by the in-game avatar, which requires quick movements and strengthens the outer muscles. In contrast, pears require to be held for a few seconds, which strengthens the inner muscles of the body. Bananas require a body twist, as bananas appearing left on the screen need to be picked with the right hand and vice versa. This requires more coordination and activates more muscles. In later levels (not evaluated), carrots require a squat gesture that focuses on the leg and back muscles. To ensure medical soundness, we cooperated with a medical professional and a physiotherapist during the development.

In a user-centered and participatory design process, we developed the exercise game "FitnessFarm" with 1) early focus on users and their tasks, 2) empirical measurement of product usage, and 3) an iterative design process as suggested by Gould and Lewis [28]. The design started with paper prototypes and the first functional prototype was evaluated outside the living lab in a doctor's office [11]. This study showed a high usability for younger and older users and attested that the scenario, the visual presentation, as well as the gestures were accepted by elderly people.

This game is targeted at elderly and therefore honors related guidelines [26]. For example, the game has no setup routine and only asks for the player's name (can be left out). The game has exertion management and a dynamic game difficulty in the sense that slower, impaired, or less ambitious players receive lower scores but can still progress in the game. Movement gestures are introduced and then practiced within the game one after another, thus using scaffolding as an instructional approach [5]. Continuous player support provided by visual and auditory feedback for positive events (e.g., a fruit is collected) or negative events (e.g., if players leave the sensor area, feedback is provided and a thunderstorm indicates the urgency of this event). Also, the level's remaining time is mapped to the daylight shown within the game, as the background gets darker later in a level. The graphics in the game are large and have high contrasts and the sounds use lower frequencies to honor visual or auditory impairments that may come with age. Figure 1b shows a player interacting with the game prototype.



(a) A view of the ambient assisted living lab (image Kai Kasugai).

(b) Participant interacting with a game prototype (image Kai Kasugai).

Figure 1. Ambient assisted living lab.

4. Method

The study addresses three central research questions: First, which user factors contribute to the performance within exergames. Second, which factors contribute to acceptance of these games. Third, do exergames influence the player's perceived health.

4.1. Procedure

The user study was carried out in RWTH Aachen University's Ambient Assisted Living Lab (see Section 2.1). After a brief introduction to the room, the participants answered the first questionnaire (capturing the independent and explanatory variables), then they played three levels of the game. Finally, they answered a second questionnaire (which captured the user's evaluation of the game). The study took ≈ 45 min. per participant.

The next three sections describe the independent (explicitly controlled), explanatory (independent but not specifically controlled), and dependent variables (capturing the interaction with the game).

4.2. Independent variables

Age and gender[2] of the participants was assessed. The sample was constructed to have 50% male and 50% female subjects (for understanding gender effects), as well as 50% older and 50% younger users (for understanding age-related effects).

4.3. Explanatory variables

The explanatory variables, which cover user factors such as personality, technical expertise, and attitude towards health and games, are described in the following.

Gaming frequency across 11 different games and related activities was surveyed. These games and activities contain both computer-related activities (e.g., playing video games) and classic games (e.g., playing card games), as well as indoor and outdoor activities.

Technology experience was captured on three different dimensions: Usage frequency (TUF) and perceived ease of use (TPEU) across several electronic devices and self-efficacy in interacting with technology (SET) were measured on a scale by Beier [7]. Self-efficacy profoundly influences perceived ease of use, effectiveness, efficiency, satisfaction, and learnability when interacting with electronic devices [13, 12] and is influenced by age and gender [4].

Need for Achievement was surveyed on a shortend scale (4 items) based on the Leistungsmotivations-Inventar [65]. The need for achievement determines a person's desire to achieve a difficult and distant goal, to perform very well, and the determination win.

Attitude towards health. Due to the lack of a widely accepted scale for assessing an individual's risk behavior towards his or her own health [14], the health sub-scale of the Domain-Specific Risk-Taking (DOSPERT) scale [9] was used as a foundation and extended by new aspects. The applied scale covers nutrition, smoking and drinking, sleeping, physical inactivity and hectic lifestyle with 6 items.

Furthermore, the *Five Factor Inventory* [52] was measured using the questionnaire by Satow [63] to ensure the sample's ecological validity and to understand if these personality dimensions relate to performance and evaluation of the game.

Finally, the participants' *height* was surveyed, as the Kinect sensor's position in the lab makes tracking

[2]Gender is dummy coded with 1=male and 2=female.

smaller players difficult, which may bias performance and the evaluation of the game.

Note that a basically the same experimental setting was used to evaluate technology acceptance patterns for a serious game targeted at training and retaining the cognitive abilities of residents of AAL environments[73]. The game *Cook it Right* is situated in a kitchen environments and the stimulation of planning abilities is mediated through the preparation of meals through point-and-click interactions on a multitouch display.

4.4. Dependent variables

The study's dependent variables were the following:

Perceived pain of the players is surveyed for 8 body parts (hands, arms, feed, legs, hip, neck, shoulders and head) before and after playing.

Perceived exertion of the player is measured before and after playing on the Borg scale [10]. Although this scale uses subjective ratings, it correlates very strongly with the actual heart of the users.

Performance within the game is captured by interaction log files and measured as *fruit/s*.

The eight dimensions from the UTAUT2 model (i.e., performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value, habit, and behavioral intention) were covered with 3 item each (see section 2.3 for details).

4.5. Statistical methods

All subjective measures were assessed on 6-point Likert scales. The data was then analyzed using bivariate correlations, Pearson's χ^2, uni- and multivariate analyses of variance (ANOVA/MANOVA), and multiple linear regression. The type I error rate (significance level) is set to $a = .05$. Missing values are deleted list-wise on a per test basis. Spearman's ρ is used for bivariate correlations. Pillai's V is used and reported for the omnibus test of the MANOVAs. The effect size is reported as partial η^2. The enter method was used in the multiple linear regression and models with low std. beta were removed between the runs. Models with high variance inflation ($VIF \gg 1$) were excluded. The whiskers in the diagrams indicate the standard error.

4.6. Description of the sample

64 people have participated in the study (50% male, 50% female). Their age ranged from 17 to 85 years with an average of 43.2 years (SD=19.6). To understand age-related effects with factorial methods, we divided the sample into two groups: young ($n = 32$, $M = 25.7$, $SD = 4.5$) and old ($n = 32$, $M = 60.6$, $SD = 11.4$). There was no connection between gender and age group ($\chi^2(1, N = 64) = .250$, $p = .617 > .05$, ns.). A quarter (26%) of the subjects reported chronic illnesses, mainly asthma, diabetes mellitus, and cardiovascular diseases, and the likelihood of chronic illnesses increases with age ($\rho(62-2) = .338$, $p = .002 < .05$, sig.).

Regarding the Five Factor Model, the sample is comparable with the reference data, attesting that we gathered a valid subset of the basic population.

Age influences perceived pain (before the game) ($\rho(64-2) = .319$, $p = .010 < .05$, sig.) with older people perceiving higher levels of pain. However, pain is not affected by gender ($\rho(64-2) = .031$, $p = .810 > .05$, ns.).

As expected, age influences usage frequency ($\rho(64-2) = -.565$, $p < .01$, sig.), perceived ease of use ($\rho(64-2) = -.770$, $p < .01$, sig.), and self-efficacy in interacting with technology ($\rho(64-2) = -.367$, $p < .01$, sig.) with elderly being less inclined to technology. Gender influences perceived ease of use ($\rho(64-2) = -.273$, $p = .029 < .05$, sig.) and self-efficacy ($\rho(64-2) = -.331$, $p < .01$, sig.) but not the usage frequency ($\rho(64-2) = -.122$, $p = .336 > .05$, ns.), and men are more inclined to technology than women.

Moreover, gender is unrelated to attitude towards health risks ($\rho(64-2) = -.127$, $p = .316 > .05$, ns.), gaming frequency ($\rho(64-2) = -.165$, $p = .192 > .05$, ns.), or need for achievement ($\rho(64-2) = -.144$, $p = .264 > .05$, ns.). However, age is related to gaming frequency ($\rho(64-2) = -.486$, $p < .01$, sig.) but not with health risks ($\rho(64-2) = -.142$, $p = .263 > .05$, ns.) or need for achievement ($\rho(62-2) = .040$, $p = .758 > .05$, ns.).

5. Results

The results section is structured as follows: First, the factors that determine performance are presented. Second, the influences on technology acceptance are examined. Finally, the game's effect on the participants' perceived pain and exertion levels is investigated.

5.1. Determinants for performance

The average performance decreases significantly between the 1st, 2nd, and 3rd level of the game ($V = .779$, $F(2, 59) = 103.922$, $p < .01$, $\eta^2 = .779$, sig.). Gender does not influence performance ($V = .055$, $F(2, 59) = 1, 729$, $p = .186 > .05$, ns.), but younger players are significantly faster than older players ($V = .125$, $F(2, 59) = 4.205$, $p = .020 < .05$, $\eta^2 = .125$, sig.). On average, the performance of younger players is 43% (1st), 39% (2nd), and 43% (3rd level) higher than the performance of older players (see Figure 2).

A multiple regression analysis with the independent and explanatory variables as independent variables and performance as dependent variable revealed three significant models. The first model with age as single factor explains $r^2 = .498$ (50%) of the variance in performance. The second model consisting of the

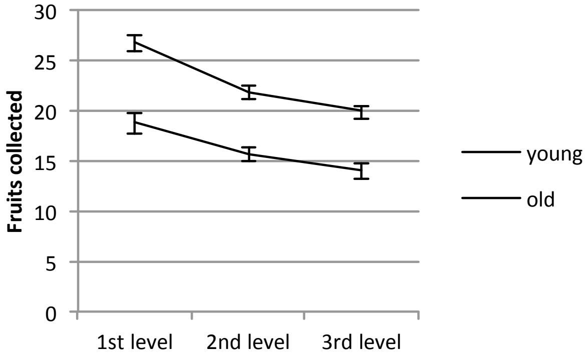


Figure 2. Performance over three levels by age.

Table 1. Linear regression table for average performance.

Model	B	SE B	β	T
(constant)	26.463	2.127	–	12.443
Age	-.173	.021	-.672	-8.310
Need f. Achievement	1.131	.375	.245	3.012
Gender	-2.229	.817	-.227	-2.788

factors *age* and *need for achievement* explains additional δr^2 = .076 (+8%) variance. Individuals with a higher need for achievement were faster in the game. The third model incorporating gender (female players being slower) explains a total of $r^2 = .602$ (60%, δr^2 = .050, +5%) of the variance in game performance and is presented in Table 1.

For validation of our technical setup, we calculated the influence of body height on performance ($\rho(64-2)$ = .286, p = .022 < .05, sig.). Obviously, gender and body height are related, and if controlled for gender, the influence between height and performance fades ($r(64-3) = -.094$, p = .464 > .05, ns.).

5.2. Determinants for technology acceptance

To reveal the determining factors for technology acceptance, we first investigated the influence of only the independent and explanatory variables on behavioral intention and then considered with a holistic model with independent and explanatory variables and model variables from UTAUT2.

A multiple linear regression with the independent and explanatory variables, as well as performance as independent variables and behavioral intention as dependent variable, revealed a single significant model with gaming frequency as the only predictor for behavioral intention (see Table 2 for the model's parameters). People with higher gaming frequency are also more inclined towards using the game. The model explains adj. r^2 = .200 (20%) of the variance and

Table 2. Linear regression table for behavioral intention based on independent and explanatory variables.

Model	B	SE B	β	T
(constant)	2.747	.257	–	10.695
Gaming frequency	.588	.146	.462	4.033

Table 3. Linear regression table for behavioral intention based on independent, explanatory, and UTAUT2 model variables.

Model	B	SE B	β	T
(constant)	-.133	.401	–	-.331
Habit	.510	.102	.449	5.008
Gaming frequency	.428	.102	.336	4.193
Social	.448	.119	.331	3.765

leaves 80% of the variance of the behavioral intention unexplained.

The second multiple linear regression incorporates UTAUT2's model variables and three significant models were revealed. The first predicts 44% (adj. r^2 = .443) more variance of behavioral intention than the scale mean and is based on UTAUT2's habit dimension, i.e., when players can envision using this game on a regular basis, they have a higher behavioral intention. In addition, the second model adds gaming frequency and explains additional 11% of the variance in behavioral intention (δr^2 = .106). The final model is based on habit, gaming frequency and UTAUT2's social influence dimension and adds another 9% (δr^2 = .087, adj. r^2 = .604) explained variance, with social influence having a positive effect on behavioral intention. The model's parameters are presented in Table 3.

Table 4 presents the correlations between the user factors and the factors from the UTAUT2 model. We speculate that a larger sample size would reveal additional influencing factors as many of UTAUT2's model variables are related to behavioral intention. Still, it should be noted that behavioral intention is not related to age ($r(64-2) = -.097$, p = .446 > .05, ns.), gender ($r(64-2)$ = .014, p = .915 > .05, ns.), need for achievement ($r(62-2)$ = .102, p = .432 > .05, ns.), attitude towards health ($r(64-3)$ = .053, p = .680 > .05, ns.), or in-game performance ($r(64-3)$ = .198, p = .116 > .05, ns.)[3]. Also, body height is not related to the behavioral intention ($\rho(64-2) = -.031$, p = .810 > .05, ns.).

[3]Assuming a test power of $1-\beta$ = .8, we can safely find correlation coefficients ρ > .3, meaning that accepting the null-hypothesis still leaves a margin of error of 20% for all correlation coefficients ρ < .3.

Table 4. Relationships between independent and explanatory variables and the UTAUT2 dimensions ($n = 64$).

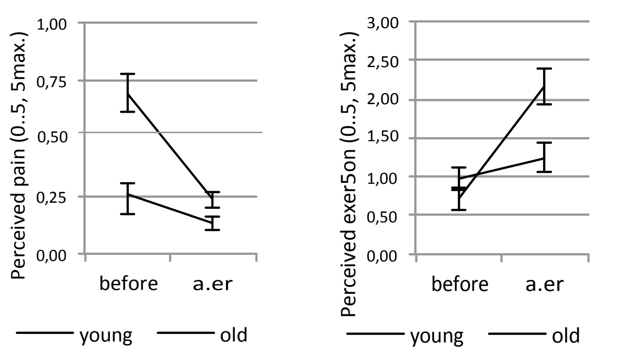
	PERF	PE	EE	FC	HA	SO	PV	HE	BI
In-game Performance (PERF)	–		.432**	.446**					
Performance Expectancy (PE)		–			.538**	.374**		.422**	.367**
Effort Expectancy (EE)	.436**		–	.456**		.254*		.254*	.281**
Facilitating Conditions (FC)	.451**			–					.285**
Habit (HA)					–	.443**	.280*	.507**	.627**
Social Influence (SO)						–	.378**	.386**	.537**
Price Value (PV)							–		.368**
Hedonic (HE)								–	.393**
Age	-.680**	.271*		-.258*				.258*	
Gender	-.343**								
Gaming Frequency	.549**			.311*					.472**
Technical self-efficacy	.585**		.268*	.476**					.300**
Need for Achievement	.262*								
Attitude Towards Health									

Note: * p <.05, ** p < .01. Gender is dummy coded with 1=male, 2=female.

5.3. Effects on perceived exertion and perceived pain

Playing the game has a significant effect on the player's perceived pain ($V = .243$, $F(1, 60) = 19.308$, $p < .01$, $\eta^2 = .243$, sig.). On average, the pain more than halved from $P = .47$ ($SD = .65$) to $P = .18$ ($SD = .28$). The decrease in pain is independent of the participants' gender ($V = .005$, $F(1, 60) = 19.308$, $p = .595 > .05$, ns.), but related to age ($V = .098$, $F(1, 60) = 6.492$, $p = .014 < .05$, $\eta^2 = .098$, sig.), as the perceived pain of older players decreases from .70 to .23 (−2.97×) and reaches the initial levels of younger players. Younger players' perceived pain also decrease from .25 to .13 (−1.91×). This decrease is illustrated in Figure 3a.

The perceived exertion increases significantly during the game ($V = .190$, $F(1, 60) = 14.033$, $p < .01$, $\eta^2 = .190$, sig.). Again, this increase is not affected by gender ($V = .011$, $F(1, 60) = .666$, $p = .418 > .05$, ns.) but by age ($V = .102$, $F(1, 60) = 6.789$, $p = .12 < .05$, $\eta^2 = .102$, sig.). On average, the perceived exertion increases from .84 to 1.69 (2.01×). Older players' exertion increases slightly from .97 to 1.22 (1.26×), while younger players' exertion triples from .72 to 2.16 (3.00×). This is illustrated in Figure 3b.



(a) Decrease of perceived pain. **(b)** Increase of perceived exertion.

Figure 3. Change of perceived exertion and perceived pain for older and younger users before and after the game.

6. Discussion

The study evaluated the influence of user factors on performance and acceptance of exergames in ambient assisted living environments and revealed expected findings but also some astonishing results.

It is no surprise that age decreases performance in exergames. Age is related with a decline in psycho-motoric abilities, which obviously negatively influences performance in (exercise) games, be they technology mediated or not. Gender also plays a minor role for performance, which is also consistent with research that investigates gender differences in psycho-motoric performance. The influence of need for achievement on performance relates well with its theoretical background: Need for achievement influences the choice of and power within tasks; hence, it should also influence the performance in exercise games. No other considered factor plays a major and independent role for performance. Although high technical self-efficacy and high gaming-frequency are associated with higher performance, these factors are mediated by age.

That the performance decreases over the course of the levels is an expected finding as new fruits were introduced in the second and third level. Pears require a short rest and bananas demand additional cognitive and physical effort for the crosswise movement (see section 3); hence, the overall performance decreases with these newly introduced fruits.

A technical trifle is the finding that body height (if controlled by gender) does neither influence performance nor behavioral intention. Hence, the Kinect's unusual mounting well above the player does not introduce any difficulties.

A person's intention to use exergames is driven by three central aspects: The beliefe that playing the game can become a habit, the current gaming habits, and the perceived social influence.

The most important leverage for the successful adoption of serious exercise games in AAL is the individuals' belief that they can make playing the game a habit. Hence, the introduction of serious exergames must be accompanied by measures that strengthen the belief in successful habituation, for example, by providing role models that successfully integrated regular exercises with these games into their life. Following Bandura's self-efficacy theory [6], these role models will increase the individuals' perceived control and, therefore, also their performance and endurance. Also, the smart living environment may use its intelligence to sense suitable moments for exercising and nudge its resident into playing the game.

The second strongest predictor for later use is gaming frequency. The revealed connection seems natural, yet this still contradicts a finding from an earlier iteration of the game: An earlier, but comparable, prototype was evaluated in a doctor's office with a similar sample and absolutely no relationship between usage intention and gaming frequency was found [12][4]. To resolve this mystery, a followup study must be carried out that focuses on the modified factors. Specifically, we changed the context (doctor's office vs. lab) and how and which potential subjects were addressed (a doctor asked patients to test the game[5] vs. recruiting subjects through personal networks and posters).

The third observed control for increasing the intention to use exergames is the perceived social influence by others and whether friends and family are perceived as being positively inclined towards these games. We believe that this factor can be successfully harnessed if games for multiple players are considered. In fact, collaborative and cooperative games have already been found to increase the likelihood of performing rather boring activities [64], and the opportunity to connect with friends, children, or grandchildren is considered an important aspect in meaningful play for elderly [19]. Based on the acceptance theories, we can expect that a sensible social embedding will increase the acceptance and later use of these games. Actually, the current development branch of the game also supports colocated and distributed play and an early evaluation suggests that this has a positive effect on the players' motivation and acceptance of serious exergames for elderly.

Surprisingly, even the performance expectation – i.e., the participant's perception of the efficacy of the game – plays only a subordinate role for the usage intention and projected adoption. Also, the analysis indicates that the intention to use an exergame in ambient assisted living environments is independent from other user factors, such as age and gender, technical expertise, technical self-efficacy (if controlled for age), health consciousness, and the facets of the Five Factor Model (this finding is in line with our previous study). Most importantly, neither the need for achievement nor the attained performance within the game influences the usage intention. Hence, this and similar games will be accepted by people, at least if they have an inclination towards playing games.

With "Cook it Right" we developed a second serious game that addresses the cognitive functioning of elderly [73] and it was also evaluate with the same research framework as presented here. Although both games are utterly different in training domain (i.e., exercises vs. cognitive functioning), interaction paradigm (i.e., motion control vs. point-and-click interaction on multitouch displays), and game scenario (i.e., gardening vs. kitchen) the results were in general comparable, indicating their generalizability.

In conclusion, serious exercise games for health care in ambient assisted living environments are a viable solution for promoting physical fitness among elderly. This will positively influence their life quality through less or less severe chronic illnesses and the health-care systems will be strengthened to successfully meet the demographic change through reduced costs for caregiving.

7. Limitations and outlook

The study gives an insight into exergames for health care in ambient assisted living environments. It is limited insofar as the living lab is a current vision and prototypic implementation of how future ambient assisted living environments might be. Yet, the fast pace in research and development might lead to different scenarios. Also, the study captures the short term evaluation of the game and the gain in perceived health might fade after longer or more frequent interactions with the game. Hence, the findings must be re-validated in a long-term study.

The new Kinect One™ sensor offers exiting new possibilities for exergames. For example, the player's pulse can be monitored over a distance, enabling games to adjust their difficulty to the player's level of exertion. However, this touches the perceived privacy of the

[4]Here, the relationship between gaming frequency and intention to use is ($\rho(64-2) = .472$, $p < .01$, sig.), whereas no relationship was found in the preceding study ($\rho(70-2) = -.006$, $p = .959 > .05$, ns.).
[5]Of course, without mentioning a medical indication.

players, which may lead to different and currently unexplored acceptance patterns.

The current study investigated a serious exergame in which a single player competed against the clock and therefore against his or her own ego. A different picture might emerge when multiplayer exergames are considered: The interaction between two or more players – either colocated or over a distance, synchronous or asynchronous – will certainly influence the acceptance of these games.

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