ExerCube vs. Personal Trainer: Evaluating a Holistic, Immersive, and Adaptive Fitness Game Setup

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Figure 1: The ExerCube (middle, right) provides players with a playful full-body functional fitness experience that is on par with personal training sessions (left). The player is surrounded by three walls, which serve as projection screens and a haptic interface for energetic bodily interactions. Movements are tracked with two HTC Vive trackers attached to players' wrists.

ABSTRACT

Today's spectrum of playful fitness solutions features systems that are clearly game-first or fitness-first in design; hardly any sufficiently incorporate both areas. Consequently, existing applications and evaluations often lack in focus on attractiveness and effectiveness, which should be addressed on the levels of body, controller, and game scenario following a holistic design approach. To contribute to this topic and as a proof-of-concept, we designed the ExerCube, an adaptive fitness game setup. We evaluated participants' multi-sensory and bodily experiences with a non-adaptive and an adaptive ExerCube version and compared them with personal training to reveal insights to inform the next iteration of the ExerCube. Regarding flow, enjoyment and motivation, the ExerCube is on par with personal training. Results further reveal differences in perception of exertion, types and quality of movement, social factors, feedback, and audio experiences. Finally, we derive considerations for future research and development directions in holistic fitness game setups.

CHI 2019, May 4–9, 2019, Glasgow, Scotland UK

ACM ISBN 978-1-4503-5970-2/19/05…$15.00
https://doi.org/10.1145/3290605.3300318

CCS CONCEPTS

• **Applied computing** → **Computer games**; • **Human-centered computing** → *Empirical studies in HCI*;

KEYWORDS

ExerCube; fitness game; exertion game; adaptivity; flow.

ACM Reference Format:
Anna Lisa Martin-Niedecken, Katja Rogers, Laia Turmo Vidal, Elisa D. Mekler, and Elena Márquez Segura. 2019. ExerCube vs. Personal Trainer: Evaluating a Holistic, Immersive, and Adaptive Fitness Game Setup. In *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019), May 4–9, 2019, Glasgow, Scotland UK*. ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3290605.3300318

1 INTRODUCTION

For many years now, exertion games—games in which players exercise in order to play—have been embraced by digital native users. Sports science and health-related studies on commercially available and bespoke exergames such as the Nintendo Wii [65] confirm the potential of these playful training technologies to increase energy expenditure [60], positively affect learning of sensor-motor and coordinative skills [19, 43], strength and endurance [75] and exercise program compliance [28]. This multifaceted game genre has also captured attention in HCI (often referred to as exergames [66], active video games [13], movement-based games [57] or motion games [38]). Today, exertion games can be played in many contexts (e.g., at home, in public spaces, or the gym), and aim to provide an effective and attractive workout experience for a wide variety of users. The spectrum of playful training solutions thus encompasses a wide range. Exergames like the Nintendo Wii [65] are associated with the gaming sector, featuring state-of-the-art game design and controllers, but lack in proper training concepts [69, 88]. In contrast, other game-based fitness applications like Technogym Skillrow [81] clearly belong to the fitness sector, covering professional adaptive workouts and accurate tracking devices, but pay less attention to game design. This bipolar division has been echoed by existing related work in the context of specific sports-based exergames and general exertion games [33, 38, 49, 58]. The majority of applications lack in focus on the combination of attractiveness and effectiveness; these should be addressed on the levels of players' body (e.g., steering movements based on traditional training concepts), controller (tracking system and interactive hardware), and game scenario (audio-visual appearance, game mechanics, and balancing) following a holistic design approach to establish playful fitness solutions as beneficial additions or alternatives to traditional fitness training.

Towards a better understanding of the interdependent elements of an attractive and effective fitness game, how they impact users' multi-sensory and bodily experiences, and how they can be designed in a holistic manner, we: **i)** introduce the research-based design of the ExerCube, an immersive and adaptive fitness game setup following a holistic design approach on the levels of body, controller, and game scenario; **ii)** present findings from a user study comparing the ExerCube with its non-adaptive counterpart and a personal training session, focused on benefits of game adaptivity, and the participants' bodily and multi-sensory (and in particular, auditory) experiences; and **iii)** derive considerations to inform further development of the ExerCube, as well as future research in holistic fitness game design.

2 RELATED WORK

HCI research has often stated the need to re-think exertion game design to better integrate game mechanics and fitness concepts [33, 38, 49, 58]. Beyond the two extremes of playful training solutions, several applications do successfully incorporate elements from the opposite side (game design or fitness), yet overall their design approach remains closely linked to either game-first (e.g., Beat Saber [47]) or fitness-first (e.g., ICAROS [24]). Playful training solutions that sufficiently cover both fields of expertise—game design and sports—remain sparse. Two examples of digitally augmented exercise setups have successfully demonstrated benefits of a thoughtful and holistic design approach: ValoClimb, an augmented playful climbing wall [39] and ValoJump, a game-based trampoline platform [40]. Both developed from research projects into commercially available fitness products, and target one-to-one training of sports-specific movements via respective training devices. For more general full-body fitness training, there remains a huge gap.

HCI research and sport science offer numerous guidelines and frameworks aiming for more attractive and effective full-body motion games [27, 30, 48, 49, 57, 58]. Insights into player experiences with existing motion-based games yield considerations for their design on the levels of body, controller and game scenario. By designing along these levels in a holistic manner, fitness game setups can achieve an optimal attractive and effective training experience. In the following, we elaborate on selected insights on the three levels in more detail.

Body. In general, the inclusion of holistic physical activity into gameplay is found to be a positive predictor for immersion and engagement [6]. Segura et al. [48] highlight technological, physical, and social issues that arise during the design process of "body games", and highlight bodily engagement as a source of enjoyment, and thus an important design resource. Overall guidelines by Mueller and Isbister [57] suggest embracing movement ambiguity resulting from tracking inaccuracies. Marshall et al. [49] criticize existing exertion games for a lack of meaningful degrees and nature of body movements, as well as connection of exertion and game design. They propose strategies for the design of exertion trajectories (e.g., create a trajectory across individual play sessions for skill-learning, in consideration of cognitive load and the exertion trajectory), design around pain (e.g., celebrating positive pain), and design for social facets of exertion (e.g., around by-standers). Further, most existing, commercially available exergames for consoles such as Wii Sports [64], Wii Fit [65], and Kinect Sports [68] have been criticized for disregarding performance aspects that are key to successful workouts, e.g., accuracy and precision [69, 88] as well as intensity [30]. By validating inaccurate movements with successful game performance, these games lack feedback information regarding movement mistakes [69, 82, 88].

Controller. In the context of movement-based games, game controllers have been criticized for limiting bodily design potentials [48] or "instrumentalizing" the body too much [32]. The same applies to existing products available on the fitness market; the implemented fitness devices act as game controllers, but often lack a meaningful and natural connection between exertion and game design [49]. To counteract this problems, Mueller and Isbister [57] among others suggest incorporating limits of sensor technology as a design resource (i.e., give room for errors). Kim et al. found that an embodied exergame interface improves user experience, energy expenditure, and intention to repeat the experience [42]. The precision of movement recognition [63], as well as the natural integration thereof into the game scenario and the related movement feedback are decisive indicators for the "incorporation" of the game controller, and for the immersion into the game world [67]. We can clearly identify a need for body-centered controllers that serve as an additional physical playground, easily integrate into players' body scheme, provide a balance of guided and free movements, and allow for social exertion and social play in cooperative as well as competitive settings.

Game Scenario. The look and feel of immersive, virtual game scenarios for fitness settings should appeal to the target group and involve specific preferences for game mechanics, levels, visuals, sound, and narrative, making it important to involve the target group in the design process from the start [50, 53]. The literature offers suggestions for key elements of the game scenario. For example, games should include immediate celebration of movement articulation, yet also accommodate high cognitive load (especially during learning phases) by providing direct and constrained amounts of feedback [57]. Others recommend achievable short-term challenges to foster long-term motivation, and helping players to identify rhythm in their movements, for example by setting movements to specific sound, and visualizing previous and upcoming movements [57, 58].

Exergame experiences are closely related to immersion and the experience of flow. Flow [10] describes the feeling of complete and energized focus on an activity, alongside high levels of enjoyment and fulfillment. A prerequisite to this experience is a match between a person's skills and the challenges associated with their task. Flow has also been defined as a result of immersion or involvement in an activity (e.g., while playing) [84]. In its application to a both physically and mentally challenging exergame, this has been described as "dual flow" [73]. With regards to dual flow, an optimal exergame experience requires a balance between game-related challenge and player skills, as well as between the intensity of required movement input and players' fitness levels. It is thus important that exergames provide an adequate challenge that matches individual skill levels, and their progression over time [49, 58].

Game research is increasingly exploring adaptivity as a balancing mechanism [1, 51], to increase engagement and immersion in competitive play [3, 12, 71] and exercise motivation [52]. However, how well adaptivity is accepted by players depends on the situation; negative side effects can affect self-esteem [3, 20, 23, 83]. In body-centered games, balancing can keep exertion within a desired range, for example by monitoring heart rate [27, 59, 78]. Further, it can be adjusted through internal mechanisms (player-based adjustments, e.g., adding weights to wrists) or external mechanisms, i.e., environment-based adjustments (e.g., changes to the physical location, social factors such as the opponent, or the mechanics and components of the game setup) [1].

Audio in (Exer-)Games. As the impact of audio in exergames has not yet been examined in detail, but has been shown to affect athlete's motivation and performance in sports [41], we present this aspect separately. In traditional games, audio is used to support cognitive appraisal and hide the medium [14]. Background music (BGM) in particular facilitates immersion, but can also decrease it (e.g., when unsuitable) [15]. While BGM is perceived less consciously than visuals, it affects engagement and immersion, and through these, flow and presence [5, 61]. Specific attributes (e.g., speed) can improve player performance, control, and flow, yet adverse effects are speculated to occur when music overshadows sound effects (SFX), by impairing feedback functionality [9, 21, 37].

In the context of exergames, there are few empirical studies with suitable sample sizes that show beneficial effects of music on performance and gameplay experiences, although guidelines for increasing motivation in exergames have listed music as a requirement [87]. One notable example showed an increase in running performance, however the music was overlaid with motivational commands, making it difficult to pinpoint the cause [76]. Another example revealed that exergame music had an impact on some gameplay experience dimensions [86]. Outside of games, the effects of music during exercise are promising but sometimes show mixed results. A review of the literature in the context of traditional exercise (without videogames) has concluded a number of ergogenic and psychological benefits of music for endurance-based exercise, particularly a reduction in perceived exertion [41]. However, evidence varies particularly for higher intensity exercise; it is speculated that physiological processes override sensory distraction provided by music; further, effects appear to decrease for trained athletes.

In mixed reality games, audio is said to be crucial, due to its medium-masking attributes [44]. It has been shown to affect presence in VR [11, 44]. Yet in modern VR games, audio beyond what is necessary for user feedback (i.e., ambient noises and BGM, as opposed to feedback-based SFX) is perceived less prominently, possibly due to the greater impact of the sensory experience as a whole, as well as novelty bias [72]. Thus, for mixed-reality exergames, audio may be particularly important in masking perceived exertion, but its effects might also be overpowered by the sensory whole-body experience.

3 THE EXERCUBE

The ExerCube (Fig. 1) is a holistic, immersive, and adaptive fitness game setup, aimed for use in gyms in the near future. It was developed in an iterative research-based design process by an interdisciplinary team of sport scientists, game designers, and HCI researchers in close collaboration with the target audience: adults between ±18–50 years of age who are open towards new technology [53]. The development followed a threefold holistic design approach, consisting of the levels of the player's body (steering movements based on a functional training concept), the controller (tracking system and interactive hardware), and the virtual game scenario (audio-visual appearance, game mechanics and balancing). Each design level was created in heavy dependence of the others, and by taking into account potential interdependencies of experiences with single or multiple levels of the playful system (e.g., the hardware supports intense physical interactivity, but also provides a playful experience). The ExerCube design was informed by related research and development, as well as by field research in training concepts and fitness gaming. For this paper, we tested the third iteration ExerCube prototype, which will be further developed based on the results.

Body. The ExerCube follows a full-body workout concept that challenges motor-cognition and coordination, at the same time allowing for a playful and dynamic bodily experience for various player and fitness skill types. Its multipurpose functional training concept incorporates natural-feeling movements which can easily be transferred to in-game steering [49]. Functional training is well known for its overall training effects of increasing endurance, strength, and flexibility [85]. It has been defined as emphasizing multiple muscle and joint activities, combining upper and lower body movements, and utilizing more of the body in each movement [7].

We implemented six dynamic movement levels which gradually guide the player through a training progression that is meaningful in the context of movement science, and includes a warm-up phase (levels 1+2) followed by an intensity increase to players' individual anaerobe to high intensity training peak (levels 3 to 6) based on players' individual motor-cognitive and -coordinative skills:

- **Level 1:** Lateral shuffle-step with extension or flexion of the body to the upper, middle, and lower sections of the side walls with touch of the wall + squat (1 min).
- **Level 2:** Level 1 + basic jump (1 min).
- **Level 3:** Level 2 + lateral rotation to the middle of the right and left wall with punch into the wall (2 min).
- **Level 4:** Level 3 + deep lunge with knee bend to the front left and front right with punch into the side walls (2 min).
- **Level 5:** Level 4 + squad jump forwards (2 min).
- **Level 6:** Level 5 + burpee (2 min).

Controller. The HTC Vive system was used to track players' movement and body position. Players wear two HTC trackers, attached to their wrists with a specifically developed mount. The Vive cameras track players' arm positions in relation to their spatial position in the ExerCube and the pre-set targets. Players also wear a heart rate (HR) sensor during the play session. To create a virtual and physical fluently interconnected play space, we designed an open cube-like trapeze (hereafter referred to as "cube"), which physically immerses the player without isolating them, serving as part of the game controller (haptic device) and as a projection screen (interface). The cube measures ~9m^2 (length open end: 3.50m; length front wall: 2.60m × height: 2.90m; straight line depth: 2.50m). It consists of a solid steel frame covered with wooden plates. To provide an engaging haptic and tactile experience, the wooden plates are coated with a bouncy foam material, allowing players to punch the walls. The transition of the front to the side walls is slightly curved, to generate a flowing and immersive form. Three projectors are mounted on the frame above, and project the game scenario onto the walls of the cube [49, 57]. The projection can adjust the play space size to players' height (i.e., restricting the cube to the front part for smaller players).

Game Scenario. The audio-visual appearance and theme of the ExerCube were inspired by individual wishes and preferences of the target audience [53]. First, the player is guided through a movement tutorial in a virtual training room. Next, the first-person single player game takes the player on a rapid sci-fi themed underwater race. The player navigates an avatar on a hoverboard, speeding along a racing track and passing by various differently coloured gates. Each gate features a colour-coded game element relating to a specific functional workout movement. Shortly before the player passes through a yellow or red gate, the gate rotates towards the right or left to provide a target on the wall which the player needs to either touch or punch at the target position. Red gates further provide obstacles that players can overcome by jumping, or squatting low. The game interface displays the number of successfully overcome gates (combos) as a score. As soon as players make a mistake, this count resets to zero. Additionally, the track is divided into sections; players get points for successfully completed sections, while points are deducted if the player performs poorly. Players further receive immediate feedback on their performance, through visuals (mistake: graphics turn red; success: coins appear) and audio (see below), corresponding to existing guidelines [34, 87]. To provide a learning aid regarding the in-game steering movements, players are guided by a mentor (virtual character in front of them), who disappears after five minutes of playing.

To calibrate individually optimal performance, the ExerCube features an automated yet experimental game adaptivity algorithm [49, 58]: Game difficulty is adjusted to players' individual game and fitness skills in two ways: speed of race and music is tied to players' HR (pre-set range of HR), while the time frame of gate rotations is related to the number of mistakes made (i.e., players' cognitive and mental focus).

Both game adjustments are gradually adapted independently over all training levels on a 10-point difficulty scale: If a player performs error-free for 20 seconds, the cognitive difficulty will increase by one notch until they make three mistakes within 20 seconds, inducing a difficulty decrease by one notch. Beyond the gradual progression of training levels, there is no physical difficulty adjustment during the first 1.5 min of the game. Based on players' HR, game speed is then gradually adjusted ($HR < 150$ bpm for 0.5 min: increase speed slightly by one notch; $HR > 175$ bpm for 1 min: decrease speed slightly by one notch; $HR > 190$ bpm: decrease speed strongly by 2 notches).

Since HR is a challenging game balancing parameter, we used a pre-set range of HR which was informed by previous tests with the ExerCube and related work from sport science, including a comprehensive study [62] yielding the following formula to calculate age-predicted maximal HR: $HR_{max} = 211 - 0.64 * age$. This aligns well with previous studies and meta-analyses [22, 80] which suggested similar formulas. Given the mean age of our participants (M=34.45, SD=8.70) and that we aimed at an anaerobe to high intensity training (80 to 90% of HR_{max}), we set the HR target range around HR_{target} = 151 to 180 bpm (i.e., based on HR_{max} = 189 bpm).

For the study, the ExerCube also has a non-adaptive variant, with static medium physical and cognitive challenge.

The ExerCube audio design covers both feedback-based SFX and BGM, which were specifically developed by a professional sound designer. SFX appear when the player successfully overcomes a gate (combo sound) or misses one (e.g., crashed into obstacle). The atmospheric BGM reflects the underwater scifi theme. Its speed and rhythm are adaptive; with players' higher HR and good in-game performance the music increases in bpm, and becomes more bass-driven.

4 EVALUATION

Towards a better understanding of the interdependent elements of an attractive and effective fitness game and how they impact users' multi-sensory and bodily experiences, and to examine benefits of adaptivity, we compared the ExerCube with its non-adaptive counterpart and a personal training (PT) session.

Method

The user study was set up as a within-subject experiment with three conditions: The ExerCube with adaptive difficulty, adaptive BGM and feedback SFX; the ExerCube with non-adaptive difficulty, non-adaptive BGM and feedback SFX; and a control group, wherein participants engaged with a professional PT session with only BGM (Fig. 1). The same physical exercises and (non-adaptive/adaptive) BGM were featured in all three conditions. In the PT condition, the feedback sounds were replaced by the verbal and physical feedback of the trainer, who reacted with adjustments in training difficulty and complexity to each participant (comparable to adaptive ExerCube session).

The within-subject design facilitated a valid comparison between different conditions, and is commonly used in the fitness/exercise domain [26]. Furthermore, we provided participants with a 10–20 min break after each condition to ensure resting HR before they started with the next condition.

Participants

The study was originally performed with 60 participants, across whom the counterbalancing was evenly applied. Due to technical difficulties (WiFi), we could only consider the data of 36 to 40 participants (40 participants for the quantitative results, and 36 for qualitative (interviews)). N=40 participants (19 women, 21 men), aged 16 to 62 years (M=34.45, SD=8.70) reported gaming habits diverse in game literacy. All participants engaged in a variety of physical activities to some extent, with fitness classes (n = 29) and jogging (n = 21) being the most popular. More than half of the participants (n = 25) had prior experience with exergames, mostly with the Wii Fit.

Measures

To assess players' experience of flow, we employed Rheinberg's Flow Short Scale [18, 70], which includes the constructs flow (α = 0.90) and worry (α = 0.77) on a 7-point Likert scale. We also used the scale resulting from the GameFlow model of player enjoyment [43, 79] to calculate an overall enjoyment score (α = 0.68, 7 items on a 6-point scale, including immersion). Additionally, participants were asked to rate a series of single-item measures capturing different aspects of the player experience such as enjoyment, motivation, as well as feeling overwhelming, insufficient, or optimal challenge, as well as a particular focus on how the ExerCube's audio affected their experience.

Qualitative experiences were assessed via semi-structured interviews targeting aspects of all three levels of the holistic approach. Interviews were audio- and all sessions video-recorded for subsequent qualitative and interaction analysis.

Procedure

After consent forms, participants provided demographic information and reported sports and gaming habits. Furthermore, we asked them if they had cardiovascular problems, a screening parameter, and whether they worked with individual HR_{max} or other individual HR-values. Then they were introduced to the ExerCube by a study investigator in a familiarization phase. Participants who started in the PT condition were also introduced by a study investigator. All participants engaged with all three conditions for 10 minutes each, in counterbalanced order and were looked after by a certified trainer. Each session was video recorded and tracked (logs of in-game performance and HR), and followed by the surveys. At the end, we conducted semi-structured interviews with 36 participants (~25 min). Twelve interviews were conducted with two participants at once.

Analysis

The interviews were assessed by two of the authors following an iterative thematic coding approach based on qualitative content analysis [54], beginning with the levels of holistic design as first categories. For five interviews at a time, the coders individually transcribed and coded the data. In three iterations, the coders discussed emerging results after each set of five interviews until agreement was reached. A codebook was developed based on the third iteration, and used by the coders to individually assess the remaining interviews.

The videos were analyzed by two other authors of this paper following a qualitative analysis approach based on ethnomethodological methods (IA) [36], using concepts from movement analysis (e.g., within Laban Movement Analysis [45]), and biomechanics of human movement and anatomy [8]. An initial screening of all videos was performed, to identify salient features, including body orientation and movement patterns, as well as physical interaction with the game interface. The coding scheme then followed major observed patterns across all conditions, including movement trajectories and patterns, gaze orientation, as well as reoccurring interactive strategies during the gameplay. Finally, a focused micro-analysis of a selection of snippets was performed.

The log files are omitted for scope, however we did briefly check the HR variance of some participants in the adaptive ExerCube condition. Over the full session this ranged from 131 bpm during the warm-up to 194 bpm in the peak exercise level.

5 RESULTS

In the following, we report on all quantitative and qualitative results.

Questionnaires

To check whether the three conditions differed in terms of flow, game flow, and worry, we conducted a series of repeated measures analyses of variance (ANOVAs), with Greenhouse-Geisser correction where necessary. All descriptive values and test results are listed in Table 1. The conditions did not significantly differ in experienced flow, overall game flow score, or perceived worry. We explored the immersion item in the game flow survey separately; there was a significant difference between conditions, F-value=6.18, η^2=0.08 (small effect [2]), p<.01. Tukey's HSD as a post-hoc test showed the adaptive condition was significantly more immersive than the PT condition (p<.01). We also investigated the additional items on the game experience. There was no difference in experienced enjoyment, motivation, or feeling overwhelmed. However, there was a significant difference in optimal challenge, F-value=5.30, η^2=0.06, p<.01. Tukey's HSD showed challenge was rated less optimal in the non-adaptive condition compared to the PT condition (p<.02). There was a significant difference in insufficient challenge, F-value=4.54, η^2=0.06, p<.05. Tukey's HSD showed the non-adaptive condition was rated significantly higher for insufficient challenge than the PT condition (p<.05).

With regards to audio, no significant differences were observed with regards to whether participants were consciously aware of the music during the experience. However, the degree to which the music was remembered by participants varied significantly, F-value=3.7, η^2=0.09, p<.05. Post-hoc analysis revealed that participants thought the music was more memorable in the adaptive compared to the PT condition (p<.05). Regarding the perceived importance of the music for the experience, the ANOVA first indicated a significant difference, F-value=6.82, η^2=0.15, p<.01, however, Tukey's HSD

Variable	$M_{adaptive}$	SD	$M_{non-adaptive}$	SD	$M_{personaltraining}$	SD	F-value (df)	η^2	p
Flow	5.62	0.81	5.49	0.9	5.53	1.08	0.3 (78)	.008	.74
Game Flow	4.89	0.47	4.76	0.58	4.94	0.57	2.13 (78)	.05	.13
Worry	2.91	1.61	2.89	1.63	3.25	1.68	2.95 (78)	.07	.06
Immersion	5.68	0.57	5.45	0.82	5.18	0.75	6.18 (78)	.17	.003∗
Enjoyment	5.33	0.86	5.45	0.85	5.2	0.85	1.07 (78)	.03	.33
Motivation	5.75	0.54	5.68	0.69	5.55	0.71	1.66 (78)	.04	.2
Optimal Challenge	4.9	1.15	4.83	0.96	5.4	0.78	5.3 (78)	.12	.007∗
Feeling Overwhelmed	2.85	1.08	2.7	1.09	2.78	1.31	0.19 (78)	.005	.83
Insufficient Challenge	2.13	1.18	2.4	1.32	1.68	1	4.55 (78)	.1	.01∗
Aware of Music	2.18	1.01	2.28	1.01	2.55	1.15	2.58 (78)	.06	.08
Remember Music	4.8	1.84	4.7	1.83	3.95	2.15	3.7 (78)	.09	.03∗
Importance Music	5.2	1.91	5.33	1.61	4.3	2.1	6.82 (78)	.15	.003
Motivation Music	5.18	1.93	5.35	1.59	4.25	2.01	8.01 (78)	.17	<.001∗

Table 1: Descriptive statistics and ANOVA results; measures with significant differences between conditions after post-hoc tests are indicated with ∗.

Table 2: Mapping of participant IDs to study conditions: for example, $_{a \cdot na \cdot p}$ means the participant experienced the ExerCube conditions first—adaptive, then non-adaptive—, followed by personal training (PT).

$a \cdot p \cdot na$	P4, P7, P31, P33	$na \cdot p \cdot a$	P6, P8, P12, P13, P16, P22, P23, P25, P35
$na \cdot a \cdot p$	P1, P3, P30, P32, P36	$p \cdot a \cdot na$	P5, P9, P14, P18, P20, P24, P26
$p \cdot na \cdot a$	P2, P10, P11, P17, P21, P34	$a \cdot na \cdot p$	P7, P15, P19, P28, P29

contradicted this. Whether music was perceived as motivating also differed between conditions, F-value=2.56, η^2=0.06, p<.001. Compared to the PT condition, music was experienced as more motivating in the adaptive (p<.01) and the non-adaptive condition (p<.001). As SFX were only rated in the ExerCube conditions, we conducted t-tests for dependent samples. No significant differences emerged with regards to whether participants were aware of the SFX, their perceived importance for the experience and whether SFX were experienced as motivating. Overall, music and SFX were rated very favorably, indicating a ceiling effect.

Interviews & Video Material

In the following, all quotes indicate the participant ID; Table 2 lists the order in which they experienced the conditions. We refer to the ExerCube condition with adaptive difficulty with the subscript $_a$, the non-adaptive version as $_{na}$, and the personal training condition as $_p$.

Players' Overall Experience. When participants were asked to describe their most memorable impression, they elaborated on their immersion experience ("*totally present in the game world*"–P33), and overall excitement ("*full of focus, cognitively as well as physically, on the game, [...] entirely exhausted after a few minutes and full of endorphins*"–P8).

All participants reported that the steering movements felt natural and familiar. From a somatic perspective, we relate this to the kinds of movements and movement qualities of the in-game "everyday actions" (e.g., reaching, ducking, hopping). Nevertheless, participants experienced a strong learning curve with the ExerCube components (steering movements, tracking system and hardware, as well as game mechanics). Especially in their first ExerCube session, some players felt slightly over-challenged during the first minutes ("*didn't really know what I'm doing*"–P17). This was compounded by tracking limitations and issues of communicating timing for steering movements, causing some participants to experience short moments of frustration ("*I was frustrated because it didn't register my movements*"–P32). This is also reflected in the videos through frustration gestures and sounds upon missing a target. However, when considering the overall ExerCube sessions (after the initial learning curve), participants generally felt neither overwhelmed nor insufficiently challenged ("*fit just right*"–P8). Almost all participants indicated an experience of immersion and flow, in particular, losing track of time ("*time flew by [...] a very immersive experience where you really forgot yourself*"–P24; "*you have no chance to think of anything but what is coming at you in that moment [...] you lose any sense of time*"–P29) and dissociation ("*you can forget yourself through the game*"–P20). From a somatic perspective, a strong mental focus was observed in the videos in the form of postural readiness, i.e., many maintained a default base posture looking forwards, with slightly flexed knees and elbows.

Comparison of Experiences. Particularly with the adaptive condition, most participants experienced optimal challenge and a great feeling of interactivity: "*[$_a$] it got faster and faster*

[...] that was fun, yeah, it was challenging [vs. $_{na}$*:] was a little boring*"–P15; "*[*$_{na}$*:] was sub-challenged [vs.* $_{a}$*:] then it got cool [...] there was an improvement*"–P22. In the videos, this was reflected in bodily engagement that evolved as the challenge increased. The readiness poses early in the game (e.g., low positions with flexed knees, gaze on front wall), and strategies to safely score (e.g., waiting on the target ahead of time), progressed to hectic movements, like thrusting jumps from one wall to the opposite, accompanied by laughter or a frustration gestures upon missing a target.

Some explicitly noticed the adaptivity: "*The first time [*$_{na}$*] I couldn't do anything, and the second time [*$_{a}$*] was great because it was tailoured to me.*"–P13. They appreciated when the game sped up or slowed down in moments of physical or cognitive over- or underload: "*I noticed that the game got slower and gave me more time to think [...] very pleasant because I needed the time*"–P16; "*it's cooler when it adapts [...] you see I'm getting better somehow, and then the game also gets more challenging*"–P19. Only some participants felt thwarted if the game slowed down, but this frustration then also turned into increased motivation: "*then I'm even more motivated [...] until it works*"–P7.

Several factors emerged as distinct between participants' experience in the ExerCube conditions, and the PT condition. In the following, we report several aspects of our findings in which we observed contrasts between the ExerCube and the PT, following the three mentioned design levels. Contrasting themes are bolded. We begin with the *keywords* the participants chose to succinctly summarize their experience with each condition, which the differences. For the PT, keywords talked of the focus on feedback (*correction*), being challenged (*pressure*, *pushed to the limit*, *drill*), personal characteristics that they associated with the trainer (*experience*, *expertise*, *seriousness*), and aspects relating to a social connection (*feeling exposed*, *face to face*, *you want to please [the trainer]*), as well as being motivated through him. For the ExerCube, the most common association was playfulness (most commonly *fun*, but also *play a game*), while others referred to absorption (*flow*, *total involvement*, *loss of time*), and potential novelty aspects (*curiosity*). It showed direct contrasts with workouts (*doesn't feel like sport*) and the motivation described appeared more intrinsic: *no pressure but still willing to perform.*

Player: Body and Mind. There was a difference in participants' **mental focus**. In the ExerCube conditions, players were focused on the game ("*you're not explicitly conscious with your body [...] you're more driven by the game*"–P9; "*very clearly only concentrated on the game*"–P33; "*[my focus] was definitely on collecting points*"–P16). Generally, participants reported experiencing a strong cognitive challenge and were extremely focused and concentrated throughout the ExerCube sessions ("*it keeps challenging you [...] always have to think*"–P31). This relates to the observations of bodily posture readiness explained before. Also, the heightened focus on in-game targets and scoring translated into target-focused movement, consisting of postural and gestural strategies (e.g., double-tapping, pressing with two hands, and punching on the walls). These could be understood as strategies to ensure a target is hit. In contrast, in the PT, participants focused on the trainer (see social factors below) or their own body ("*was able to focus more on the body*"–P20; "*more focused on the movement pattern*"–P4).

The difference in mental focus was accompanied by a distinct difference in **perception of exertion**. Despite clear signs of exertion in the videos, such as panting, and postural cues (e.g., resting hands on hips, or hands on knees while leaning forwards in lieu of a full squat), almost all participants reportedly did not consciously notice the physical exertion during the ExerCube sessions: "*I noticed the physical exertion afterwards, but never during*"–P23. Instead, they perceived the effects of the physical strain (e.g., heavy legs, sweat) only after finishing the game ("*had to physically perform, but didn't notice it at all during, what I noticed is—afterwards when I exited—I was sweating*"–P26). Only a few participants (who were less physically active) perceived indications of physical exertion towards the end of the ExerCube sessions ("*I noticed that I'm not quite fit enough for it*"–P7).

For some, this was an ambivalent experience; despite enjoying that they did not notice the physical exhaustion, some expressed negative connotations since they felt like the missing focus on their movements might have caused posture or execution errors: "*I focused less on my body because I was very concentrated on the game [...] I didn't concentrate on executing it cleanly*"–P16. This indicates that there was a difference in **execution of movements**. In the videos, this is reflected by more indulgent postures and movements compared to the PT condition. For example, in-game, reaching targets on the side often involved a small transversal motion (few steps), and leaning towards the target from the feet (or one foot) This contrasted with the canonical full transversal motion to the side with shoulder abduction (arm reaching to the side), which movements in the PT condition more closely followed. Both movements and posture during the PT condition were more uniform throughout. In comparison, movements in the the ExerCube condition, specially the adaptive one, depended more on other factors, such as how tired the players were, and the difficulty level. In situations of increased speed, players changed some of the earlier target-focused movements and strategies, like waiting for the target while leaning on the wall.

Another prominent difference consisted of **social factors**, which were more prevalent in the PT condition. The presence of another person as part of the trainer-student relationship induced a variety of feelings: trust and respect (“*feeling secure [...] accompanied one-to-one*”–P9; “*more personal*”–P16), but also a feeling of heightened awareness (“*when I stood across from [the trainer ...] I was very very conscious of what I was doing*”–P7). Participants experienced this as a kind of exposure: wanting to do well (“*you want to please*”–P3), but also feeling pressure to do so: “*I felt stressed [...] scared that I do it wrong [...] with a human in front of you it's more important what he thinks of me*”–P26. This strong awareness of the instructor's presence translated into frequent eye contact in the PT videos. Participants would look at the instructor to get instructional cues (e.g., looking at his squat before they would do theirs), learn about the upcoming exercise (e.g., looking at him pointing at the direction of the next movement), or for validation feedback (e.g., looking at him right after they did a squat). In contrast, many participants felt more comfortable making mistakes in the cube (“*less issues having failures in a game*”–P17). Although we often observed signs of frustration when missing targets, participants also took a break at times, letting a set of targets pass without serious attempts to reach them. On the other hand, one participant explicitly disliked the lack of social factor in the ExerCube: “*too anonymous for me*”–P21. It should be noted that the study investigator sometimes provided impromptu verbal commentaries to the player in the ExerCube condition (e.g., warnings, reminders, or tips regarding upcoming targets or actions). Although this only happened occasionally, these resembled instruction cues in the PT.

Controller: Tracking System and Hardware. Concerning the HTC Vive tracking, which still had limitations in terms of accuracy, participants noted that a difficulty in understanding the tracking, particularly timing the jumps during the first ExerCube session (“*I would improve the accuracy*”–P25). However, once they got familiar with the system, most participants thought that the game could be controlled well: “*in the beginning it took a moment until you [understood] then it improves*”–P14; “*absolutely [clear]*”–P36. Participants enjoyed being physically immersed in the cube, and experienced it as focusing their attention on being absorbed by the experience: “*you're focused then, in the room [...] I find that important*”–P9 and “*you have a world for yourself, you do your own thing*”–P19. Nobody felt constricted by the cube, even those who otherwise suffer from mild claustrophia: “*you can really move freely*”–P28. Most perceived the space inside the cube as sufficient (“*you have the feeling you're in a huge room*”–P25), although a few mentioned that they would have liked a larger cube still: “*could've almost had a bit more space*”–P36. In comments after the interviews, some participants also compared the ExerCube to prior experiences with VR games, which had felt more isolating to them.

Beside the pleasant mixed reality/spatial experience, participants clearly stated that the haptic interaction with the cube patterns was an essential part of their experience, facilitating enjoyment (“*I especially liked that you didn't have to hold back when you were punching.*”–P28) and helping them to feel involved in the interactive experience: “*[made it] not like a movie that elapses.]*”–P18 and “*it marks the limits and you can go really far. You're much more in [the experience]*”–P19. As such, the cube was also perceived as functioning like a frame of reference: “*it's a reference point [...] where you get feedback, particularly with the punch*”–P31. This ties in with the video observations of target-focused movement, as well as postural and gestural strategies described above (e.g., multiple taps or punching the walls). However, a few participants mentioned a fear of damaging the ExerCube(“*scared of breaking it*”–P4), or injuring themselves (“*scared when leaping forward, that I'd jump into the wall*”–P18).

Game Scenario. As mentioned, participants liked the general appearance of the game scenario, and found it overall “*motivating*”–P24. However, they were more focused on the steering (racing track, gates with color codes, movement icons), and the visual and auditory feedback information. Some participants described the strong focus on this information as an effect of the gates' color codes being hard to memorize (“*should be more clearly differentiated*”–P21). Furthermore, the previously mentioned timing issues were often reported for the period in which they played with the virtual mentor in front of them on the virtual track: “*[wanted help with] estimating when to execute the movement*”–P4. They tended to imitate the movements of the virtual figure synchronously, instead of waiting until the target actually arrived, leading to some confusion and frustration: “*I was glad when he disappeared*”–P33; “*more confused [..] thought it was an avatar*”–P3; “*[the mentor] irritated me [...] it was too slow*”–P5. This was also observed in the videos: participants touching the wall where the target will arrive seconds before it gets there, and waiting for it to come. Only some participants found the mentor helpful to familiarize themselves with the movements (“*for the first game I thought he was great*”–P31), while most oriented themselves via the movement icons above the gates instead.

Participants reported orienting themselves towards the auditory and visual feedback to understand how well they performed in each moment (“*[understood feedback] through the red [graphics] and the sound*”–P9). However, several participants missed an overall feedback: “*in sum or the course of it*”–P24; “*I had no comparison*”–P33; perhaps partly because—as shown by the videos—their gaze was often locked to the racing track and did not include the score (displayed in the upper right of the middle screen). This contrasts with the

feedback experienced in the PT condition, which was associated with "*corrections*"–P7 and "*more control*"–P23.

Role of Audio in the ExerCube. As audio is largely unexplored for mixed-reality playful fitness systems, we report this aspect separately and in detail. The majority of participants reported that music is a powerful motivator for their workouts in general ("*almost the most important [...] the best way to forget myself*"–P20). However, some participants noted that they do not generally listen to any kind of music or sound while exercising (e.g., to better enjoy the calm and nature while jogging, or because they do sports which encourage or enforce silence during training): "*it's meditative, very consciously for myself [focusing on] the body*"–P9, and "*prefer concentrating on my breathing*"–P32.

During the ExerCube sessions, there was a difference in perception between the SFX and the music. Almost all participants consciously perceived the feedback sounds ("*[The SFX], I always noticed those*"–P35; "*the effects were what I paid attention to [...] were extremely memorable*"–P16, whereas not all participants (consciously) perceived the music ("*The music I didn't notice at all. [The SFX] were the only thing I was consciously aware of*"–P29. Some participants' remarks indicate that this may have been influenced by the game's learning curve (i.e., an increased focus on the motor-cognitive stimuli and general game navigation in the beginning): "*in the first round where I think I was more concentrated I was less consciously aware of the music [...] the second round more so*"–P31. By those that did notice the music, it was perceived as motivating ("*motivating, supporting [...] guiding*"–P3 and as a facilitator of immersion and atmosphere ("*transports me into the atmosphere. Without it I would be much more conscious of the movements*"–P8; "*it supports the flow*"–P31). It was also mentioned in the context of supporting rhythm-based movements ("*it keeps you in the movement [...] it keeps in the game*"–P1) and masking outside noises ("*[without it] I would hear voices, I'd hear the tram*"–P24). Some participants enjoyed the specific current music ("*the sound carried you along*"–P36) whereas others asked for faster, louder, more intense music tracks ("*[the music] didn't touch me [...] want something melodic [with] more push, more power*"–P6). Further, when asked, most participants reported that they would like the option of selecting their own music, although several emphasized that the SFX should remain, and a few expressed worry that self-curated music would not suit the game setting and atmosphere.

If participants did not consciously perceive the music and were told about it during the interview, they were often convinced that they did not realize it because the music perfectly matched and blended into the game scenario ("*probably because it was so [..] not distracting I didn't perceive it*"–P7). Many participants could roughly remember the music (e.g., melody, rhythm, etc.), but a few of them found it difficult to remember anything music-related: "*without the music it's not the same, but I didn't perceive the music, it was there for sure, I heard that, but what it sounded like, no idea, I couldn't tell you*"–P28). Almost all participants—even those that did not consciously perceive the BGM—stated that they thought the experience would be lacking something if the music had been absent: "*probably [would have noticed absence of music]. I think it does help to get in the flow*"–P32. Despite the variance in music perception, some participants nevertheless noticed that the music adjusted to their performance during the adaptive ExerCube session. Some players realized that the game speed was changing through changes in the music: "*by means of the music I noticed somehow that it's getting slower or faster; the game itself*"–P19. For a few, the adaptivity in the game music also functioned as feedback: "*because it adapted itself the music also got faster, that showed that you're really in the flow, that you're doing well*"–P31.

Independent of their preference for or against audio in the context of exercising and sports, participants emphasized the importance of the sound effects: "*these effects, they were necessary and important [...] the effects were what I paid attention to [...] were extremely memorable*"–P15. The feedback sounds were experienced as an important and, compared to visual feedback, often prioritized performance feedback during the fitness game sessions: "*I knew, now I made a mistake [...noticed] by the tone [...] I oriented myself along this [...] I noticed the auditory more*"–P4.

The findings show a difference in **audio perception**: during the PT condition, the large majority of participants did not notice the music: "*I noticed I wasn't aware of the music with [the personal trainer]*"–P11, and "*with [the personal trainer] I didn't hear the music at all*"–P23. Additionally, only one participant reported that they performed faster movements during the PT condition when the speed of the music increased: "*when the music got faster I also got faster, because the rhythm spurred me on*"–P31. While music was also perceived less consciously than SFX in the ExerCube, far more participants reported perceiving it and its motivating effects in the ExerCube condition than in the PT condition.

6 DISCUSSION

Our design aimed to implement a holistic playful training system that is on par with PT in terms of attractiveness and effectiveness. The quantitative results and the interview and video data indicate that this was achieved through the ExerCube. There was no significant difference in flow experience nor in overall game flow score between the ExerCube conditions and the PT. Conditions were also rated similarly with regards to enjoyment and motivation. Moreover, the adaptive ExerCube was rated as more immersive than the PT condition. The interviews reflect these results;

participants experienced considerable enjoyment and immersion, and were both physically and cognitively challenged, despite remaining tracking issues and the learning curve.

The results also shed light on the effects of adaptivity [1, 49, 52, 58, 71], as the ExerCube's non-adaptive counterpart served as a control condition for both adaptive ExerCube, and for the PT (wherein the adaptivity is implemented through the instructor). The quantitative results show that the non-adaptive condition was rated significantly lower with regards to optimal challenge, and higher for insufficient challenge in comparison to PT. Interestingly, the results also show that the non-adaptive ExerCube performed at a similar level as the other two conditions in terms of flow, worry, enjoyment, and motivation. This contrasts with existing literature on evaluations of related systems, wherein adaptivity facilitated these benefits [23, 49, 52, 58]. We speculate that this may be a side effect of the degree of adaptivity; the system could have been set as less conservative in its audio-visual adaptivity thresholds (i.e., it slowed down too early). However, we must also point out that the non-adaptive ExerCube was otherwise the same as the adaptive version in terms of visual and auditory design, and featured the same basic physicality in its interaction concept, which increases engagement and intensifies affective experiences [6]. As such, this could indicate that the system's attractiveness and effectiveness was sufficient to induce positive player experiences [72, 74], and that beyond that, the importance of adaptivity (i.e., higher standards of effectiveness) becomes prominent only over longer periods of use. Nevertheless, we can report that players clearly appreciated the speed-up and slow-down balancing elements, particularly in the adaptive condition, and related to both the physical and cognitive challenges (i.e., the dual flow experience).

The qualitative findings illustrated several factors in which the ExerCube differs from PT; in these factors, participants' preferences and motivations appeared the discerning variable for whether they appreciated how the ExerCube differed. The results showed a very clear difference in the perception of exertion [31], and mental focus; this is tied closely to players' experience of the system as a game. The ExerCube was perceived as playful, challenging, and immersive, and thus distracted them from the physical exertion. This also meant that participants lacked detailed movement and posture correction [25, 69, 82, 88], and some simply disliked the lack of seriousness in the context of exercise. Overall, the prototype was not conducive to claustrophobia. While some players displayed slight fear of damaging the prototype or personal injury, this was heavily outweighed by the importance and enjoyment they associated with haptic feedback [6, 56, 67].

The game scenario was perceived positively, despite minor usability issues and the strong learning curve. The results emphasize the importance of auditory and visual feedback [82]. This was reflected further by participants' strong wish for more overall feedback beyond the moment-to-moment physical actions. Participants' audio perception indicates that auditory feedback signals through SFX may be more important than visual ones for a large portion of players. In terms of BGM, opinions were divided; while most thought that it was an important part of the system, this aspect was clearly less important than the SFX—a noticeable portion of participants did not consciously perceive it [72]. For those that did, however, it was important in facilitating motivation and immersion [15, 44, 72], and for some functioned as a signal of the system's adaptivity.

Design Considerations

Following, we derive six generalizable design considerations, which address both attractiveness and effectiveness of a holistic fitness game setting, apply existing findings from game research to the field of exergames and extend existing knowledge with novel findings from our R&D work.

Distraction Through Holistic Design. Exertion technology and body-centered games often lack a meaningful connection between the exercises, the controller or input device, and the game design [4, 88]. In the ExerCube, key aspects of the game design (e.g., the targets, and adaptive game challenge), helped to create a dual flow experience. In particular, it presented the players with a cognitive distraction to their physical exertion. We argue that *shifting the focus of attention to game elements yields a delayed perception of exertion, which can prove useful to achieve a flow state* during training.

Comprehensive Movement Feedback. In this evaluation, the PT condition was rated better than the current ExerCube iteration in terms of feedback on performance. We attribute this to the current feedback provided, an immediate right-or-wrong assessment, and to the position of the overall score display, outside participants' field of view while playing. The ExerCube does not yet incorporate feedback on additional performance aspects, like feedback on and reminders about body postures, encouraging comments, and heads up about upcoming challenges, which were frequently delivered in the PT condition by the trainer, and rarely by the facilitator in the ExerCube condition. These are important instructing strategies in instructed-based training practices [82]. Hence, *future feedback strategies could extend binary assessments of wrong/right performance, and incorporate a wider spectrum of feedback elements, beyond error correction.*

Adapt to Individual Motivations. The findings show that some participants want more "serious" workouts, and despite their enjoyment of the ExerCube, they see playful fitness systems as a warm up option, or a leisure activity. Many others saw it as a training equivalent or substitute. *The degree* *of movement feedback that is incorporated in the system should adapt to users' goals.* This may also apply to the adaptivity thresholds; the degree of induced frustration and how quickly this turned into motivation varied, indicating a potential for customization in this aspect [82, 88].

Haptic Feedback & Physical Immersion. Haptic feedback [56] emerged as a very important aspect in the ExerCube. However, it is equally important to let players know that the system is robust and safe, i.e., it cannot break easily, and materials are soft enough to mitigate personal injury. Further, haptic feedback and its combination with physical immersion in a room appears to facilitate and enhance awareness of proprioceptive cues, as also suggested by the literature [55], which is key for physical skill acquisition [35]. Based on our findings, we speculate that while VR is unable to emulate haptic feedback and support people's proprioceptive mapping of their kinesthetic movements in the cube, *the mixed reality approach is better suited to playful fitness systems.*

Social Connection. One of the potential drawbacks of the ExerCube that emerged from the interview data consisted of the comparative lack of social connection. Hence, we foreground that *developers of playful fitness systems should explore ways to leverage the positive aspects of the social factor that is present in the PT condition* [82]. Inversely, the absence of a social connection was also a benefit for some participants. As such, while we concur with existing guidelines, we also point out that *designers should be careful with the addition of social factors, and design them as opt-in* to avoid the mentioned downsides: social pressure, self-consciousness, and fear of failure. Through careful design, mixed-reality playful fitness systems may be able to cover a wide middle ground between the potential isolation of VR [77], and the social factors of PT.

SFX as Main Feedback; BGM for Motivation and Immersion. SFX emerged as the prioritized feedback channel for a majority of participants, regardless of whether music generally plays a role in their everyday exercises. As such, *playful fitness systems should make sure that the sound design is clear in this functionality.* BGM was less consciously perceived, and so has lower priority than SFX—nevertheless, almost all participants agreed the system would be missing something without it. Those aware of it emphasized its ties with motivation and immersion, and its signaling of adaptivity [5, 14, 15, 37, 44, 72]. Our findings confirm that these functions of music also apply to mixed reality fitness games.

Future Research and Development Work

Future studies will explore the adaptivity thresholds; we speculate that the importance of high levels of effectiveness (i.e., through optimal balancing) will increase in importance over long-term use. Furthermore, we will explore a prediction/control model for individual HR response, inspired by related work [29, 46], along with alternative physical balancing parameters, such as movement accuracy. Finally, future ExerCube iterations are being implemented to feature cooperative and competitive multiplayer scenarios (in a shared and in multiple ExerCubes). This will allow interesting avenues for future research in multiplayer balancing (e.g., effects of social facilitation [16, 17]).

Limitations

Since the ExerCube is still work in progress, we had to face some tracking limitations as well as some issues due to design. For example, the colors of the gates were hard to read for participants, and the upper limit of the audio-visual game speed could have been higher, as some participants felt slightly slowed down by the game. The virtual mentor led to movement timing problems, because participants assumed they were actually the mentor, rather than the avatar behind the mentor. Further, generally, the play session were too short; longer familiarization phases would have been an advantage. In terms of the study design, the WiFi issues reduced the sample size and thus could have led to order effects due to weakened counterbalancing (see Table 2).

7 CONCLUSION

Our work addresses the gap of physical training solutions to include both game design and fitness concepts. Towards an attractive and effective proof-of-concept system that balances both aspects, we presented the ExerCube, resulting from a holistic design approach. Further, we report on a study comparing the multi-sensory and bodily experiences of participants when playing an adaptive and non-adaptive ExerCube version, as well as a comparable PT session. Although the cube is still work-in-progress, our mixed-methods analysis revealed that the adaptive ExerCube is on par with the PT. We also found differences in participants' experience of the three main design aspects (body, controller and game scenario), particularly their perception of exertion, types and quality of movement, social factors, feedback, and audio experiences. Last, we derived considerations which inform future fitness game design and help to establish this promising body-centered game genre as an attractive and effective full-body workout setting.

8 ACKNOWLEDGMENTS

Anna Lisa Martin-Niedecken thanks Sphery Ltd, Koboldgames, Roman Jurt and Ronnie Gaensli for the excellent collaboration in developing the ExerCube.

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