



“HIIT” the ExerCube: Comparing the Effectiveness of Functional High-Intensity Interval Training in Conventional vs. Exergame-Based Training

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Regular physical activity is crucial for a physically and mentally healthy lifestyle. Training methods such as high-intensity interval training (HIIT) have become increasingly popular as they enable substantial training effects in little time. HIIT typically involves recurring short phases of close-to-maximal exercise intensity, interspersed with low-intensity recovery phases. Originally mainly practiced via uniformly repetitive movements, newer variations include varied functional and holistic exercises (fHIIT). While HIIT facilitates many health advantages, fHIIT is considered more beneficial since it activates more muscles, requires more coordination, strength and balance, and mimics more natural movements which transfer well to daily life. However, fHIIT is a very intense training approach; it requires strong focus and intrinsic motivation to frequently push beyond perceived physical and mental limits. This is a common barrier to exploiting the full potential of this efficient training method. Exergames may facilitate this kind of training due to their playful, immersive, motivating nature. Yet so far, few studies have investigated HIIT-exergames – no fHIIT-exergames. This is possibly because few exergames featured both (1) an effective training concept that is comparable to HIIT, and (2) an attractive and motivating game design. We believe that this lack of holistic integration of both aspects is partly why there is currently little evidence for long-term motivation and training effects in exergame-based training. Our work addresses this gap through the design of an adaptive fHIIT protocol for the ExerCube fitness game system, creating a HIIT-level functional exergame. We conducted a within-subjects study to compare objective and subjective training intensity induced by the ExerCube against a conventional fHIIT session with healthy young adults. Furthermore, we evaluated participants’ subjective experience with regards to motivation, flow, and enjoyment during both conditions. Our results contribute empirical evidence that exergames can induce HIIT-level intensity. While perceived physical exertion was slightly lower in the ExerCube condition, it yielded

significantly better results for flow, enjoyment, and motivation. Moreover, the ExerCube seemed to enable a dual-domain training (higher cognitive load). We discuss these results in the context of exergame design for fHIIT, and provide practical suggestions covering topics such as safety precautions and physical-cognitive load balancing.

Keywords: exergame, high-intensity interval training, functional training, effective, attractive, heart rate, ExerCube

INTRODUCTION

Regular physical activity is crucial for a physically and mentally healthy lifestyle at all ages, as it protects against cardiovascular diseases and diabetes (Folsom et al., 2000; Steinbeck, 2001) and mental disorders such as depression (Biddle and Asare, 2011). However, especially in young adults, a lack of motivation is a common barrier to participating in regular physical activity (Trost et al., 2002; Teixeira et al., 2012). Therefore, training methods such as high-intensity interval training (HIIT) have become increasingly popular due to their good dose-effect relationship, i.e., substantial training effects in little time (MacInnis and Gibala, 2017). HIIT typically involves recurring short phases of close-to-maximal exercise intensity [beyond 80% of the maximum heart rate (HR)], interspersed with low-intensity recovery phases (Gibala et al., 2012). Originally, conventional HIIT (cHIIT) was mainly practiced via uniformly repetitive movements such as cycling on an ergometer, rowing on a rowing machine or running on a treadmill. Only 20 min of cHIIT three times a week can result in significant health benefits (Kilpatrick et al., 2014; Weston et al., 2014). Newer HIIT variations follow the same structure, but include functional multi-joint exercises such as squats, lunges, and burpees (Feito et al., 2018). Although cHIIT positively affects aerobic fitness, body composition, insulin sensitivity, blood lipid profile, blood pressure as well as cardiovascular functions (Burgomaster et al., 2008; Babraj et al., 2009; Kemi and Wisløff, 2010), functional HIIT (fHIIT) is considered more beneficial (McRae et al., 2012; Buckley et al., 2015; Kliszczewicz et al., 2019; Menz et al., 2019). It activates more muscles activity (Folsom et al., 2000), requires more coordination (Wilke et al., 2019), positively affects motor functions such as strength and balance (Weiss et al., 2010; Wilke et al., 2019), and mimics more natural daily movements which transfer well to daily life (Weiss et al., 2010). Overall, HIIT has been shown to have a more beneficial impact on fitness and cardiovascular health than other exercise methods (Weston et al., 2014).

However, HIIT—in all its variations—is a very intense training approach; it requires strong focus and intrinsic motivation (Teixeira et al., 2012), as participants have to frequently reach for or push beyond their perceived physical and mental limits. It has been shown that while the high intensity component of HIIT is useful for health benefits, the motivation to continue

exercising decreases as the intensity of the exercise increases (Peng et al., 2011; Foster et al., 2015). Therefore, many people lose motivation when doing HIIT (Haller et al., 2019). These concerns are supported by a recent study which found that following a HIIT intervention with overweight and obese adults, only 40% adhered to the program 12 months later (Roy et al., 2018).

Exergames, if designed properly with regards to effectiveness and attractiveness (Sinclair et al., 2009), appear to be a suitable and appealing tool to facilitate this kind of training due to their playful, immersive, and motivating nature (Oh and Yang, 2010; Farrow et al., 2019). So far, only few studies have investigated exergames in the context of cHIIT (de Bruin et al., 2019; Farrow et al., 2019; Haller et al., 2019; Keesing et al., 2019) and none in fHIIT. This is possibly because few exergames feature both (1) an effective training concept that is comparable to cHIIT, and (2) an attractive game design to sustain players' motivation (Martin-Niedecken et al., 2019). We believe that this lack of holistic integration of both aspects in exergames is partly why currently little evidence exists for long-term motivation and training effects in exergame-based training (Best, 2015). Prior to long-term investigation, the research and development community needs to design suitable exergames and investigate their feasibility. Thus, there is a need to design and evaluate exergames that combine the best of gaming and fitness; i.e., developing training tools that are both motivating and effective, while following more holistic HIIT variations.

One exergame specifically designed in terms of this holistic approach is the ExerCube: a commercial immersive fitness game setting by Sphery Ltd. (Martin-Niedecken and Mekler, 2018; Martin-Niedecken et al., 2019). The company is open to making the ExerCube available to researchers as a research platform. Thus, the first early stage functional fitness game prototype designed for this system was found to be on par with personal training regarding immersion, motivation, and flow as shown in a previous empirical study (Martin-Niedecken and Mekler, 2018; Martin-Niedecken et al., 2019). This previous study with the ExerCube (Martin-Niedecken and Mekler, 2018; Martin-Niedecken et al., 2019) largely employed self-reported and subjective measures, leading to a research gap with regards to its objective training intensity. An objectively high training intensity is necessary to achieve benefits of HIIT. This leads us to explore the following main research question: How does objective and subjective physiological training intensity in the ExerCube compare to that induced by conventional fHIIT (cfHIIT)?

Our work explores this research gap, with the goal of better understanding the design requirements of and potential for holistic HIIT in attractive and effective exergames. Therefore, we provide both design and research contributions: First, we

Abbreviations: HIIT, high-intensity interval training; fHIIT, functional high-intensity interval training; cHIIT, conventional high-intensity interval training; cfHIIT, conventional functional high-intensity interval training; HIFT, high-intensity functional training; HR, heart rate; HR_{max}, maximum heart rate; VR, Virtual Reality; CHR_{max}, calculated maximum heart rate; HR_{avg}, average heart rate.

designed a fHIIT-protocol with physiological and cognitive measures for the ExerCube system to create a HIIT-level functional exergame as well as a comparable cfHIIT protocol. We conducted a within-subjects study to compare the subjective and objective training intensity induced by a single ExerCube session and a single cfHIIT session (best practice in the fitness market) with young healthy adults. Furthermore, we evaluated participant's subjective experience including motivation, flow experience, and enjoyment during both types of training.

Our results show that the employed exergame is a feasible tool for inducing HIIT-level intensity. While perceived physical exertion was lower than in the cfHIIT condition, the interquartile range of the ExerCube condition's average HR reached the HIIT threshold (moderate to high-intensity). The ExerCube condition also yielded significantly better results for flow, enjoyment, and motivation. It also seemed to trigger higher cognitive load, i.e., it achieved a dual-domain training. We present a comparison with high external validity and applicability within the fitness industry; our results thus contribute empirical evidence that an exergame can be used to induce HIIT-level intensity in addition to positive effects on motivation. Based on the results, we discuss how effective and motivating exergames should be designed to implement fHIIT, and inform future explorations of their effects in terms of associated health benefits and long-term motivation.

RELATED WORK

HIIT is an extremely time-efficient and beneficial training method, originally often performed with an ergometer, rowing machine or by running (Feito et al., 2018). Back in 1996, Tabata et al. (1996) were the first to demonstrate that a 4-min high-intensity workout (consisting of eight 20-s bouts of all-out performance with 10-s breaks in-between) is more effective than exercising for 1 h at moderate intensity. While both methods increased oxygen consumption ($VO_2\text{max}$), only the high-intensity training enhanced anaerobic capacity. Other studies have confirmed this finding, as also covered by a more recent systematic review (Milanović et al., 2015). Today, there are many different ways to perform HIIT. What all programs have in common is that they are characterized by periods of very heavy effort combined with periods of either complete rest or low-intensity recovery. HIIT variations such as spinning classes have been extremely popular for years; by allowing for social interaction and group dynamics, they increase or maintain motivation and help people to stay with this intensive training approach long-term (Caria et al., 2007). This is also reflected in the "Worldwide survey of fitness trends 2019" (Thompson, 2018), where HIIT took third place. Parallel to this trend, the survey reports functional fitness training in ninth place, and first place for wearable technologies such as HR sensors. This tendency clearly indicates a combination of certain training approaches (frequent endurance training with additional regular strength training and neuro-motor exercise) that most attract today's young adults, and are recommended in this combination by international guidelines on physical activity (Thompson et al., 2010; World Health Organization, 2010). However, cfHIIT does

not necessarily incorporate major stimuli improving strength, coordination, and motor control (Wilke et al., 2019).

From HIIT to HIFT to fHIIT

A newer HIIT-related variation is high intensity functional training (HIFT) which is a combination of functional multi-joint movements. These movements are adjustable to any fitness level and elicit greater muscle recruitment than more traditional exercises (Feito et al., 2018). These functional training elements, i.e., exercises that mimic movements of daily living (e.g., squats and lunges), have been shown to simultaneously improve strength and balance (Weiss et al., 2010). While HIIT exercise is characterized by relatively short bursts of repeated vigorous activity, interspersed by periods of rest or low-intensity exercise for recovery, HIFT utilizes constantly varied functional exercises and various activity durations that may or may not incorporate rest (Feito et al., 2018). The commonly practiced combination of both approaches is fHIIT.

A recent study compared effects of moderate aerobic exercise and circuit-based fHIIT on motor performance and exercise motivation in untrained adults (Wilke et al., 2019). The circuit-based fHIIT enhanced physical functions (strength and endurance) and motivation to exercise more effectively than the moderate condition. Another study examined the physiological effects of an fHIIT program on endurance and strength of physically active adults over a 4-week period and found rapid physiological improvements in strength as well as in aerobic and anaerobic capacity (Kluszczewicz et al., 2019). fHIIT seems to be a beneficial variation of HIIT as its protocols allow for multiple performance and physiological adaptations that are not observed by training using unimodal HIIT methodology (Feito et al., 2018). fHIIT combines the best of HIIT and HIFT, benefits the whole body (endurance, strength, coordination, flexibility, etc.) and transfers more to daily life activities (McRae et al., 2012; Buckley et al., 2015; Feito et al., 2018; Menz et al., 2019).

Today's fitness market is reacting to this and provides special fHIIT classes with different foci (e.g., BodyAttack®) which—similar to spinning classes—enable an intense and socially motivating group workout on a holistic level. Mobile fitness apps such as Freeletics¹ further provide options for digital fHIIT-like training for users "on the go" and allow them to share, compete, and cooperate with one another. Although fitness providers frame HIIT and fHIIT as motivating as possible, it remains an extremely challenging training approach.

Exergames: A Promising Training Tool

In today's digital age, exergames (Oh and Yang, 2010)—games that are controlled by physical exercises and provide an additional cognitive challenge for the player—are being explored as a suitable tool to introduce more people to effective training approaches and motivate them to keep on track.

Studies on exergame training in different target populations such as older adults, children, adolescents or patients indicate effects on cognitive (e.g., executive function, attention, and visual-spatial skills) (Li et al., 2016; Joronen et al., 2017; Lee

¹freeletics.com

et al., 2017; Byrne and Kim, 2019; Kappen et al., 2019; Stojan and Voelcker-Rehage, 2019), physical (e.g., energy expenditure, HR, and physical activity) (Lu et al., 2013; Lee et al., 2017; Byrne and Kim, 2019; Tondello et al., 2019), and mental (e.g., social interaction, self-esteem, motivation, and mood) (Macvean and Robertson, 2013; Lyons, 2015; Lee et al., 2017; Martin-Niedecken and Götz, 2017; Valenzuela et al., 2018) aspects. Generally, exergames are well-known for their playful combination of physically and cognitively challenging tasks and thus provide dual-domain training which promises greater effects compared to traditional single-task training approaches (Huang et al., 2014; Hardy et al., 2015; Benzing and Schmidt, 2018; Kappen et al., 2019).

Besides specific effects of exergame training, it is further known for its appealing and motivating impact, especially in physically inactive populations (Wüest et al., 2014; Hoffmann et al., 2016). By providing different players [of different motivational types (Isbister, 2016)] with audio-visually, narratively appealing, and immersive game scenarios, exergames shift players' (cognitive) focus onto the playful experience. This makes it easier to engage with a physically challenging workout (Xiong et al., 2019). Therefore, exergames have successfully been shown to increase training adherence (Kajastila and Hämäläinen, 2015), long-term motivation (Márquez Segura et al., 2013), engagement (Mueller and Isbister, 2014), immersion (Wüest et al., 2014), and flow (Sinclair et al., 2007) in players from different populations.

Exergame-Based HIIT

In the context of cHIIT, only few studies exist that investigated feasibility of exergames specifically designed for cHIIT with regards to physiological training outcomes or qualitative factors such as motivation and enjoyment. To the best of our knowledge, no exergames have been specifically designed and evaluated for fHIIT as of yet.

de Bruin et al. (2019) investigated the feasibility and effects on cardiovascular fitness of an exergame-based HIIT program in untrained elderly people. The 4-week training included a cognitively-simple game which required fast steps for the intense training phases, and games that were cognitively more but physically less challenging for the low-intensity phases. In the low-intensity phase, participants ranged within 50–70% of their maximum heart rate (HR_{max}). Both used a step-based platform as game controller. They found that the exergame-based HIIT was a feasible and well-accepted approach and led to the intended physical intensity (70–90% of HR_{max}). Furthermore, their collected qualitative feedback identified certain aspects which could increase study outcomes in future iterations (e.g., game music, more audiovisual feedback, and increased challenge).

Farrow et al. (2019) compared different in-game conditions (allowing participants to race against their own performance or by increasing the resistance) in a head-mounted virtual reality (VR) exergame-based HIIT on an ergometer against traditional ergometer-based HIIT in physically inactive young adults. They found that VR exergaming increased enjoyment during a single bout of HIIT and led to an average of 74–89% of HR_{max} over all tested conditions in untrained individuals. Furthermore, the

presence of a virtual ghost to compete with appeared to be an effective method to increase exercise intensity of VR-based HIIT.

Barathi et al. (2018) proposed and evaluated an interactive feedforward approach (a method based on competition with oneself, i.e., against an improved self-model of the player) to rapidly improve performance in a HIIT cycling VR exergame. They found that the interactive feedforward method led to improved performance (participants' average HR was above 80% of HR_{max}) while maintaining intrinsic motivation and was superior to competing against a virtual competitor.

A different VR-HIIT exergame was developed for a rowing machine by Keesing et al. (2019). They utilized gameplay mechanics and the synchronization of rowing rhythm with music rhythm to automatically induce HIIT without the need for a physical instructor. They reported that gameplay and music were both effective at inducing HIIT, but music had a stronger effect on both performance and enjoyment.

Haller et al. (2019) investigated the effects of virtual spectators (and their rhythmic clapping based on participants' ergometer speed) on motivation during a HIIT-exergame. They found that virtual crowd feedback increased cycling speed and participants' HR [to around 171 beats per minute (bpm); percentages of HR_{max} were not reported].

Finally, Moholdt et al. (2017) compared HIIT with an online multiplayer ergometer-based exergame to walking in male students. Their exergame elicited an average intensity of 73–83% of HR_{max} and a higher enjoyment than walking.

In summary, the evaluated exergames did not feature full-body functional exercises, nor necessarily a comprehensive, meaningful, audio-visually appealing, and adaptive game design. By this, we mean that—besides different training approaches—these exergames did not follow a holistic design approach covering all design levels of an exergame (Martin-Niedecken and Mekler, 2018; Martin-Niedecken et al., 2019) as well as taking into account potential interdependencies and interaction effects between these, which can affect the targeted game experience. An attractive and effective exergame design encloses the player's moving and sensing body (Bianchi-Berthouze et al., 2007; Mueller et al., 2011) and allows for effective and playful exercises (Marshall et al., 2016). These exercises in turn are mediated by the game controller technology which should be easily and naturally embedded into the moving player's body scheme (Pasch et al., 2009; Kim et al., 2014; Shafer et al., 2014). Moreover, the virtual game scenario represents the player's bodily input in the virtual environment and provides audio-visual as well as haptic or tactile feedback for the player and their reacting body (Shaw et al., 2017). Furthermore, the aforementioned exergames did not necessarily feature individually adjustable cognitive and physical challenges (Sinclair et al., 2009). Thus, to the best of our knowledge, while there are HIIT exergames, there are no exergames specifically designed for fHIIT, nor studies investigating them.

MATERIALS AND METHODS

Based on this gap, we aimed to explore whether an fHIIT exergame can induce the same exercise intensity as a cHIIT

in our primary research question. For this comparison, we designed an fHIIT exergame that leverages the full potential of exergames: (1) targeting whole body exercise (holistic) while also providing challenges for coordination and cognition, (2) with attractive audio-visual design to increase motivation, and (3) automatic challenge adaptation (physical and cognitive) by the system's algorithm.

The baseline for this kind of exergame was cfHIIT as it is currently practiced on the fitness market, i.e., also at its full potential: (1) targeting whole body exercise, (2) with music to ensure roughly equivalent auditory appeal, and (3) with physical-challenge adaptation by the instructor, plus to a degree self-chosen adaptation. Further, cfHIIT is often offered in small groups, i.e., leveraging social factors for motivation. Given a secondary research question on whether an fHIIT exergame can compare to cfHIIT in eliciting motivation, we considered it a not field-compatible comparison if the cfHIIT would have been practiced in individual sessions.

Stimuli: The ExerCube

The ExerCube (Martin-Niedecken and Mekler, 2018; Martin-Niedecken et al., 2019) is an immersive mixed-reality fitness game. Players are surrounded by three walls, which serve as projection screens and a haptic interface for energetic bodily interactions. A customized motion tracking system tracks players' movements via HTC Vive trackers (attached to their wrists). To ensure an ideal workout experience [in terms of attractive design and effective exercises (Sinclair et al., 2009)] for a wide spectrum of players with different skill sets, the ExerCube continuously adapts game difficulty to players' individual fitness and cognitive skills. Training intensity is measured via continuous HR tracking (i.e., players wear a HR-sensor chest strap) and set to an individual pre-defined HR training range. Cognitive skills are measured via in-game performance (reacting to visual stimuli at the right time).

The Sphery Racer (see Figure 1) is a single-player game experience designed for the ExerCube setting. It was developed in several iterations based on the prototype presented and evaluated by Martin-Niedecken and Mekler (2018) and Martin-Niedecken et al. (2019), and it is now being employed as a research object by several research groups. In collaboration with the ExerCube's development team, we modified the game design (game mechanics and audio-visual design), the level structure and the HR-based game adaption algorithm to be comparable with a cfHIIT.

Like its prototypical predecessor, Sphery Racer asks players to progress along a fast-paced race track via an avatar on a hoverboard. The motion tracking system transfers player movements (based on a functional workout) onto this avatar and thus on the virtual racing track. Along the race, players are challenged by obstacles that require physical exercises (e.g., squats, lunges, and burpees) and by an additional cognitive challenge including quick information processing, which exercise has to be performed when (i.e., reaction, time, and coordination challenges).

The game starts with an on-boarding tutorial scene during which the game is calibrated to the exact height of the player.

After successful calibration, the player's avatar drives onto the racing track and to the first instructional pitstop sequence (see Figure 2). The game contains five training pitstops (~0.5–2 min. each, see Table 1), which serve as tutorials to become familiar with the respective steering movements. All exercises are instructed audio-visually (i.e., the avatar shows the exercise, written instructions are added, and a voice provides additional hints). The exercises start with low-to-moderate intensity (in terms of both physical and cognitive demand) and over time gradually increase until reaching high-intensity exercises (e.g., skippings and burpees).

After each pitstop, players return to the racing track, where they perform all thus-far learned movements in five racing sections. To integrate a warm-up phase followed by gradually intensifying level design, the racing section durations range from 2.5 min (first and second sections), to 5 min (third and fourth), and finally 10 min (last section). A complete workout session in the ExerCube takes 26–28 min.

The physical and cognitive game difficulty adjustments are gradually adapted independently over all training levels on a 10-point difficulty scale, where one level is defined as one step on the 10-point scale (e.g., from 5 to 6). Like previously, the algorithm determines players' individual calculated HR_{max} (CHR_{max}) based on the following formula (Nes et al., 2013):

$$CHR_{max} = 211 - 0.64 \times age \quad (1)$$

A comprehensive fitness study proved that this formula adequately explained HR_{max} by considering an age range of 19–89 years (Nes et al., 2013). Previously the ExerCube's algorithm also aimed toward reaching a high intensity training level (80–90% of HR_{max}), by a less finely tuned algorithm (HR <150 bpm for 0.5 min: increase speed slightly by one level; HR >175 bpm for 1 min: decrease speed slightly by one level; HR >190 bpm: decrease speed strongly by two level). However, the algorithm was not found to reach this training intensity. For the purpose of the presented study, we refined the algorithm: During the racing sections, the game aimed to get players to a specific HR range (70–90% of CHR_{max}) and then kept them at this level. Outside of this range, a lower HR lead to an increase in physical challenge, i.e., speed, exercise frequency (one level per check), while a higher HR lead to a decrease (once 100% of CHR_{max} was reached, this decrease was sped up by three levels to ensure players' safety). For the first two racing sections, the system employed a strategy for increasing players' HR, i.e., when 70% of CHR_{max} has not been reached, it checked actual HR_{max} every 30 s (whereas every 60 s otherwise). For the subsequent racing sections (3–5), the system checked more often (every 20 s in the increasing phase, and 10 s when above 90% of CHR_{max}).

Since the focus of the presented study was to compare the physical training intensity, we employed the same algorithm for cognitive game difficulty adjustment as used by Martin-Niedecken et al. (2019). The main cognitive challenge of the game related to how early players were visually instructed about the direction (right or left) of the upcoming exercise (e.g., a yellow gate rotates to the right for a high touch). If a player performs error-free for 20 s, the cognitive difficulty increased

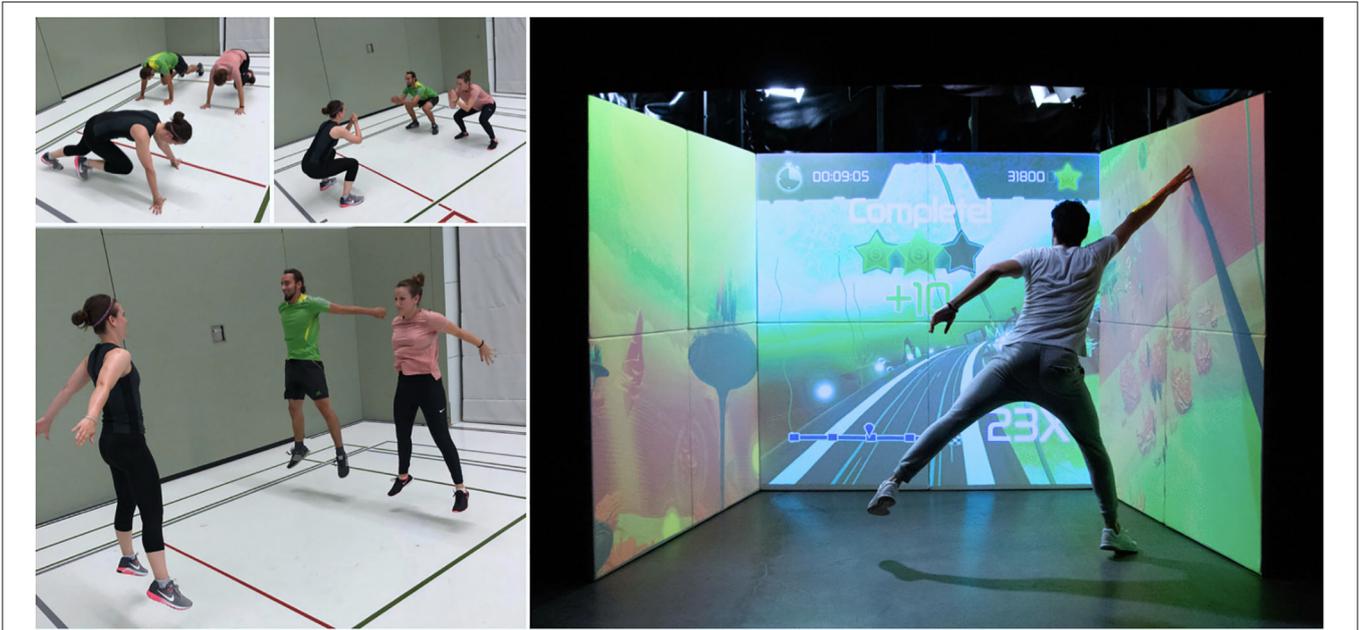


FIGURE 1 | The ExerCube training (on right) reaches high-intensity training thresholds and is perceived as more motivating, enjoyable, and offering better flow than a conventional functional high-intensity interval training (on left).

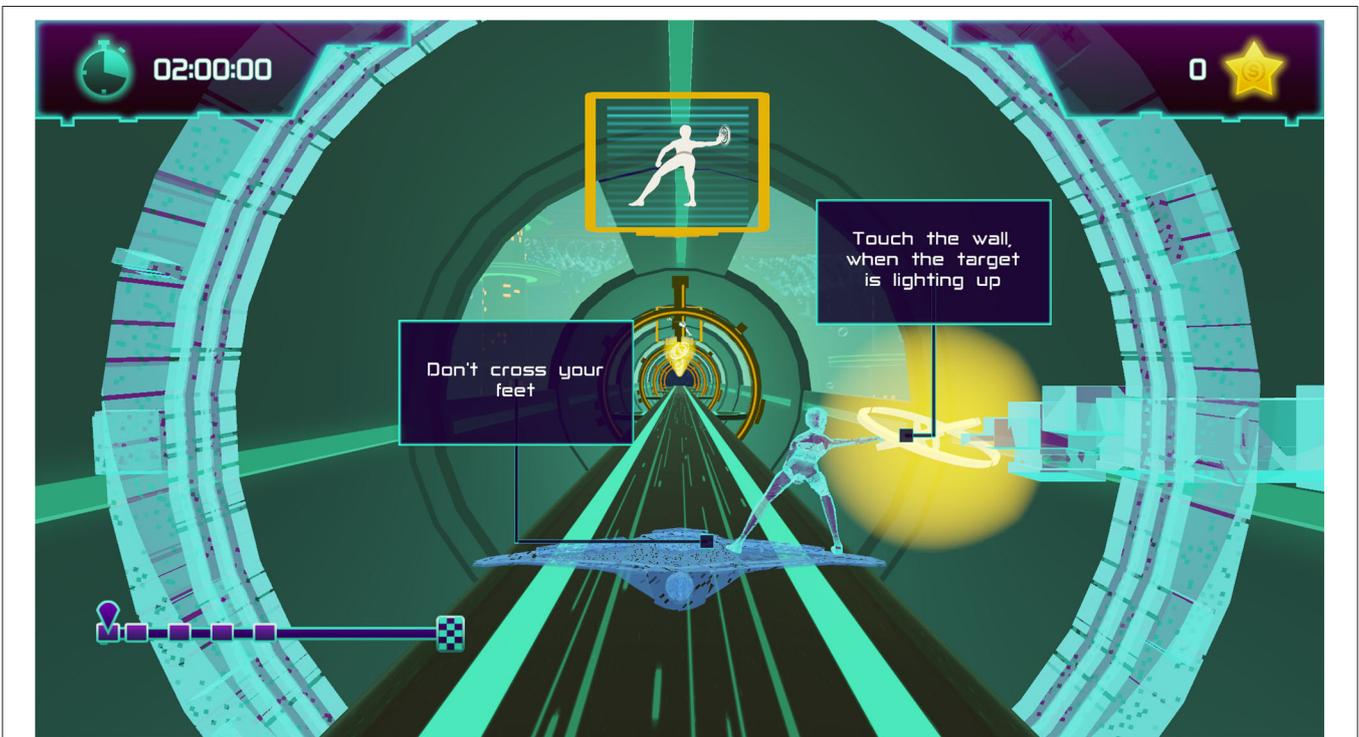


FIGURE 2 | Pitstop tutorial in the ExerCube.

by one level (resulting in a delayed display of the direction of the next exercise) until they made three mistakes within 20 s, inducing a difficulty decrease by one level (resulting in an earlier display of the direction of the next exercise).

However, since the first ExerCube iteration (Martin-Niedecken et al., 2019), a new physical-cognitive challenge was added to the game scenario: players are rewarded with up to three stars depending on their timing. The audio design was

TABLE 1 | Exercise protocols of ExerCube and cfHIIT condition.

	Exercube	cfHIIT
Duration	26–28 min	28 min
Exercises	<p>Level 1: Touch, Touch Low, Touch High (L/R)</p> <p>Level 2: + Squat, Jump, Punch (L/R)</p> <p>Level 3: + Lunge (L/R)</p> <p>Level 4: + Skippings</p> <p>Level 5: +Burpee</p>	<p>Block 1: Warm-up Routine</p> <p>Block 2: Suicide Drills and Jump Squat</p> <p>Block 3: High Knees to Toes and Sumo Squat with Punches</p> <p>Block 4: Mountain Climber and Lunge Jumps</p> <p>Block 5: Burpee with 180° Jump and Skippings and Skater Plyos</p>
Intervals	<p>Racing: 2.5–10 min</p> <p>Pit stops (breaks): 30 s–2 min</p>	<p>Workout time per block: 4–6 min (8–12 times: 20 s workout and 10 s break)</p> <p>Break between blocks: 1.5–2 min</p>
Instructor	Avatar	Coach
Difficulty and intensity	Automatically and individually adapted	Self-regulated

cfHIIT, conventional functional high intensity interval training.

developed further to emphasize the background music's rhythm, emphasize feedback via sound effects, and incorporate audio instructions. Finally, the visual feedback system was iterated for clarity.

Stimuli: Conventional fHIIT

To provide a comparable training protocol, we created a specific cfHIIT (see **Figure 1**) that was as close to actually practiced fHIIT as possible, still comparable to the ExerCube's training protocol. The ExerCube's exercises and intervals thus served as a basis to ensure a similar physical load in both conditions (**Table 1**).

The fHIIT protocol consists of five blocks. It started with a short warm-up block (block 1: 5 min stretching and toning) followed by four interval training blocks, whereby blocks 2–4 included two different exercises (e.g., jump squats and lunge jumps) and block 5 included three different exercises (e.g., skipping). This ensured an increase in physical load toward the end of the training session and matched the ExerCube's last interval. Each (non-warm-up) exercise interval consisted of 20 s of workout (alternately performing the respective exercises) and 10 s of rest. These 30 s workout-rest phases were repeated 8 times (blocks 2–4) or 12 times (block 5), leading to a total duration of 4 min (blocks 2–4) or 6 min (block 5). Interval blocks were separated by short breaks of 1.5 min (blocks 2–4) or 2 min (between blocks 4 and 5). Overall, the cfHIIT lasted about 28 min.

Participants were instructed by the coach that they could individually adapt exercise intensity themselves by choosing a lower or higher level of the initial exercise (e.g., lunges instead of lung jumps) based on their subjective experience of their physical

exertion. Additionally, participants were offered a mobile device positioned on the floor nearby the participants that showed their current HR in real time to allow them to keep track of their individual training intensity.

The cfHIIT session was accompanied by music that also functioned as a timer for the intervals. The selected music was specifically composed for HIIT with a pace of 128 beats per minute (bpm), while slower songs were chosen for the breaks in-between intervals to support recovery. The music was played to enhance participants' motivation, to facilitate similar conditions as the ExerCube training (accompanied by a specifically developed and adaptive sound design), and to present a realistic scenario.

Study Design

Two study objectives were determined to investigate the manifestation of objective and subjective components of a single fHIIT exergame session in comparison to a single cfHIIT session. The primary objective of this study was to evaluate the objectively and subjectively experienced training intensity of a single fHIIT exergame session in comparison to a single cfHIIT session. The secondary objective was to assess motivation, flow, and enjoyment during the two training approaches.

The comparative study was set up as a within-subjects design allowing the comparison of two different training methods: an ExerCube vs. cfHIIT session. Whereas, the ExerCube session was performed as a single-player session and controlled by a certified fitness coach, the cfHIIT was performed in small groups of 2–3 participants and instructed by the same coach. Although the ExerCube was mainly self-explanatory, the coach instructed participants and supervised them throughout the session. In the cfHIIT condition, the coach directly instructed the exercises and performed the training session together with the participants. In both sessions, the coach provided corrections, verbal support and cheers, if needed. Moreover, participants did not interact (physically or verbally) with each other in the cfHIIT session.

Participants

The sample size was calculated a priori based on a previous study comparing two HIIT protocols regarding cardiac responses (Schaun and Del Vecchio, 2018). Their study showed the following during exercise: average HR (HR_{avg}) 144.2 ± 11.9 bpm and 130.6 ± 10.4 bpm. Considering an 80% power and 5% significance level, a sample size of 11 subjects would have been necessary. To account for a potentially smaller difference in HR_{avg} between the two training types of our study and regarding possible losses or refusals, the final sample size was set to 16–20 participants.

Twenty participants (10 male, 10 female) were recruited by word-of-mouth and by emailing, without offering any financial compensation for the attendance. The selected study population included healthy young adults (self-reported using a health questionnaire) aged 18–35 years ($M = 23.8$ years, $SD = 3.2$). Fifteen participants had experience with exergames, five did not. Participants were excluded from the study if one of the following exclusion criteria was met: (1) history of cardiovascular issues or musculoskeletal injuries that would prevent training

participation, (2) asthma (not controllable), (3) pain that would be reinforced by sportive activities, (4) pregnancy.

The recruited participants reported an average exercising time of $M = 300.3$ min/week ($SD = 167$), and reported their subjective fitness as an average of $M = 3.9$ ($SD = 0.9$) on a 6-point scale (1 = poor, 2 = satisfactory, 3 = average, 4 = good, 5 = very good, 6 = competitive). Their resting HR measured $M = 70.3$ bpm ($SD = 9.9$)—we thus calculated their CHR_{max} at $M = 195.8$ ($SD = 2.0$).

Measures

We distinguish between primary outcomes—relating to training intensity—and secondary outcomes, which relate to the qualitative experience of the two training types.

Primary Measures: Training Intensity

HR data were used as an objective measurement of training intensity. The HR recording was assessed during the training session, measuring average and maximal HR (HR_{avg} and HR_{max}). To enable HR data collection, participants wore a HR receiving chest belt of the brand Wahoo (Wahoo Fitness 2014, Atlanta, Georgia, USA)—either connected to and recorded with the ExerCube (log files) or with the compatible “Wahoo RunFit” App, which was installed on an Apple mobile device (.csv files).

The Borg 10-point rating scale was selected as a subjective measurement of training intensity (where 1 = very weak and 10 = very, very strong) (Borg, 1982). This scale was used to assess both physical ($Borg_{physical}$) and cognitive ($Borg_{cognitive}$) perceived exertion.

Secondary Measures: Motivation, Flow, and Enjoyment

We employed the Situational Motivation Scale (SIMS) to assess participants' intrinsic and extrinsic motivation by 16 items (Guay et al., 2000). The SIMS questionnaire comprises four factors: intrinsic motivation, identified regulation, external regulation, and amotivation. The Flow Short Scale (FSS) was used to evaluate participants' flow experience by 13 items (Rheinberg et al., 2003). The flow experience is measured overall and as three factors: fluency of performance, absorption by activity, and perceived importance. Further, we assessed participants' enjoyment of the training via the Physical Activity Enjoyment Scale (PACES), consisting of 18 items (Kendzierski and DeCarlo, 1991; Motl et al., 2001). All three questionnaires were rated on a 7-point Likert scale (SIMS: 1 = corresponds not all, 7 = corresponds exactly; FSS: 1 = not at all, 7 = very much; PACES: (1 = disagree a lot, 7 = agree a lot). These standardized questionnaires were implemented as they are widely used in the area of physical exercising and exergaming and therefore allowed quantifiable comparisons.

Procedure

After study explanation, each participant gave written informed consent. Afterwards, participants filled out a demographic questionnaire to screen for inclusion and exclusion criteria and to assess baseline characteristics such as gender, age, physical activity time, fitness status, and exergame experience. Participants were randomly assigned to one of the two trainings.

Each training session lasted 26–28 min. After the training, participants rated their perceived physical and cognitive exertion using the Borg Scale and answered questionnaires covering motivation, flow, and enjoyment. A training session with subsequent questionnaires was then repeated with the other type of training on a different day (but same time of day), after a minimum of 4 days and a maximum of 14 days in-between. The study procedure is illustrated in **Figure 3**.

Analysis

Statistical analysis was conducted in SPSS (IBM SPSS 26). The level of significance was set at $p < 0.05$. The comparison of the data was performed using Wilcoxon signed-rank tests. Wilcoxon signed-rank was used because the assumptions for parametric statistics were not fulfilled. Correlations were calculated using the Spearman correlation coefficient. See Cohen (2013) for an overview of thresholds for correlation coefficients and effect sizes.

RESULTS

Each participant successfully completed both training sessions and all data were considered for further analysis.

Primary Outcomes

Table 2 presents the results from the comparison of the average and maximal measured HR and Borg values between the ExerCube and cfHIIT sessions. Absolute ($z = -2.878$, $p = 0.003$, $r = 0.46$) and relative ($z = -2.837$, $p = 0.005$, $r = 0.45$) average HR values were significantly higher for the cfHIIT session than for the ExerCube training. For the maximal HR, no significant differences were found for absolute ($z = -0.262$, $p = 0.806$, $r = 0.04$) and relative ($z = -0.302$, $p = 0.388$, $r = 0.05$) values. In terms of Borg values, the cfHIIT resulted in a significant higher physical Borg rating ($z = -3.020$, $p = 0.001$, $r = 0.48$) than the ExerCube session. No significant difference was measured for the cognitive Borg ($z = -1.603$, $p = 0.113$, $r = 0.25$).

Secondary Outcomes

The questionnaire data showed significant differences for intrinsic motivation ($z = -3.566$, $p < 0.001$, $r = 0.56$), overall flow score ($z = -3.663$, $p < 0.001$, $r = 0.58$), absorption by activity ($z = -3.436$, $p = 0.001$, $r = 0.54$), perceived importance ($z = -2.518$, $p = 0.012$, $r = 0.40$), and physical activity enjoyment ($z = -3.884$, $p < 0.001$, $r = 0.61$), see **Table 3**. For all of these factors, scores were higher for the ExerCube training session. Additionally, a significant correlation ($r_s = 0.365$, $p = 0.021$) was found between average HR and physical Borg values across all training session data (ExerCube and cfHIIT). No significant correlations were found for $Borg_{physical}$ - HR_{max} ($r_s = 0.276$, $p = 0.084$), $Borg_{cognitive}$ - HR_{avg} ($r_s = -0.224$, $p = 0.164$), or $Borg_{cognitive}$ - HR_{max} ($r_s = -0.133$, $p = 0.412$).

DISCUSSION

Following, we discuss the meaning of our findings in the context of future design and research of effective and attractive fHIIT exergames.

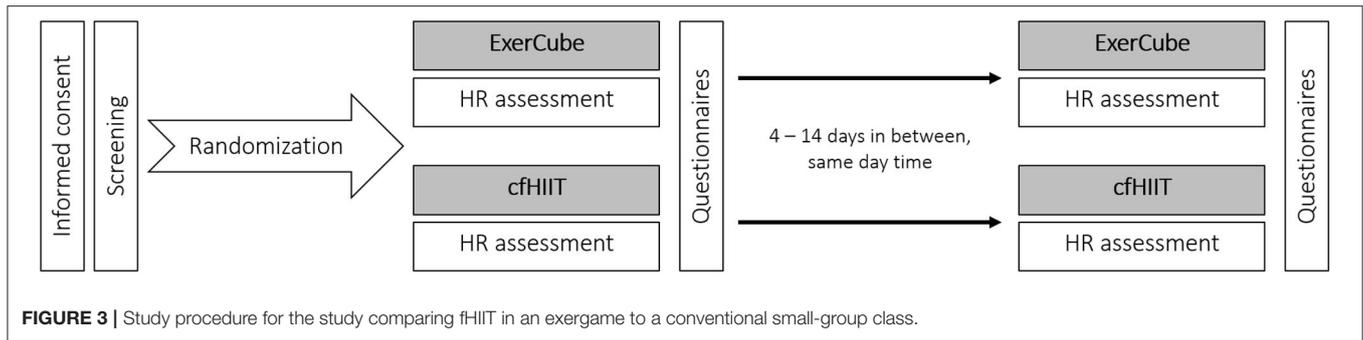


FIGURE 3 | Study procedure for the study comparing fHIIT in an exergame to a conventional small-group class.

TABLE 2 | Comparison of heart rate and Borg values.

	ExerCube	cfHIIT	z	p	r
Average HR [bpm]	155.0 [141.5; 161.3]	159.5 [150.3; 167.0]	-2.878	0.003*	0.46
Average HR as percentage of calculated HR _{max}	78.7 [72.6; 82.2]	81.1 [77.9; 85.8]	-2.837	0.005*	0.45
Maximal HR [bpm]	182.5 [172.0; 191.0]	180.5 [176.0; 190.8]	-0.262	0.806	0.04
Maximal HR as percentage of calculated HR _{max}	93.0 [88.7; 97.4]	91.6 [93.6; 101.4]	-0.302	0.388	0.05
Borg _{physical}	7.0 [6.0; 8.0]	9.0 [8.0; 9.0]	-3.020	0.001*	0.48
Borg _{cognitive}	6.5 [5.0; 8.0]	5.0 [4.0; 6.0]	-1.603	0.113	0.25

N = 20. Data are shown as median [interquartile range]. Comparisons were calculated using Wilcoxon signed-rank test. *p < 0.05. p-values are exact values and two-tailed. Effect size r, r = 0.10–0.29 indicates a small effect, r = 0.30–0.49 indicates a medium effect and r ≥ 0.50 indicates a large effect. Maximal heart rate was calculate: (HR_{max} = 211 – 0.64 × age). cfHIIT, conventional functional high intensity interval training; HR, heart rate.

Training Intensity: Effectiveness

The primary interest of the presented work was to objectively and subjectively investigate the intensity of an exergame-based fHIIT with the ExerCube, and thus to explore the feasibility of a specifically designed exergame as a suitable training tool for effective fHIIT. Besides this general proof of feasibility (i.e., reaching the 70–90% range of CHR_{max}), we found implications which seem to be important for future research and development work.

HR-Based Physiological Adaption

For HR_{avg}, the cfHIIT condition showed significant higher HR values compared to the ExerCube condition. This could have been caused by the ExerCube’s explorative adaption algorithm. The physical game difficulty adaptations were triggered by the system, implementing an objective orientation toward 80% CHR_{max} (range: 70–90%) that overlaps with the high intensity zone [80–90% of CHR_{max}, anaerobic zone (78)]. In contrast, adaptations for cfHIIT were triggered by subjective regulations as the participants were allowed to decide on the exercise level themselves, with instruction by the coach.

For safety reasons, the ExerCube’s game difficulty adaption avoided too high HR values with regards to CHR_{max} over a longer period of time, as the exergame is meant to be used in a standalone version without supervision of a coach for the full session. However, fHIIT classes in gyms are always accompanied by a certified coach, and can thus aim for a more persistent high HR_{avg}.

It should also be noted that the CHR_{max} for the ExerCube’s physical-difficulty adaption was determined via calculation based

on a well-validated generalizable formula (Nes et al., 2013). However, actual HR_{max} can differ; it is a very individual parameter depending on a variety of aspects in addition to age [e.g., gender, fitness level (Nes et al., 2013), and genetics (Wang et al., 2009)]. This could be a reason why the ExerCube’s provided training levels did not fully meet respective individual capacity, and thus its HR_{avg} remained slightly below 80% of HR_{max}. Yet the relative HR_{avg} values (% of CHR_{max}) of the ExerCube training did reach values in the fHIIT zone [80–90% of HR_{max} (Edwards, 1994)] for parts of the game duration—and is well-situated in the moderate-intensity zone [70–80% of HR_{max} (Edwards, 1994)]. Furthermore, while the design for safety has to be considered, the measured HR_{max} values show that the ExerCube has the capacity to reach high exercise intensities and to trigger high HR values in young healthy adults.

Future fHIIT exergames should therefore allow for a more individual game difficulty adaption by allowing users to manually insert their pre-assessed individual CHR_{max} or more specific HR prediction models (Ludwig et al., 2018), to then serve as the basis for the algorithm (Hoffmann et al., 2016). In the interest of safety, the implemented explorative algorithm used in the present study could also be refined further to check HR—and if required—adapt more frequently (e.g., every 10–20 s from the very beginning of the game).

Adaptive Training Protocols

Another reason for the significant difference in HR_{avg} could have been the small deviations of the training protocols of both study conditions (i.e., different intervals and sequences in the training structure of the cfHIIT). However, we aimed at designing

TABLE 3 | Comparison of questionnaires.

		ExerCube	cfHIIT	z	p	r
SIMS	Intrinsic motivation	6.5 [5.8; 6.8]	5.1 [4.5; 5.5]	-3.566	<0.001*	0.56
	Identified regulation	6.3 [5.5; 6.7]	6.0 [5.6; 6.7]	-0.029	>0.999	0.01
	External regulation	1.3 [1.0; 2.4]	1.6 [1.3; 2.7]	-0.940	0.367	0.15
	Amotivation	1.0 [1.0; 1.6]	1.3 [1.0; 1.9]	-0.939	0.388	0.15
FSS	Overall	6.0 [5.6; 6.4]	5.4 [4.9; 5.8]	-3.663	<0.001*	0.58
	Fluency of performance	6.3 [5.5; 6.5]	5.7 [5.2; 6.4]	-1.708	0.088	0.27
	Absorption by activity	6.0 [5.5; 6.5]	4.9 [4.5; 5.8]	-3.436	0.001*	0.54
	Perceived importance	1.7 [1.0; 2.2]	1.0 [1.0; 1.8]	-2.519	0.012*	0.40
PACES		6.3 [6.0; 6.6]	5.0 [4.7; 5.5]	-3.884	<0.001*	0.61

N = 20. Data are shown as median [interquartile range]. Comparisons were calculated using Wilcoxon signed-rank test. **p* < 0.05. *p*-values are exact values and two-tailed. Effect size *r*, *r* = 0.1 – 0.29 indicates a small effect, *r* = 0.3 – 0.49 indicates a medium effect and *r* ≥ 0.5 indicates a large effect. FSS, Flow Short Scale; cfHIIT, conventional functional high intensity interval training; SIMS, Situation Motivation Scale; PACES, Physical activity enjoyment scale.

a realistic cfHIIT that is comparable to those in fact practiced in the current fitness sector.

It would be interesting to explore different variations of fHIIT protocols in an exergame and link the game difficulty adjustment more closely to the exercises provided in the respective game level. For example, instead of slowing down the game speed when measured HR is too high, provide less exhausting exercises (e.g., holding tasks) and a higher cognitive load.

Effects of Physical-Cognitive Challenge

Another aspect of note is the ExerCube's higher multi-sensory stimulation compared to the cfHIIT, which could have also influenced the HR_{avg}. While the cfHIIT was a single-task training, which required functional movements of participants' own body only, the dual-task training in the ExerCube required participants to concurrently process and react to multi-sensory stimuli (audio-visual, spatial, and game mechanical) while still performing a fHIIT to control the game. This approach constituted more comprehensive executive and attentional functions [(pre-)frontal lobe functions (Funahashi and Andreau, 2013)] than the cfHIIT, and this in turn likely activated more cognitive resources. This was also reflected in the results for perceived exertion of the cognitive domain during our study revealing higher values for the ExerCube compared to the cfHIIT. A subsequent side effect on physical performance can be explained with findings from motor-cognitive research: individuals tend to slow down physical movement when asked to perform a relatively challenging secondary dual-task simultaneously (Yogev-Seligmann et al., 2010). Interestingly, we also found that (while not a significant correlation) participants showed higher HR values for lower cognitive exertion values;

in contrast, lower HR values were assessed for higher cognitive load values. This tendency could be caused by the destabilizing effect of dual-tasks that involve competing demands for cognitive and physical resources; this effect is termed "dual-task cost," wherein motor-cognitive interferences can cause deterioration of one or both tasks (Al-Yahya et al., 2011). Thus, we speculate that the multi-sensory stimulation in the ExerCube condition required additional cognitive resources, which in turn limited the physical resources for performance and, therefore, the possibility to reach higher training intensity while also providing additional cognitive training benefits (Benzing et al., 2016; Herold et al., 2018; Stojan and Voelcker-Rehage, 2019).

Future exergame research should further explore and keep in mind these interdependencies. For instance, the ExerCube or a similar exergame could be adapted to investigate effects of varying cognitive loads with a constant physical load on training intensity. Future exergame design should extend existing approaches of physical-cognitive game difficulty adaptation and develop environments that allow for more individualized cognitive-physical and physical-cognitive game challenges. This will allow exergame designers to provide a more individualized dual-domain training (Huang et al., 2014; Hardy et al., 2015; Benzing and Schmidt, 2018; Kappen et al., 2019; Stojan and Voelcker-Rehage, 2019), which could then focus more strongly on either cognitive or on physical challenges depending on the player's needs and skills.

Training Experience: Attractiveness

Additionally of interest to our work was the comparison of the subjective training experience of exergame-based fHIIT with the ExerCube to a cfHIIT. Besides the general proof of feasibility of the ExerCube to be an attractive fHIIT exergame, we again found implications for future research and design toward more appealing exergames.

Shifting Attentional Focus

Regarding training motivation, enjoyment, and flow experience, our study showed significantly higher values in favor of the ExerCube condition. This might have various reasons. In the ExerCube condition, participants' focus seemed to be primarily tied to the game environment and not to their bodily exertion (which indeed was less than in the cfHIIT condition). One indication for this attentional focus shift is the previously discussed higher rated cognitive challenge for the ExerCube condition. Furthermore, flow was significantly higher rated for the ExerCube condition (assessed by FSS) and especially the items "absorption by activity" and "perceived importance." These results match findings of the ExerCube study by Martin-Niedecken et al. (2019), wherein participants reported that they were totally immersed by the game and had to focus on its mechanics to succeed (i.e., a flow experience). In contrast, participants were much more focused on their body with the study's personal coach condition, as they had to concentrate to keep up and perform the exercises correctly. This included more social pressure, i.e., wanting to perform well in front of the coach. These results in combination with those in this study, point toward a trade-off between the two training options. Exergames

can provide a degree of playfulness and strong cognitive focus that frees players of the perceived physical and additional social challenges elicited by the presence of coaches. However, coaches provide a degree of guidance and “workout spirit” that leads to greater accuracy in terms of movement; effects that exergames should strive for in their design.

Future exergame design and research should explore in between variations of exergames and trainers to combine the benefits of both approaches (Turmo Vidal et al., 2018).

User-Centered Design

In the exergame condition, game difficulty and complexity were automatically balanced based on each participant’s fitness and gaming skills. Thus, in theory, they were never physically over- or under-challenged, nor stressed or bored. Being in this “dual flow” zone is generally considered an optimal workout mode in terms of motivation, enjoyment, and performance (Jackson and Csikszentmihalyi, 1999; Sinclair et al., 2009; Martin-Niedecken and Götz, 2017; Martin-Niedecken et al., 2019). These optimal user-centered demands were reflected by the significant higher rated PACES and the item “intrinsic motivation” (SIMS) for the ExerCube condition, and were likely due to the multi-sensory implementation that was developed and refined by a collaboration of game designers, sport scientists, and the target population in iterations and studies. Co-design allows for including wishes and needs specific to a target group and has been shown to positively affect people’s identification with and enjoyment of a product (Birk et al., 2016; Martin-Niedecken and Götz, 2017; Martin-Niedecken et al., 2019). Enjoyment of an activity has a positive impact on physical activity participation and adherence and therefore plays an important role in maintaining an activity-based health care intervention in the long term (Salmon et al., 2003; Hagberg et al., 2009; Rhodes et al., 2009). The results here substantiate the potential of enjoyable exergames for the promotion of physical activity through careful and iterative design and might therefore be a particularly suitable tool for individuals who have trouble motivating themselves to undertake conventional training methods (Wüest et al., 2014; Hoffmann et al., 2016; Moholdt et al., 2017).

Future exergame developments should, therefore, focus on more target population-centric co-designs (i.e., including potential players, but also trainers or therapists in the design process) to ensure that the result meets the players’ expectations as well as specific needs and requirements.

Social Exergaming Effects

One difference between our two training stimuli was the single-player mode in the ExerCube session as opposed to the cfHIIT being conducted in a group of 3–4 people, as is common on today’s fitness market. We had assumed that this would be a point in favor of the cfHIIT, as social experiences can increase motivation and enjoyment (Campbell et al., 2008; Mueller et al., 2011; Mandryk et al., 2014). However, the questionnaires showed no significant values in favor of cfHIIT. With regards to motivation, flow experience, and enjoyment of physical activity, the ExerCube yielded significantly higher results.

Based on this, it could be assumed that the social factors involved in cfHIIT are not as influential as we had expected. However, we know from related work that in games and exergames the presence of a physical (Emmerich and Masuch, 2018) or virtual (Emmerich and Masuch, 2018; Farrow et al., 2019) co-player or component often enhances player motivation as long as players feel a need to belong (Kaos et al., 2019). This could have increased the experiential quality in the ExerCube. It should also be noted that the social group experience in the cfHIIT also has potential downsides; the social pressure to perform well in front of the coach and other class attendees—similarly observed by Martin-Niedecken et al. (2019) with the personal coach condition—can be overwhelming. Social facilitation is, thus, generally considered positive in exergames, but can instead negatively affect game experiences depending on individual characteristics (e.g., how comfortable is the player at being observed and urged on while working out).

Social facilitation effects in fHIIT exergames are an important aspect for future research. It is in theory possible to play the original Sphery Racer game with the ExerCube in co-located cooperative or competitive mode. This will have to be explored in future work.

Limitations

One limitation of the study consists of the differences between our two training stimuli. While we endeavored to design the two conditions to be as comparable as possible, we also wanted to keep the cfHIIT version as realistic as possible. Thus, the racing sections of the ExerCube are equivalent to with the intervals of the cfHIIT and the lower-intensity pitstops are the equivalent for the resting phases of the cfHIIT. However, there are differences in movement sequence (e.g., repetitive movements per block in the cfHIIT vs. varied movements in the ExerCube) and compositions (e.g., different exercises per block in the cfHIIT vs. accumulated exercises over time in the ExerCube). This should be considered in future work with the ExerCube.

This also includes not artificially removing potentially beneficial social factors from the cfHIIT condition by exploring this in individual sessions instead of groups. However, as the player experience factors were largely higher for the ExerCube condition, a lack of social factors in exergames may not be as much of an issue as expected. However, it should also be noted that participants experienced the ExerCube for the first time in this study, whereas as some of them had prior experience with cfHIIT group classes. The questionnaire results could thus have been influenced by a novelty effect. Future work has to explore whether this effect remains long-term when players become used to the ExerCube, or when the cfHIIT condition is conducted with pre-existing social groups with prior social bonds (our participants did not know each other or exercise together prior to the study).

Another difference lay in the audio-visual scenarios of the stimuli. The ExerCube provides music that adapts to in-game events, with the addition of sound effects for feedback [shown to be important for exergames in previous work (Martin-Niedecken et al., 2019)]. Our cfHIIT stimuli did have comparable music, however, it was not adaptive beyond following

and matching the exercise and rest periods. There are some indications that adaptive music can benefit game experiences (Wharton and Collins, 2011; Rogers and Weber, 2019)—and music certainly positively influences exercise (Karageorghis and Priest, 2012)—nevertheless, this has largely not been explored in the exergame context.

When compared to the exergame condition, another difference is that the cfHIIT featured a degree of subjective self-regulation (participants deciding which exercise version they picked, and how fast and intensely to perform them—albeit with guidance from the coach), while the ExerCube featured more objective adjustments (automatically based on the algorithm). We emphasize that we did offer all participants a mobile device positioned on the floor nearby which showed their current HR in real time. As such, they (including the coach) were in theory able to keep track of their individual training, although we cannot report to what degree they used this option.

Finally, the maximal CHR_{max} in the ExerCube was calculated by a formula that determines relative HR values; these kinds of formulas are based on data from the general population. However, this study was conducted with young healthy adults, whose individual HR_{max} could potentially be higher than what is predicted by the formula. In future work, we will explore whether the determination of individual HR_{max} can provide a more customized, higher training intensity without neglecting safety concerns.

CONCLUSION

The aim of this study was to investigate whether an exergame specifically designed for fHIIT can reach a training intensity comparable with cfHIIT classes and the levels of physical load required for physiological HIIT benefits. Regarding the exergame's training intensity, i.e., its effectiveness, our results reveal that the ExerCube reached high range of physiological training intensity, although the specific adaptation algorithm may need to be adjusted to reach it on average throughout the session. While the cfHIIT yielded higher training intensity (higher average HR) than the ExerCube, participants experienced significantly higher flow, training enjoyment, and motivation in the ExerCube, as well as less perceived physical exertion. Therefore, our results indicate that specifically designed exergames such as the ExerCube are a motivating and enjoyable training approach with the capacity to reach high training

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intensities. We concluded that exergames or fitness games—if designed properly with regards to fitness protocol (effectiveness) and game design (attractiveness)—have the potential to increase physical activity and training effects to HIIT levels and therefore may be able to facilitate health benefits in young adults. Our results can inform future R&D work which is needed to examine further important aspects in exergames, such as (1) individual and sport-specific determination of physical and cognitive parameters used for pre-game settings and in-game adaptations, (2) refined balancing of cognitive and physical load, and (3) long term effects and training adherence.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethics committee of the ETH Zurich, Switzerland (EK 2015-N-10). Before any measurements were performed, all eligible participants had to sign written informed consent according to the Declaration of Helsinki. The study involved no vulnerable populations. Written informed consent was obtained from the individuals for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

AM-N, AS, and KR drafted the manuscript and provided substantial contributions to the conception and design of the manuscript. AM-N, AS, and AM created the study design and carefully selected the assessment methods. AM-N co-designed the ExerCube stimuli, whilst AM and AS co-created the conventional fHIIT protocol. AM conducted the study (supervised by AS, AM-N, and EB). AS led data analysis and interpretation. AM-N and KR also contributed to the latter. All authors critically reviewed and approved the final manuscript.

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Conflict of Interest: AM-N is the Co-Founder and CEO of the startup company Sphery Ltd. that developed the ExerCube. AS has been working at Sphery since November 2019, but was not yet employed at the time of the study conduction. No revenue was paid (or promised to be paid) directly to AM-N, to Sphery or the research institutions.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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