The Jungle Warm-Up Run

Augmenting Athletes with Coach-Guided Dynamic Game Elements

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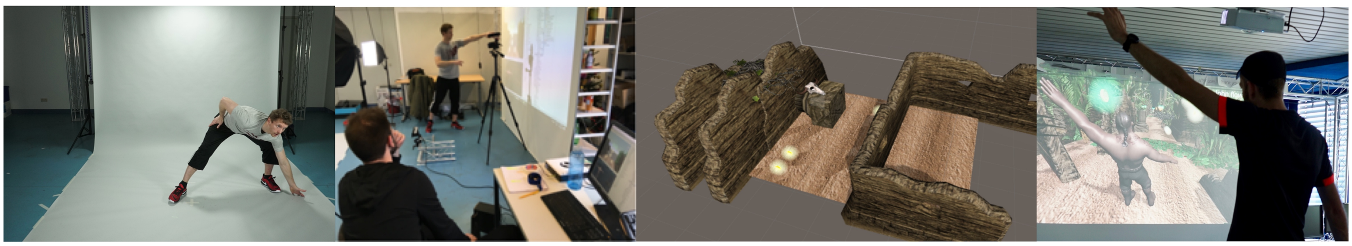

Figure 1: Design flow of coach-guided dynamic game elements from left to right: the original exercise of the coach is interactively encoded into a digital game element by repositioning and creating Unity assets on the fly. The coach then iteratively tests and provides feedback to the programmer, until a game element induces the desired movement in the resulting exercise. The compatibility, speed and ordering of the created game elements with their correspondent exercises undergo an overall assessment by the coach while playing the game multiple times. This comprises Step 3 in our design approach.

ABSTRACT

In virtually all sports, warming up is considered important to physically and mentally prepare an athlete for intensive efforts. General warm-up procedures with a correct technique for exercises are widely accepted to prevent injuries. However, most athletes do not warm up at all, or they do not follow a correct procedure. To address this, we designed and evaluated an exergame for warm-up guidance in a user-centered design process involving a fitness expert. The game augments the athlete with coach-guided dynamic game elements. With an online survey (N=466), we investigated general warm-up habits and provide insights on design game elements in this domain. In a between-subject user study (N=12), we compared our proposed exergame against a classic video instructor. As a result of using the exergame, the participants were more engaged (i.e. longer warm-up duration, higher relative intensity, more enjoyment) while reporting the same level of exertion.

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CCS CONCEPTS

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

KEYWORDS

Augmented sports; avatar; exergames; sports; warm-up

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1 INTRODUCTION

Physical activity and exercise can have immediate and long-term health benefits. It significantly decreases the occurrence of chronic diseases, serves as a countermeasure for psychological disorders, and greatly limits the severity of episodes of anxiety and depression [37, 58]. The counterpart to all these benefits is that engaging in physical activity is often associated with a higher risk of injury at all ages [57]. These include soft tissue damage, fractures, ligament and tendon tears, and nerve injuries [37]. Acute injuries are more likely to occur in sports that include high-speed running, rapid movement, or full-body contact, whereas aerobic low-contact sports that include long training sessions may produce overuse injuries [37].

General countermeasures are avoiding overtraining, correcting the technique, and maintaining a healthy lifestyle. Additionally, injury prevention strategies should be adapted to the individual characteristics of female and male athletes [8]. However, as one of the main sports injury prevention mechanisms, different studies show that physical activities should be preceded by a suitable warm-up procedure (WU) [37, 48, 51]. WU has become a standard practice among professional and recreational athletes [5, 6]. By increasing the body's tissue temperature, it reduces the likelihood of musculoskeletal-associated injuries [27, 30, 47] and the amount of muscle and joint soreness of the beginning of the follow-up exercise [24]. Muscle elasticity depends on blood saturation; hence, cold muscles with a low blood saturation are more susceptible to injury [38, 48]. Another benefit of WU is an increase of the range of motion due to an increase in the extensibility of the tendons, ligaments, and other connective tissues [48]. The most relevant effects of WU can be attributed to physiological mechanisms like increased muscle temperature, decreased resistance of muscle and joints (decreased stiffness), increased oxygen delivery to muscles, increased nerve-conduction rate and speedup of metabolic reactions [5]. In a meta-analysis of relevant studies, it was found that an adequate WU supports an improvement in performance in 79% of the research studies analyzed [12]. In a study that investigated the link between a WU and psychological processes [28], it was found that athletes who performed a proper WU routine before engaging in more demanding physical activity demonstrated significantly higher levels of exercise related motivation and enjoyment.

Despite the benefits of warm-ups, the majority of athletes do not integrate them into their regular workouts. In a study surveying warm-up habits of golfers, 70% of the participants stated that they never or seldom warm up, with only 3.8% reporting warming up on every occasion [11]. In a preliminary online survey we conducted as part of this work (N=446), we found that 55.8% of the participants reported engaging in a warm-up routine, consistent with a former study by Fradkin et al., who found that 54.3% of amateur golfers performed some form of warm up activity (N=1040) [10]. Common reasons for not warming up were the perception that warm-ups were boring, or lack of knowledge of the procedure. To address this, we combine the warm-up exercises in an attractive and effective form of physical exercise video games (exergames) by utilizing game elements that potentially increase motivation, exercise enjoyment, and engagement.

Towards a better understanding of how fitness experts and sports science principles can inform the design of exergame elements, we introduce a multi-stage design process that i) derives sport-specific exergame aspects via early prototyping and user feedback, ii) present an interactive design approach to create game elements for exergames with fitness experts, and iii) present findings from a user study comparing our proposed exergame against a classic video instructor.

2 RELATED WORK

Our work is related to previous sports medicine studies on warm-up procedures as well as prior work on exertion games in human-computer interaction (HCI).

2.1 Warm-Up from a Sports Science Perspective

In sports, a warm-up is defined as a period of preparatory exercise that is carried out to physically [22, 61] and mentally [48] prepare the athlete for the demands of the subsequent physical activity. Warm-ups have been suggested to enhance subsequent competition or training performance and improve muscle dynamics to reduce the risk of sport-related injury [48]. Engaging in a warm-up before a follow-up sport was found to have a variety of benefits for the athlete as described in the introduction, e.g., an improvement in performance of 79% [12], or higher levels of exercise related motivation and enjoyment in the follow-up activity [12].

Typically, a warm-up includes a short, low-intensity preparatory activity which is followed by a stretching routine and sport-specific exercise [24, 46]. It continues with some cardiorespiratory endurance activities and can optionally include functional (neuromotor) sport-specific activities at reduced intensity. Stretching may be included, and it should gradually increase heart rate and breathing rate [24] and have a positive effect on the range of motion (ROM) [48].

Warm-up procedures should ideally be adapted to the follow-up physical activity performed (sport-specific), the level of competition, and the age of the participants. Moreover, the ideal warm-up should include the muscle groups that are required during the training or competition [37]. In general, it is suggested that a proper warm-up should use general, whole-body movements and last five to ten minutes, followed by a five-minute recovery period [6].

However, only a small proportion of amateurs perform appropriate warm-ups [10–12]. Some reasons are that athletes question the importance of the warm-up, find it tiresome, or being pressed for time and eager for instantaneous results, start with the more strenuous activity immediately.

2.2 Exertion Games and HCI

An exertion game (exergame) is a computer game that uses physical exertion as the main interaction element, since the goal cannot be fulfilled without physical effort [40, 44]. To the best of our knowledge, exergames have not been researched in the context of warm-ups and there is no exergame design procedure that has included a professional coach to interactively change game elements. However, they have been applied for physical education [54] and are an attractive alternative to physical therapy [17].

2.2.1 Exergame Design. Exergames for motivational purposes in the context of physical activity have been established [9, 14, 19, 21, 29, 45]; some of these exergames balance game design and sports science well [2, 20, 21]. A recent holistic design approach balances attractiveness and effectiveness and introduces ExerCube, as a proof-of-concept [35, 50]. Most exergames either favor game design or fitness concepts; hence, the authors followed an original design approach for exergames considering the player's body, the controller, and the game scenario [35]. However, on the body part level the work did not focus on implementing sport-scientific principles as a set of steering movements based on a non-specific functional training concept. We learn from this broad and holistic design approach, and contribute further by providing depth to the levels of body with an approach to the design of the exercise game elements by including a human coach in the design process.

Benford et al. [4] suggests a physical and digital interplay to design exergames by taking into account the trajectory that participants may take during the experience. However, there is a lack of design methodology for integrating sports scientific principles into exergames' game elements, i.e., the physical relationships of a specific exercise, and the use of suitable sports-related evaluation tools. Game elements have been created with regard to their transferability into game steering [32, 35] or ambiguity resulting from tracking devices [39]. Recent research investigates multiplayer adaptive exergames that realize game-based group workouts [33]. A more pragmatic approach is a set of guidelines for movement-based game design presented by Mueller and Isbister [39] and design recommendations for exertion games by Mueller et al. [40]. Mueller and Young [43] further proposed five lenses for designing exertion games. These lenses inform the design of exertion games from different perspectives and can be used as quality assurance for exergame designs. A similar approach has been used by Mueller et al. [42] to present a set of design tactics for experiencing the body as play. We used these guidelines for inspiration during the design phase of the project.

An exergame approach can be used to provide an entertaining way to physically and mentally prepare an athlete for intensive efforts [31]. Staiano and Calvert [54] claim that through the increase of energy expenditure during game play, exergames have the potential to motivate players to engage in physical activity more regularly, promote social interaction, and even enhance cognitive performance. Apart from exercise, exergames have been used in other application domains such as art and education [1]. Recently, exergames have also been studied for their potential health and rehabilitation benefits including in diverse patient populations, such as individuals with multiple sclerosis, Parkinson's disease, and stroke [3, 56, 59].

2.2.2 Exergame Evaluation. For the evaluation of exergames with their novel user experiences, there is still a lack of common methodology. Mueller and Bianchi-Berthouze proposed various game-specific methods, as a generic approach is still missing. Traditional HCI methods that are meant for keyboard- and gamepad-style input, do not account for the bodily involvement in exergames. Often, methods from HCI, gamification and games user research are used in conjunction [41], with the aim to evaluate effectiveness, attractiveness and motivational effects [2, 15, 34, 36].

As a conclusion to the related work review, we choose to evaluate our warm-up exergame by making use of sports science methods (physiological measurements, the subjective Borg scale, gyniometer measurements for the range of motion of joints) to assess the exergame-induced warm-up quality from a sports science perspective and design the game with the constraints and recommendations given by the sports science literature. We think applying sports science methods to evaluate exergames in general could be beneficial; the focus is not purely on energy expenditure, but also whether the performed movements need to conform to specific sports science standards. Additionally, we apply games user research methods (PES, PACES) and classic HCI methods (SUS, semi-structured expert interviews) to assess the game design. In particular we aim to investigate how these methods can be used to inform steps in an iterative design process.

Figure 2: Early Warm-up Exergame Prototype

3 DESIGNING A WARM-UP EXERGAME

We derived design implications for exergames that provide proper warm-up guidance in a multi-stage design process: First, we pilot-tested an early prototype of a warm-up game as a proof of concept in order to gather initial user feedback. In the following stage, we established an understanding of the user group and derived requirements based on an online survey. We assessed general warm-up habits and gathered user feedback for our early prototype. In the following step, we applied expert interviews to create game elements that corresponded to sport-science-inspired exercises outlined in Figure 1. We thereby ensured correct guidance and technique as well as a proper overall warm-up procedure. Lastly, we integrated expert and user feedback into the final exergame and evaluated it in terms of game- and sport-specific measures.

3.1 Step 1: Pilot-testing the early prototype

To gather user feedback and derive sport-specific exergame aspects, we created an early warm-up game prototype in Unity inspired by Subway Surfers [25] and Temple Run [26] as a 3D endless running game that can be played for the recommended sport-specific warm-up duration, in which we applied virtual performance augmentation in terms of running speed and jump height. A similar setting in VR recently has shown to elicit medium to high physical exertion in an immersive and intrinsically motivating manner, raise competence and flow and possibly also increase motivation for physical activity [16]. It constitutes the creative starting point and the software and hardware basis for the final warm-up exergame example that undergoes the multi-stage design process described in this work.

3.1.1 Sports Science. The initial exercise set was adapted from the FIFA warm-up program[1] which focuses on core and leg strength, balance, and agility and is medically supported [18, 52, 53]. This program has been shown to have significant impact on injury reduction and can lead to improvements in thigh muscle strength, jump

[1] http://www.f-marc.com/home-3

height, and sprint speed [49]. We reviewed the warm-up program and combined it with our application and hardware restrictions. The following exercises were found to be suitable for the prototype solution: *jump right*, *jump left*, *jump up*, and *squat*. These movements could be easily tracked with Kinect 2, could be correctly performed without any prior knowledge, and did not require additional sports equipment.

3.1.2 Hardware & Software. The early prototype exergame was created using the Unity 5.6 game development platform. Players' movements were tracked with a Microsoft Kinect 2, placed between 2-3 meters in front of the player below the screen. The game engine runs on a NEN Steam Machine (Intel Core i5-6400T, GeForce GTX 960) using a short-throw projector (Optoma X605) mounted on the ceiling (see Figure 2).

3.1.3 Game Mechanics. The player controls a simplified stick figure (avatar) on a projection screen by doing typical warm-up exercises, e.g., squats, jumps, side jumps and jumping jacks (see Figure 2). We realized exercise guidance indirectly by letting the user avoid obstacles and collect coins. Collecting coins increases the overall score while hitting obstacles decreases it. Both events triggered audible and visual feedback. We decided against the use of on-body trackers and virtual reality headsets, since they would be impractical and unhygienic for the warm-up scenario. As a potential location, we targeted gyms, where a quick start or player change could be advantageous. There is also a potential for motion sickness, which would be problematic when pursuing sports that demand coordination.

In order to create an immersive game environment that would shift users' focus from the exertion of the exercise to the game, we employed some basic initial game mechanics [60] with points and visual feedback. The player earns 3 points by collecting a coin and loses 5 points when hitting an obstacle. In order to avoid hitting an obstacle, or to collect a coin, considerable movement was required. In the course of the game, the player's current score was displayed in the right corner to indicate progress.

3.1.4 Pilot-testing. The first prototype implemented basic warm-up principles such as a gradual increase of intensity by computing an aggregate of the player's center of mass and joint movement to adapt the speed of the game. While pilot-testing the early prototype with 10 students of different fitness levels, we found that playing the game can potentially guide users through general warm-ups, i.e., pilot testers reported an immersive experience and found the exergame more enjoyable than a normal warm-up, as found in semi-structured interviews. By first observations, we found that the indirect exercise guide with coins and obstacle avoidance intuitively induced the desired movements with little room for cheating. Tracking the head position of the player to adapt the viewing direction in the game further increased the immersion.

These insights informed the design of the second prototype as the general initial exergame approach appeared to be worthwhile for a second design iteration in terms of immersion, exercise guidance, and enjoyment. We recommend early prototyping with informal pilot-testing as a first step of our exergame design approach, as it gives room for creativity to test different game designs at an early stage.

3.2 Step 2: Online Survey

After pilot-testing the early prototype, an online survey was conducted to investigate requirements and the general acceptance of warm-up exergames. The general idea in the second design step is to follow a user-centered design, and thus, investigate the context of use, characteristics and habits of target audience, and requirements for the next exergame design iteration.

We realized this design step by conducting on online survey, asking about basic demographics, as well as more specific questions regarding their regular sports activities and warm-up behavior and preferences. Lastly, we included a video of the early prototype in the questionnaire and gathered open-ended qualitative feedback. The survey was accessible for two weeks and was advertised via social networks and mailing lists. No incentives were given to the participants for taking part in the survey.

3.2.1 General Questions. In total 446 individuals with an average age of 30.16 participated in the survey, of which 45.7% were female and 54.3% male, aged from 17 to 58 ($SD = 6.49$). The majority (99.1%) of the participants were amateur (recreational) athletes, while only 4 participants claimed to be professional athletes (defined as being paid for doing sports). All participants rated themselves to be physically active and engage in some form of sport activity at least once per week.

More than half of the participants (77.4%) reported being regularly engaged in sports activities over the whole year, while 22.6% were less regularly active for only a few months per year. Regarding weekly training session occurrences, 34.1% participants reported having 1 to 2 and 37.7% having 3 to 4 workouts per week, while 12.1% of the participants reported taking part in sports activities irregularly (less than once per week). Most of the participants (63.9%) reported having training sessions which lasted between 1 and 2 hours. The second most prominent training session duration reported by participants was less than an hour (28%). Only $N = 35$ participants reported working out more than 3 hours.

Moreover, 56.3% of the participants stated that they prefer exercising alone, while 19.3% prefer working out with a friend (or friends) and 24.4% in a group/class. Having a coach available was not prevalent among the participants (11.7%).

3.2.2 Workout and Warm-Up Preferences. More than half of the participants (56.3%) reported always warming up before sports activities, whereas 43.7% reported not warming up regularly before physical exercises. We analyzed their warm-up behavior separately by group (see Figure 3), with the most notable difference being for athletes who participated mostly in groups, of which 73.49% always performed a warm-up before exercise.

3.2.3 Warm-Up Routines. We asked the 251 participants who reported always warming up before the training session about their average warm-up duration. The most common duration was between 5 and 10 minutes (43.4%). Next, 26.3% reported warming up for less than 5 minutes, 25.5% between 10 and 15 minutes and, lastly, 4.4% reported warming up more for than 15 minutes. Only one respondent reported warming up for less than a minute. Furthermore, the warm-up duration was stated to be independent of the following training session duration. The most common warm-up routine, reported by 55.8% of the participants, was sport-specific, while a

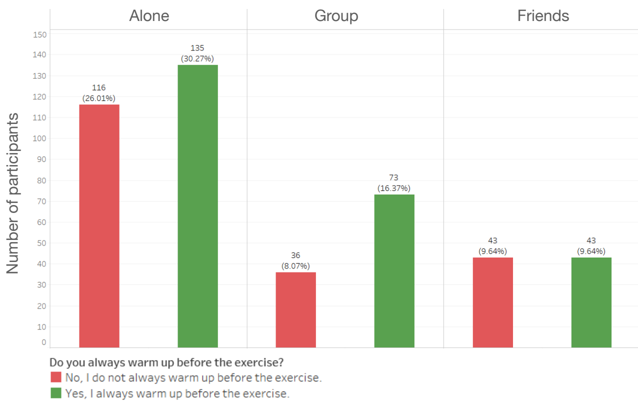

Figure 3: Results per group "*Most of the time, do you exercise alone/with a friend/in a group?*" to "*Do you always warm up before the exercise?*"

general (non-specific) warm-up type was reported by $N = 111$ (44.2%) of them. None of the participants reported performing passive warm-ups.

Furthermore, 55.8% of the participants who regularly warm up reported having no inclination towards warming up in a group. Also, 40.24% of this group stated that they do not follow any specific warm-up procedure. Next, when asked about their preferences towards warming up when given instructions, $N = 156$ (61.4%) out of $N = 251$ reported favoring warm-up sessions when they are instructed and demonstrated by someone else. Complementarily, $N = 111$ (44.2%) reported enjoying warm-ups in a group. Lastly, $N = 150$ participants (59.76%) stated that they follow some warm-up procedure.

We also asked the participants how the warm-up procedure was introduced or recommended to them. Among $N = 150$ participants who gave answers to this question, $N = 81$ (54%) claimed that the warm-up procedure was introduced by a coach, $N = 27$ (18%) had seen the procedure online, and $N = 13$ (8.67%) had read about it. The remaining group reported observing others to do similar movements before the sports activity ($N = 4$) or had the warm-up procedure introduced by a friend ($N = 9$). Participants who regularly engage in warm-ups were asked to describe their typical warm-up routines in a free text form. We grouped the answers based on textual occurrences of exercises in their description. The most frequently described exercises with their number of occurrences were: *stretching* (117), *running* (99), *squats* (43), *jumping jacks* (34), *cycling* (31), *push-ups* (27), *arm circles* (24), *jogging* (19), *walking* (14), *jumps* (10), *rowing* (10), *rope jumping* (9), and others each having less than 4 occurrences (33).

After stretching, the second most common exercise was running (indoor and outdoor). The participants usually start their warm-up with a few minutes of running followed by a full-body stretching program. Apart from that, exercises like squats, jumping jacks, push-ups, arm circles, and cycling were also common exercises among the participants. Some participants, on the other hand, use a treadmill, cross trainer, rowing or elliptical exercise machine for warming up. We note that most of the participants do not follow

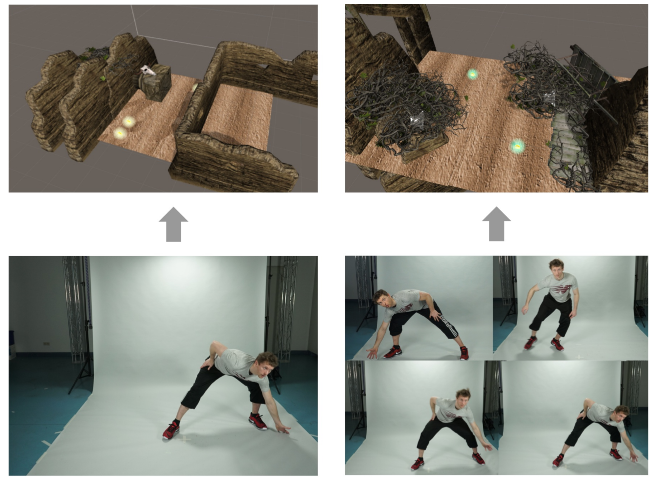

Figure 4: Interactive design of game elements: the images in the lower part represent two different exercises performed by the coach that have been translated into the game elements above

any specific warm-up routines, but use general exercises before sports activities. A certain number of participants, on the other hand, not only listed but described an example warm-up routine.

3.2.4 Reasons for Not Warming Up. The most common reasons reported by the participants, who reported not warming up regularly ($n = 195$), were time constraints ($n = 84$) and the monotonous and tiresome nature of the warm-up procedure ($n = 81$). Furthermore, $n = 41$ participants stated their lack of knowledge of the warm-up procedure was responsible for their not warming up, while for $n = 37$ participants claimed the warm-up procedure represents an insignificant and unnecessary activity. Generally, the reasons for not warming up were mostly tied to the specifics of the sports, as well as the participants' beliefs that it is not critically important for the sports they engage in.

Male participants reported primarily time constraints ($N = 50$, 15.58%), dullness ($N = 50$, 15.58%), and meaninglessness ($N = 45$, 14.02%) of the warm-up procedure as main reasons for not warming up. Female participants had the tendency to feel uncomfortable warming up when other people are present ($N = 13$, 4.05%), did not know how to perform the procedure ($N = 36$, 11.21%), or avoided warm-up exercises because no one else was doing them ($N = 18$, 5.61%).

We further noticed that the majority of participants who reported not warming up due to time constraints ($N = 51$), or the monotonous ($N = 47$) and meaningless nature ($N = 25$) of the warm-up procedure, usually engage in sports activities alone. Moreover, we observe that individuals tend to skip warm-ups more in cases when no one warms up in the group they are part of. Individuals who carry out a sport activity alone are more likely to skip the warm-up routine than those doing it with a friend or in a group.

3.2.5 Discussion. Concerning the most common reasons for not warming up, we cannot address time constraints, but the stated monotonous and tiresome nature of the warm-up procedure seems to confirm that there is a general lack of motivation that could be addressed by an exergame. Moreover, by guiding the user through the warm-up procedure, the lack of knowledge of the warm-up exercise sequences can potentially be solved as well. Further feedback of the user study concerns a wider variety of game scenarios, a multiplayer option and multiple levels.

A suggested multiplayer option could be considered as well, but we think this should be realized only after investigating the single-player version. We did not integrate it in the final exergame, although recent findings have shown that game-based group workouts are very promising [33]. Most participants pointed out that the presented solution was not suitable for group (or multiplayer) exercises. Since some of the participants often engage in group sports, they would expect that the game would also include a version where they could compete with someone while warming up, or just warm up using the game together with the group (or friend) they exercise with. This feature could hypothetically engage more categories of athletes to warm up regularly, provide users with a solid reason to keep returning to it and, in turn, help with creating a healthy habit of warming up before more strenuous exercises.

Another suggestion was the introduction of multiple levels. Each level, according to participants, could have a different difficulty and new obstacles. This way, each level could require new movements in order to avoid those obstacles. Introducing multiple levels is an option worth considering. By continuously increasing the difficulty of the warm-up game, implicit levels can be implemented, or they can be made explicit in well-designed step (e.g., time, difficulty, change, repetitions, etc.). A multiplayer option could potentially also conflict with the exercise preferences stated. We observed that more than half of the participants ($N = 251$) prefer exercising alone (56.3%), so this feature might depend on the actual sport activity.

Based on the remaining results of the online survey, we derived a set of design changes for our final warm-up exergame which we discuss in the following.

Game design-related improvements.

(1) *Different game sceneries:* According to the participants, in the absence of captivating visuals and scenery, the game can become monotonous and boring after a while. Thus, visually appealing and varied scenery should be provided in order to make the exertion more enjoyable and long-lasting.
(2) *Avatar design:* In the online survey, the participants argued that the avatar used in the prototype version of the game is not relatable enough. So a humanoid model with correct realistic movements and body postures was preferred over an abstract avatar model for the final warm-up game.
(3) *Different obstacles:* In the early prototype game, only one type of obstacle was present. As expected, the participants argued that the number and types of obstacles need to be increased in order to make the game more attractive. Again, a varied set of game elements should be provided to avoid monotony.
(4) *Achievements, rewards, and scoreboards:* The prototype version of the game did not include any rewards or achievements. According to the participants, including such elements would make the game more challenging and motivate them to take part in it more often. So reward mechanisms like coin collection have the potential to enhance the user experience in a warm-up exergame. In particular, scoreboards were brought up by many participants as a way of encouraging players to compete.
(5) *Feedback and metrics* The participants also suggested that the game should monitor the correctness of the movements performed by the users and, in the case of incorrect ones, inform them in a way that does not affect their performance in the game. The feedback should also include different metrics concerning users' energy and calorie expenditure, as well as which muscle groups are used in certain movements during the game.
(6) *Customizable game settings:* The participants preferred a game with adjustable game elements (segments and avatar), speed, intensity, and duration. They liked to be able to manage and manipulate all the game's features based on their workout preferences. While some of these requests could be easily implemented (e.g. personalized avatars), others must be considered with care since they might affect the overall goal of the warm-up (e.g. intensity too high vs. too low).

Movement and exercise-related improvements.

(1) *Increase required movements:* The participants pointed out that only a few movements were required in the game, which made it one-dimensional, neglecting the warm-up for the arms and upper body. Introducing only a limited number of segments and requiring only a few movements was determined to be sufficient to present our idea of a warm-up exergame and assess its general acceptance. This shows that it is important to give the athlete the impression that a universal warm-up is provided.
(2) *Sport-specific exercises:* Some of the participants argued that the prototype game required only general movements and did not target muscle groups that are relevant for the sports they engage in. This indicates that the sensors that are used to track the activity should be carefully chosen.
(3) *Include stretching exercises:* Since stretching is part of most participants' warm-up routine, they also expected that the presented solution would not include movements and exercises of this type. They proposed having movements that focus on the whole-body stretching.

3.3 Step 3: Coach-Guided Dynamic Game Elements

3.3.1 Involving fitness experts in exergame design. During the development of our exergame, a fitness and exercise expert was consulted in order to design game segments that would require movements often performed before physical activity and be executed by the users without prior exercise knowledge. We conducted semi-structured interviews with one coach in three sessions. He has more than 10 yeas of experience as a professional coach with a diploma in sports science. Using our exergame warm-up software setup, it was possible to react to his requested changes in real time, concerning the placement of objects in the game and adaptation to proper procedures such as increasing intensity and coverage of all muscle groups, due to the nature of the Unity platform with its in-game editing and coding capabilities.

Based on the comments received from the expert, we modified existing segments so that movements are more coordinated from a sports science perspective, i.e., we adjusted the sports science and distances, and changed complete game assets to match with the exercises proposed by the expert. The modular design approach allowed us to easily add segments that required movements suggested by the experts on the spot, and modify existing ones. Suggestions and additional features recommended by experts were taken into account while designing all the game segments used in the final version of the exergame.

Figure 1 illustrates the interactive design of game elements to adapt them for proper guidance and correct technique. Figure 4 gives an impression of how we derived game elements from the fitness expert's original exercises.

3.4 Step 4: Final Warm-Up Exergame

To make the game easily adjustable and compliant with the user requirements and expert interviews, we used procedural content generation (PCG) [7], a well-known method that combines our game elements as shown in Figure 4 to generate the game world at runtime. In the final version, we increased the number of game elements with different obstacles, since we found multiple levels to provide more variety.

Having done this, the set of required movements to be performed in order to avoid those obstacles also increased. Lastly, we introduced an algorithm that generates game segments according to the feedback from the coach. This way, each warm-up session became unique, in that the order in which game segments, and the obstacles, were presented to the user was random.

That is, each movement (exercise) to be performed by the user was encapsulated in one distinct game segment. The game system is divided into smaller parts that could be independently generated and then used accordingly. That way, we combined game segments (with their corresponding exercise sequences) according the fitness expert recommendations. By combining game elements on-the-fly, a game map was generated each time the user played the exergame. The end result of this approach was that our game is not constrained by one global map, but game elements can be dynamically combined to adapt to the user's performance. This modular system allowed us to easily add new game elements and offer a rich set of exercises. Also, this way we could easily update or discard segments and movements that users disliked or that were difficult to perform. This makes our exergame scalable and extensible for future design iterations, e.g., if it were to be adapted for sport-specific or stretching exercises.

To illustrate the actual gameplay and interaction, we publish an accompanying video, which will provide additional explanations behind key design choices, including the theme and aesthetics of the game.

4 USER STUDY

The goal of this study is to evaluate the designed exergame's effectiveness and attractiveness qualitatively. Additionally, we applied sports science methods in order to assess the physiological warm-up specific measures and compare these to those of a control group who have been given instructions by a coach. We hypothesize that, regarding physiologically desirable warm-up effects (range of motion, heart rate, perceived exertion), the warm-up exergame is on par with the video instructor. Also, we expect participants in to have a higher physical enjoyment when using the exergame compared to the participants the control group, and to engage in warm-up sessions for longer than participants in the control condition.

4.1 Participants

Ten participants (two female) were recruited via printed posters, social media and email. The age of the participants ranged from 24 to 30 years ($M = 26.7$, $SD = 1.77$). The participants reported no physical impairment at the time of participating in the study. All of the participants were amateur athletes who engage in some physical activity on average 4 times per week. Out of 10 participants, 3 reported not engaging in WU before sports sessions.

4.2 Method

The user study was set up as a between-subject experiment with two conditions, to which participants were assigned randomly:

Exergame Warming up with the exergame, guiding through the warm-up procedure, projected on a wall in front of the participant.

Control Warming up with a video of a professional coach guiding through the exact same warm-up procedure as induced by the exergame, projected on a wall in front of the participant as video.

The video was a looping recording of a professional coach who guided the participants through the warm-up routine that was captured once before the study. It was synced with the exergame and movements the coach executed were individually discussed and evaluated as described in Step Four. A standard physical activity, exercise, and sport pre-study questionnaire (PARQ) was used to determine health status [52]. Additionally, physical activity levels were assessed with the standardized BSA-F [13] questionnaire.

4.3 Measures

The following measures were collected as dependent variables during the experiment:

- *Warm-up duration* The duration of the warm-up exercise was measured in both conditions.
- *Range of motion (ROM)* The participants' ROM was measured before and after the warm-up routine using a goniometer.
- *Heart rate* The participant's heart rate data was captured and measured during the warm-up procedure.
- *Rated Perceived Exertion (RPE)* The participants rated their perceived exertion on the Borg scale.
- *Physical enjoyment* The participants rated their physical enjoyment with the PACES questionnaire.

We further collected feedback with a post-study questionnaire and report observations we made during the study.

4.4 Tasks

In both conditions a combination of the following exercises was performed while the speed was gradually increased: right hand movement up, left hand movement up, jump right, jump left, jump up, star jump, and squat.

In the exergame condition, the game begins with a starting scene. We accompany this paper with a video that shows footage of both conditions, including the interfaces with this paper. The researcher inputs the participant's name and hits *start*. After a 5 second countdown, the game proceeds with scenes in which the participant is required to perform specific movements in order to avoid obstacles and collect coins. The control warm-up procedure started with a video that displays a coach who instructs the participants in which movements need to be performed. The participants were asked to repeat the exercises shown by the coach. In both conditions, the duration of the warm-up is not fixed, and it is performed up to the point when the participant "subjectively feels warmed up enough".

4.5 Procedure

The study was approved by the ethics board and each participant signed a consent form before the study. Each assigned participant took part in a single test session one hour in duration. During this session, all the participants performed one warm-up session, after which they completed a set of questionnaires.

In the lab, only one participant was present at a time and was guided by the researcher. The participant first completed the preliminary questionnaires (PARQ, BSA-F, demographics). The researcher determined, based on the PARQ results, if the participant was eligible to continue. After a short introduction, the participant put on a heart-rate belt. Before the warm-up, the participant's ROM rotation and extension of both shoulders and the flexion and extension of the hip was measured with a goniometer. The researcher explained the task to the participant depending on the condition, while the participant had time to rest. A place on the floor was marked as the starting point for the warm-up procedure. The participant stopped when she or he felt "properly warmed up". Directly afterwards, they reported their perceived level of exertion. Subsequently, the researcher assessed the ROM of the participant again, and a 5-minute rest was taken. The post-study surveys were completed and each participant was compensated with 10 Euros for taking part in the study.

4.6 Apparatus

The experiment was conducted in a laboratory. We used exactly the same hardware setup as described in Step 1 for the early prototype. The participant was instructed to keep an optimal distance of at least two meters from the sensor during the experiment. This distance was the most suitable in order for the system to function properly in terms of skeleton tracking. A video camera on a tripod captured the participant from behind during the warm-up procedure for general observations. A Bluetooth heart rate belt (Polar H7) was used to track heart rate synchronized with the time of the machine playing the game/video.

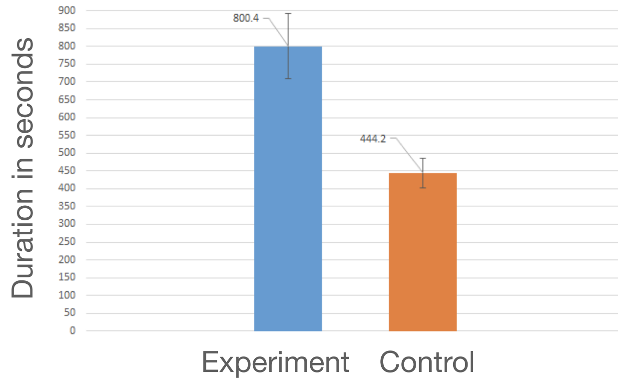

Figure 5: Average warm-up duration for the experiment (blue) and control (red) condition in seconds

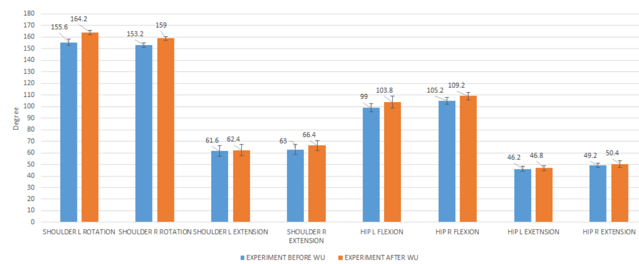

Figure 6: ROM results for the exergame condition

5 RESULTS

5.1 Warm-Up Duration

The duration of the warm-up session was measured from the game or video start until the moment the participant stopped the warm-up session. The participants were instructed to play the game or follow the video instructions for as long as they usually spend on a warm-up session before some physically strenuous activity. The average warm-up duration for the exergame condition was 800.4 seconds ($SD = 205.4$, $x_{max} = 1122$, $x_{min} = 616$) and 444.2 seconds for the video condition ($SD = 94.2$, $x_{max} = 576$, $x_{min} = 345$). The results are presented in Figure 5. An independent-samples t-test was conducted to compare average warm-up duration in the exergame and video conditions. There was no significant difference in the scores for experiment ($M = 800.4$, $SD = 205.4$) and control ($M = 444.2$, $SD = 94.2$) conditions ($t(8) = 2.89, p = 0.20$).

5.2 Range of Motion

Range of motion was assessed for each condition before the warm-up session and immediately after the participants completed the procedure. To take the measures, a goniometer with 1 degree increments was utilized. The average ROM values are presented in Figures 6 and 7.

The average values after the warm-up session for all measured joints were higher in each experiment condition. The increased measures imply that both the exergame and the video instruction positively affect the participants' ROM as desired. When comparing

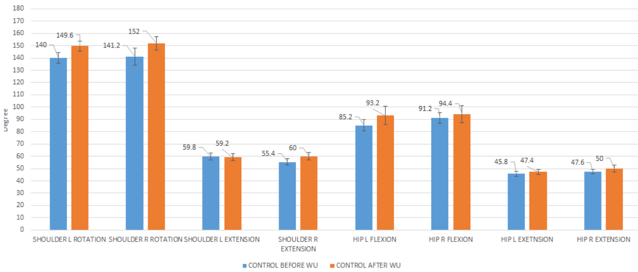

Figure 7: ROM results for the video condition

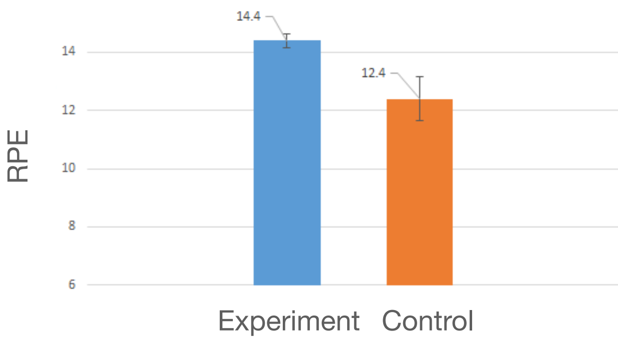

Figure 8: Average perceived perceived exertion results (RPE)

the increase of ROM from the exergame with the control condition, we could not find a significant difference.

5.3 Physical Effort

The physical effort of the warm-up was measured via heart rate and rated physical exertion (Borg scale). The heart rate data was captured and monitored using a Polar H7 Bluetooth Heart Rate Sensor. The heart rate was captured from the beginning of the warm-up until the moment the participant claimed to be warmed up properly for a subsequent hypothetical physical activity. The average maximum heart rate per participant, relative to the maximum heart rate, was computed for each participant using the Karvonen method [55] based on age, resting heart rate, and heart rate reserve: $M_{exergame} = 0.919$, $SD_{exergame} = 0.043$, $M_{video} = 0.84$, $SD_{video} = 0.050$. The average maximum heart rate was 174.20 ($SD = 7.01$, $x_{max} = 186$, $x_{min} = 170$) for the participants in the exergame group and 158.8 ($SD = 10.06$, $x_{max} = 169$, $x_{min} = 144$) for the participants in the video group.

The zones of the target heart rate (THR) were calculated for each participant based on the maximum heart rate. Only one participant's (P4) heart rate was close to the maximum target heart rate (THR_{max}). On the other hand, the maximum heart rates of the participants in the video group fall in the lower range of high intensity and upper range of moderate intensity exercise, with one participant (P7) in the middle range of the moderate intensity exercise zone. The participants in the exergame group reached higher heart rate zones compared to the participants in the video group.

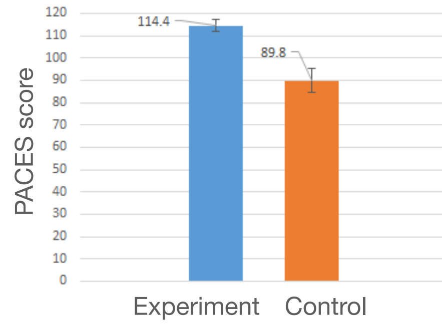

Figure 9: Average PACES scores

5.3.1 *Rating of Perceived Exertion (RPE).*

The RPE score, also known as the Borg scale, for participants in the exergame condition was 13.8, and 12.6 in the video condition, without a significant difference between the two (see Figure 8). This reflects how difficult a performed exercise felt to the participants, combining all sensations and feelings of physical stress, effort, and fatigue. All the participants received standardized instructions and were encouraged to focus upon their overall (whole body) perceptions of exertion.

5.4 Physical Enjoyment

The Physical Activity Enjoyment Scale (PACES) was used to investigate how participants perceived the physical activity they engaged in. The PACES test consists of 18 questions on a 7-point Likert scale that was originally designed to measure positive affect associated with involvement in physical activities in college students [23]. High scores obtained on the positive items and low scores on the negative items indicate a high enjoyment of the physical activity; the total enjoyment score is obtained by reversing negative item scores and summing them to positive item scores. We coded participants' responses, where higher scores indicated greater enjoyment, with scores ranging from 18 to 126. The participants in both conditions completed the PACES test after finishing the warm-up session. Figure 9 depicts the average results for each question per condition. It shows that the participants in the experiment condition rated all the questions consistently higher compared to the scores of the participants in the control condition. Two questions received a notably much higher score from the participants in the experiment condition: Q4: "I find it pleasurable.", Q5 "I am very absorbed in this activity." This suggests that the participants found the exergame very enjoyable to interact with and, most importantly, the exergame succeeded in immersing the participants sufficiently to shift their focus from the exertion of the exercise, making it pleasing and entertaining.

The average overall score for the exergame condition is 114.4 ($SD = 5.98$, $x_{max} = 125$, $x_{min} = 111$), and 89.8 ($SD = 11.97$, $x_{max} = 104$, $x_{min} = 71$) for the video condition. We compared the means of the exergame ($M = 114.40, SD = 5.98$) and video ($M = 89.80, SD = 11,97$) group with a paired t-test ($\alpha = 0.05$) and found a significant difference; $t(8) = 4.1114, p = .0034$, whereas Cohen's d was 2.5948. Therefore, based on the fact that there was a statistically significant difference between the two conditions, we concluded that warming up by using our exergame solution positively affects the physical activity enjoyment.

6 DISCUSSION

The hypothesis that a player's ROM is increased for the measured joints after performing the warm-up session was supported. The results of our experiment also indicate that performing warm-up exercises using our exergame immediately affects the duration of the warm-up procedure, which supports our second hypothesis.

Concerning the warm-up duration, which was only higher on average toward the exergame condition, we interpret this as a hint for higher enjoyment and lower perceived exertion as these are two factors that could increase the playtime. It is not clear if this could also be a novelty effect, or if a warm-up exergame could lead to a higher overall warm-up engagement over the longterm. With the measurement of duration, we do not want to imply that a longer warm-up is a better warm-up. In a real scenario, the game should be ended after the recommended warm-up time.

When using the proposed warm-up game in real-life situations, practical aspects need to be considered to effectively increase engagement. The Hawthorne or novelty effect might be responsible for the results of our controlled in-lab experiment. Superficially, the participants played a game and may have forgotten or disregarded the "stop when you feel warmed up" instructions. However, the final design of the game with increasing speed and intensity made them stop before entering the anaerobic zone, which means they would start sweating and breathing heavily. This is indicated by the Borg scale and heart rate data. From a practical standpoint, we argue that, with the nature of a warm-up, our game could provide a regular incentive to even start a warm up, especially when the system is set up readily for direct keyless interaction in a gym, similar to other fitness equipment.

The use of the RPE generally accounts for the internal perception and listening to one's body, which worked well during the study phase. To avoid an undesirable immersion, and consequently a too-hard effort, we could imagine a more or less explicit regular prompt "do you feel warmed up?" or "What is your perceived exertion?". The latter is regularly used in practice, with a pointing gesture to a printed scale in sports science, which we could imitate with the Kinect sensor.

Overall, we conclude that participants in both conditions reached an elevated heart rate sufficient to continue with a more strenuous physical activity. The results, however, suggest that the duration of the warm-up session for the participants in the experiment group could be shortened in order to keep the heart rate at moderate levels as recommended by fitness experts. That is, we noticed that some of the participants in the exergame group spent a notable amount of time in the intense heart-rate zone and were close to reaching their maximum heart-rate before finishing with the warm-up procedure.

The RPE was used in order to determine the physical activity intensity level. The results showed that there was no significant difference in the perceived exertion between the conditions. Due to the immersive nature of our solution, expectations were that the reported average exertion level in the exergame condition would be less compared to that in the video condition. We believe the duration of the warm-up session influenced these results the most. The RPE results cannot completely confirm that our exergame elicits physical exertion. With similar heart-rate and RPE but longer duration in the exergame condition, it might be an objectively higher effort, but perceived as less intense.

In terms of warm-up guidance, all the participants who interacted with our exergame solution agreed that the movements induced by avoiding game obstacles and collecting coins felt intuitive and came naturally. This suggests that our exergame succeeded in guiding the participants through a proper and general warm-up procedure.

Regarding physiologically desirable warm-up effects (range of motion, heart rate, perceived exertion), the warm-up exergame seems to be on par with the video instructor. Except for warm-up duration, we did not find a significant difference. However, the ROM, heart rate, and RPE yielded similar values as in the control condition. Concerning our second hypothesis, we argue that our system is more attractive than using a video instructor. There was a significant difference for the PACES score found between the two conditions, suggesting that warming up using our exergame positively affects the physical activity enjoyment.

7 CONCLUSION

In this work we presented an iterative design process with resulting design implications for warm-up exergames which can be used for further sport-specific development. Based on the design implications derived from pilot-testing an early prototype, an online survey, and semi-structured expert interviews, we proposed an example of a warm-up exergame that provides guidance targeted towards amateur athletes who rarely warm up before workouts.

The individual game elements were created interactively based on exercises demonstrated and recommended by a fitness expert. The game elements are combined at runtime following basic principles of warm-up from sports science, such as increasing intensity and coverage of all muscle groups in the human body. We used a Microsoft Kinect 2 in order to track and capture players' movements and displayed the exergame on the wall using a projector. By placing various game obstacles and coins in a specific position, we promote exercise through the gameplay of repeatedly performing warm-up related movements chosen after related literature review and discussions with fitness experts.

We evaluated the final warm-up exergame in a user study, in which we compared the classical coaching approach using video instructions to our proposed game. As a result, the desired effect of a warm-up, an increase in the range of motion in most joints, was present in the exergame as well as in the video condition. Also, the warm-up exergame led to a significantly longer warm-up duration than the video condition. Finally, the participants rated the exergame higher on the PES and PACES scale and achieved higher relative maximum heart rates. At the same time, the perceived exertion on the Borg scale was not significantly different.

In future work we will conduct a long-term field study in a gym. We are currently working together with our sports-medicine department and plan to use the system as a sports-medicine study tool to investigate warm-up procedures. Overall, we think coach-guided dynamic game elements are a viable approach to be used in sport-specific warm-up exergames and are ready to be field tested with regards to long-term effects in future work.

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