

ExerSync: Facilitating Interpersonal Synchrony in Social Exergames

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ABSTRACT

Social exergames provide immersive experiences of social interaction via online multiplayer games, ranging from simple group exercises (e.g., virtual cycling/rowing) to more structured multiplayer games (e.g., cooperative boat racing). In exergame design, interpersonal synchrony plays an important role as it enhances social rapport and pro-social behavior. In this paper, we build ExerSync platform that supports various assistive mechanisms for facilitating interpersonal synchrony even with heterogeneous exercise modalities. We consider a rhythm of body movements in repetitive aerobic exercises and explore the design space of incorporating rhythm into exergames. We build a prototype system and comparatively evaluate the effectiveness of various assistive mechanisms. The experiment results show that rhythm significantly lowers the perceived workloads and provides better competence and engagement, but the accuracy of interpersonal synchrony is not dependent on the use of rhythm.

Author Keywords

Synchrony; synchronization; exergame; rhythm.

ACM Classification Keywords

C.3 [Special-purpose and Application-based Systems]: Real-time and embedded systems; H.5.2 [Information Interfaces and Presentation]: User Interfaces—*evaluation/methodology, input devices and strategies, prototyping*

General Terms

Design, Human Factors, Experimentation

INTRODUCTION

Aerobic exercises (e.g., treadmill running, elliptical training) have many well-known health benefits such as lowering the risk of diseases (e.g., high blood pressure, cancer), maintaining body shape, and improving psychological well-being [47]. The monotonous nature of aerobic exercises, however, is regarded as one of the key demotivating factors to exercise adherence [19, 13]. In

recent years, there is a growing awareness among researchers and fitness professionals that working out in groups (e.g., exercising with friends or talking group cycling/rowing classes) can effectively mitigate this problem, as social interaction in group exercise settings promotes encouragement and motivation (known as social support) [12].

Social exergames are designed not only to reap the benefits of group exercises but also to provide immersive experiences of social interaction via online multiplayer games where physical activities are used as game input [30, 55, 1, 32, 29]. The spectrum of social exergames ranges from simple online group exercises (e.g., Jogging over a Distance [30]) to more structured multiplayer interactive games (e.g., Table Tennis for Three [26], Swan Boats [1], Push’N’Pull [27], Heart Burn [43], Balloon Burst [44]). The main departure from traditional group exercises is that social exergames relax the physical constraints of co-located exercises and provide rich socio-physical interaction during workout. Further, computer-mediated interaction in social exergames can address heterogeneity of individual exercise preferences, capabilities, and goals; e.g., maintaining balanced exertion experiences based on an exerciser’s fitness level [43, 29], collaboratively steering a boat using treadmill and bike [29].

One of the important components in social exergames is to facilitate interpersonal synchrony that has positive social effects of improving rapport and entitativity (or social unit) and also making exercises more enjoyable [17, 20, 18, 6, 49, 46]. Due to online nature of social interactions, we loosely define interpersonal synchrony as the state in which physical movement rhythms of game players or physiological states are in unison on the basis of given game metrics such as speed, heart rates, and a mixture of both. For instance, in a boat racing game like Swan Boat, to steer a boat on a straight line a pair of players on the treadmill should run at the same speed; in Jogging over a Distance, distant joggers could experience interpersonal synchrony by balancing their running speed based on partner’s heart rates.

We consider a range of social exergames that use exercise intensity as game input and support heterogeneous exercise devices. In existing social exergames, a rhythm of body movements is captured by using a simple intensity metric

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like angular speed/frequency (e.g., RPM of stationary cycles). Game players use this speed information to adjust rhythmic body movements for interpersonal synchrony. In practice, however, the use of speed information is less natural, because humans feel more comfortable when coordinating rhythmic movements by tuning one's movement cycles directly to the perceived movement cycles (or the beats in music) [52, 42, 34]. For instance, to walk at the same speed, two people use the auditory or/and visual perceptions of each other's gait cycles (swing-stance pairs) to adjust their step frequencies; as a result, they will walk in step (and at the same speed). Further, interpersonal synchrony would become even more elusive, particularly when heterogeneous exercise modalities are involved (e.g., treadmill and bike).

In this paper, we build the ExerSync platform that supports various assistive mechanisms of facilitating interpersonal synchrony. Unlike existing work, we consider a rhythm of body movements to design a new assistive mechanism and comparatively evaluate various mechanisms via user studies. To be more precise, ExerSync extracts both frequency (or intensity) and phase of the current movement cycles; e.g., how fast a person is walking (step frequency), and what the current phase is (e.g., hill strike event has just happened). Given that self-stabilizing, distributed synchronization requires considerable time and effort as group size increases [34], ExerSync uses simple leader-directed group synchronization for fast convergence where a leader is elected in a game play (like a coxswain in team rowing), and the rest of users follow the leader's rhythm. Inter-person and -device heterogeneity is dealt with balancing methods proposed in the literature [43, 29, 32]; e.g., given that each user has a preferred range for exercise devices, balancing can be achieved by mapping one range to the other proportionally [32]. In this way, the leader's rhythm is translated to an individual's view (based on a preferred range and device type), and each individual uses this balanced rhythm for synchronization.

To validate the feasibility and effectiveness of rhythmic cues for synchronization in social exergames, we consider four types of equipment-based exercises, namely walking/running, cycling, hula-hooping, and jump-roping and then design novel mechanisms for extracting major phases within the movement cycles. We report the detailed design processes and the lessons learned while developing our prototype systems; i.e., (1) smart shoes that can detect hill/toe strikes to capture the stance phase of walking/running and the load/landing phases of jump-roping, (2) a wearable vest that can detect the impulse generation phase of hula-hooping, and (3) a modified bike that can monitor power-recovery phases of cycling. We perform a user study to characterize the effectiveness of rhythm cues for synchronization, to analyze synchronization performance under inter-device heterogeneity, and to understand the user experiences (e.g., intrinsic motivation, engagement).

The main contributions of this paper are two-fold. First, we analyze four kinds of repetitive aerobic exercises and explore the ways of extracting movement rhythm. Second, we build prototype systems and evaluate the effectiveness of assistive mechanisms under various configurations of exercise devices. The user study results show that when compared with the speed gauge cues, rhythm cues significantly lower the perceived workloads and provide better competence and engagement. Interestingly, even though participants reported significant improvement on perceived performance, our quantitative analysis of user study traces disproves such claims; we fail to provide statistically significant evidence that rhythm cues perform better than speed gauge cues. The rest of this paper is organized as follows. We illustrate background and related work and then detail ExerSync system by explaining its main components, namely Exercise Rhythm Extractor, Rhythm Translator, and Audio-visual Rhythm. We report our user study that examines effectiveness of synchronization, inter-device heterogeneity, and user experience studies. We discuss the implications and limitations of our main findings and conclude the paper.

BACKGROUND AND RELATED WORK

It is well known that interpersonal synchrony within group activities provides many social-psychological advantages. To name a few, it enhances cooperation between group members and binds them together [15, 23, 53]. Also, it increases social rapport, pro-social behavior and performance of joint-activity [7, 25, 48, 54]. Examples of interpersonal synchrony include dance, drill, and group exercises (e.g., aerobic dances, cycling/rowing classes); people in a group move together in time and feel strong engagement from their synchronized activities [23, 12]. Therefore, it is very important to explore interpersonal synchrony to enhance the quality of group experience in social exergames.

Before we illustrate the details, we examine interpersonal synchronization that is a process of coordinating body movement rhythms between interacting individuals [42, 34]. In the theory of synchronization [34], a rhythm of body movements (e.g., repeated stance-swing patterns of walking/running) is characterized using the angular speed/frequency (i.e., the number of movement cycles per time unit), and the phase (i.e., the quantity that increases within one cycle, proportional to the fraction of the cycle period). Interpersonal synchrony is said to occur when two people performing the same rhythmic body movements reach a common angular frequency (e.g., walking at the same speed). Note that this state does not imply that the entrained cycles coincide. In other words, there could be an arbitrary *phase shift* between movement cycles; e.g., stance-swing phases of synchronized individuals are not necessarily in unison. In particular, when there is no phase shift, this state is called in-phase synchronization (e.g., identical stance-swing phases); and when the phase shift is 180 degrees, this state is called anti-phase synchronization

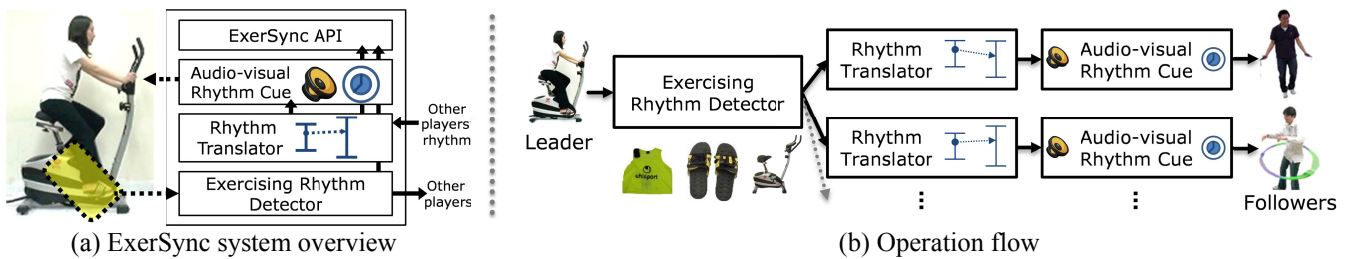


Figure 1. Conceptual overview of the proposed system.

(e.g., reversed stance-swing phases, meaning that a person's left foot coincides with the other person's right foot). Interestingly, researchers found that when visual movement information of partners (visual perception) is solely given, humans can only stably maintain without practice in-phase and anti-phase synchronization [41, 40]. In the following, we review how existing exergame attempt to facilitate interpersonal synchrony by offering audio/visual cues.

As mentioned earlier, due to online nature of interactions in social exergames, we extend the concept of interpersonal synchrony such that game players' physical movement rhythms or physiological states are in unison on the basis of given game metrics such as speed, heart rates, and a mixture of both. Having said that, interpersonal synchrony in existing social exergames can be summarized as follows. Mueller et al. developed 'Jogging over a Distance' [28] that provides joggers in different locations with a sense of presence of others. It also helps them to balance their exercising intensity by synchronizing each other's heart rate. A rhythm action game 'Dance Dance Revolution' provides Unison Mode which promotes synchronized movements of two collocated players; following shared step arrows, the players should step together in time. Another interesting example is 'Magical Truck Adventure,' an arcade pump car racing game. To move forward a pump car, two players should push their pumping bars alternately, and thereby, they have sense of synchrony and fun.

In several exergames, synchronous behavior occurs within some game contexts. Park et al. proposed 'Swan Boat,' a cooperative paddle-boat racing game [1, 33, 32] which actively utilizes exercising speeds with the exercise equipment (e.g., treadmills, stationary cycles); to steer a boat on a straight line, a pair of players should exercise at the same speed. In 'Push 'N' Pull' [26], a pair of players use resistance training devices and manipulate virtual objects. Synchrony occurs when they push and pull the devices in the same direction. In 'Truck Pull' [44], two players engage in a virtual tug-of-war by pedaling on their respective stationary bikes; synchrony can happen when they pedal at their maximal speed. Note that competitive social exergames that do not use cooperation usually lack interpersonal synchrony. For instance, in a racing game called 'Heart Burn,' each player individually controls a car using bike (speed) and game pad (direction) [43].

Besides exergames, there are also other computer-supported collaborative applications that facilitate interpersonal synchrony. Carroll et al. proposed ChoNo, a video-based

annotation tool that uses an audio-visual cue to help a dance team to practice together [9]. There are several works in the domain of networked music performance [3, 4], which supports on-line synchronous and collaborative music practice. Similarly, Reidsma et al. introduced a notion of virtual conductors interacting with human musicians [37]. However, these applications mainly use a predefined or programmed rhythm, whereas our system dynamically extracts players' exercise rhythm and shares it with other players for inter-player synchrony.

EXERSYNC SYSTEM DESIGN

System Overview

As shown in Figure 1, ExerSync consists of three key components: *Exercise Rhythm Extractor*, *Rhythm Translator* and *Audio-visual Rhythm Cue*. They are designed to effectively deal with the challenges in providing synchrony while playing pervasive social exergames. *Exercise Rhythm Extractor* detects repetition frequency of exercising players. It includes a variety of wearable sensors and sensor-enabled exercising devices. Each repetitive aerobic exercise has a series of movement phases constituting a repetition unit, which required exercise type-specific considerations to accurately detect the repetition frequency. *Rhythm Translator* converts a repetition frequency value of one player to its relative value in other players' predefined frequency ranges. For this, players define their own preferred frequency ranges in advance. Through the rhythm translation, players avoid receiving excessively high or low frequency of others that they cannot synchronize with. *Audio-visual Rhythm Cue* is designed to effectively convey the converted frequency information between players. It actively utilizes audio-visual rhythmic representation and additional visual hints to help players recognize and anticipate rhythm information, respectively. To facilitate rhythm-based group exergames, the system also supports application-program interface (API) which provides rhythm information of exercisers for game applications.

Exercise Rhythm Extractor

To extract exercise rhythm, we developed several types of hardware devices including wearable sensors and sensor-enabled exercise devices. We carefully designed these devices by multiple iterations of observing exercise movements, while creating and evaluating prototype devices.

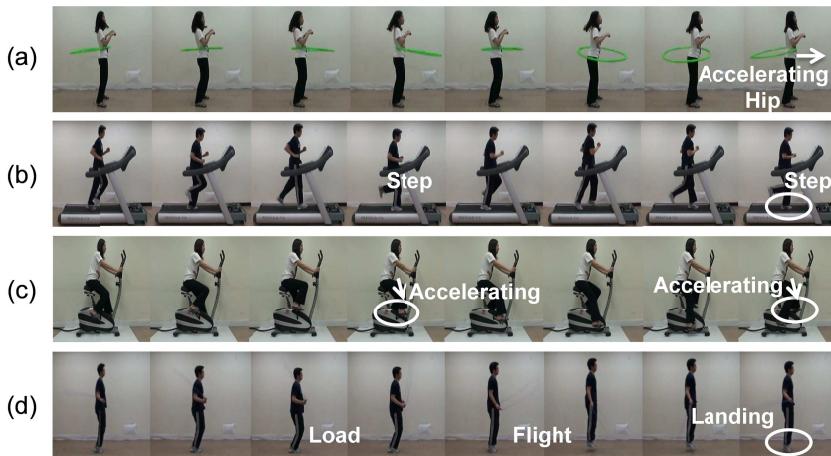


Figure 2. Repetition of exercises. (a) hula hooping, (b) treadmill running, (c) stationary cycling, (d) rope jumping.

Empirical study on exercise movement and rhythm

We define exercise rhythm in terms of repetition frequency and phase of a given exercise; here, a repetition unit is a series of well-defined movement phases. For instance, Zehr et al. [56] analyzed the movement phases of walking and cycling and showed that leg flexion and extension results in feet acceleration toward and away from the pelvis, respectively. Jump roping has load, flight, and landing phases [21], and hula hooping has joint acceleration of hip/ankle and maintenance phases [11].

While these phases are defined based on the mechanics of body movements, we need to confirm how people actually identify the beginning point of repetition in each exercise. We conducted a user study of observing the moments that the participants define as the beginning of repetition. 16 paid participants were recruited. Their ages range from 18 to 28. We asked participants to perform four kinds of exercises, but we allowed them to exclude the ones that they cannot do well with. We also asked the participants to count their repetitions like as ‘one, two, one, two, ...’ After videotaping, we analyzed the counting behavior of the participants as well as exercising movements.

We found that there are two classes of exercises depending on whether there is an explicit phase transition. First of all, running and rope jumping have ‘steps,’ the moments when exercisers’ feet strike the floor. Participants counted repetitions along with the steps. In the case of running, one exceptional case happened; a male participant counted with his left steps only. He said that it is more natural to do so because it is very similar to the physical training that he had during his military service. For the other exercises, namely cycling and hula hooping, it is elusive to exactly pinpoint the beginning of a cycle. After careful examination, we were able to find that most of participants wanted to count rhythm when they start accelerating the pedal on the foot or the hula hoop along with the waist (see Figure 2).

Note that there exists movement symmetry in running, cycling and hula-hooping. We found that people have different preferences in terms of selecting the beginning



Figure 3. Prototype devices for exercise rhythm detection.

point (i.e., 0°); yet, most of the participants prefer to select their left leg as the beginning.

Creation and Evaluation of Prototype Devices

Accelerometer-based rhythm extractor prototypes. For the first prototype, we tried to utilize 3-dimensional accelerometers which are commonly equipped on off-the-shelf smartphones. Since they are widely used to detect specific movements including walking steps, we implemented a peak-detection-based step detector [57] on top of Google Nexus One. We placed the smartphone at the right flank of participants as suggested. Similarly, we adapted the step detection algorithm for detecting exercising rhythm of hula hooping and cycling, because the waist and leg movement of these two exercises also generate near-sinusoidal waves of which the frequency is almost the same as the repetition frequency of the movement.

During preliminary tests, however, we found that this approach had a significant drawback of incurring a large detection delay. Since it continuously monitors the acceleration pattern whether it increased, reached a peak, and decreased, the algorithm inherently produces detection latencies, and even these are not consistent, ranging from 80ms to 200ms in our experiment. In the case of treadmill running, the repetition frequency at 8Kph is about 3Hz (300~350ms in a repetition period), and thus, the latencies significantly degraded the detection accuracy.

Contact-sensing-based rhythm extractor prototypes. To minimize a detection latency, we decided to focus on detecting contact events that indicates the beginning of repetitions. As shown in Figure 2, all exercises have these contact points between exercisers’ body and exercise device (hula hooping, treadmill running), exercisers’ body and the floor (rope jumping), and subparts of exercise device (stationary cycling). In the case of treadmill running and rope jumping, we can easily detect the step by monitoring contacts between soles of shoes and the floor. We implemented a contact sensor-enabled smart shoes which

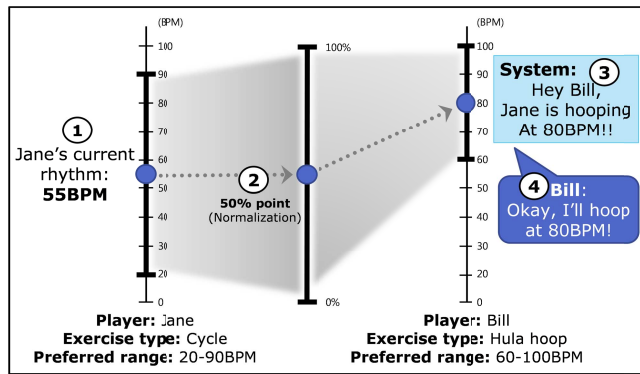


Figure 4. Conceptual example of rhythm translation.

detect the floor contacts (see Figure 3). For a stationary cycle, we attached a magnetic switch on the pedal shaft and made it detect the timing when the cranks are passing through the front vertically centered position. For a hula hoop, we utilized the fact that a hoop naturally touches around the navel when the participants start to move their waist forward. We developed a smart vest which detects pressure on the front side of belly. All of these smart devices send the contact information immediately using wireless communication channels such as Bluetooth or ZigBee. To evaluate the second prototypes, we ran a pilot test. We programmed that the participants hear a beep sound when the devices detects the beginning of the repetitions. In this experiment, all the participants strongly agreed that the devices detected their exercising rhythm accurately and immediately.

Rhythm Translator

Rhythm Translator is designed to provide a sense of synchrony between exergame players with different physical competences or heterogeneous exercise modalities. The translator converts the repetition frequency of a leader to its relative value of each following player. In brief, it maps the repetition frequency of a leader based on the preferred range of each player, as if the leader had the same physical ability and performed the same exercise with the player. Our translation mechanism is similar to the previous works [28, 32] which provide balanced and fair game play under the similar situation as this work. In the training phase, each player P_i performs the exercise at the minimum and maximum frequencies and sets her preferred range of exercise frequency as (f_{min_i}, f_{max_i}) . The user's current frequency f_i is then converted to a target frequency f_{i_t} in such a way that the ratio of the target frequency f_{i_t} in the target range (f_{min_t}, f_{max_t}) is kept the same as that of the original frequency f_i in the original range (f_{min_i}, f_{max_i}) .

Figure 4 shows a simple example. Jane, a stationary cyclist, with her preferred frequency range of (20, 90 BPM) runs with Bill, a hula-hooper with a range of (60, 100 BPM). Her current running pace is 55 BPM as measured by the rhythm extractor. The rhythm translator then converts it and notifies to Bill that her current frequency is 80BPM as if she performs the same exercise, i.e., hula-hooping, within the same preferred frequency range with him.

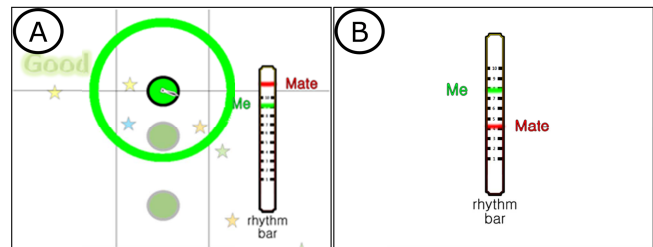


Figure 5. Visual rhythm cues. (a) proposed visual cue with rhythm rate gauge (b) rhythm rate gauge only.

Audio-visual Rhythm Cue

Each player uses audio-visual cues to coordinate her movements based on the balanced rhythm of the leader (supplied via the Rhythm Translator). The cue periodically gives auditory and visual stimuli to players; auditory cues correspond to the beginning of a cycle, and visual hints help players to intuitively estimate the remaining time till the next beat. For the auditory stimulation, we utilized a machine-generated tone with sound frequency of 4,000Hz whose duration is 50ms. This is very similar to the rhythmic sensory stimulation used for gait assistance of Parkinson's disease patients [5, 10].

We carefully designed visual stimulation considering that the frequency changes over time as the leader changes his repetition frequency. So, we designed assistive visual hints as well as traditional visual stimulation (turning on a light signal for a period of 50ms). To our knowledge, assistive visual cues have not been extensively studied in the past. However, we could find a visual metronome with assistive visual information [14]. It simply displays a moving LED light from one side to another repetitively. Also, we investigated the commercial rhythm beat games which provide assistive visual cues. Our extensive survey results show that there are two rhythm beat games featuring assistive visual hints, namely Elite Beat Agents and Hatsune Miku: Project DIVA. The former game utilizes one fixed (smaller) circle and one shrinking (bigger) circle. To help players estimate the next beat, the bigger circle getting smaller at a constant rate, and the two circles meet exactly at the beat. The latter game provides a clock hand, which rotates at a constant angular velocity and hits the direction of 12 o'clock exactly at the beat. As these two hint types do not conflict with each other in visualization, we combined the two types of visual hints without hurting or confusing them, as shown in Figure 5(a). In addition, we presented the frequency rate differences between the player and her partner using the color of the circles, similar to the colored cue suggested by Wilson et al. [52]

USER STUDY

In this user study, we seek to improve our understanding of interpersonal synchrony between exercisers, including effectiveness of the synchronization mechanisms and interpersonal and -device heterogeneity. Specifically, we examined the following research questions:

1. **Synchronization effectiveness:** Do these two mechanisms, i.e., visual gauge only vs. rhythmic cue

with visual gauge show differences on synchronization performance (e.g., perceived workloads and measured accuracy of synchronization)? Is there a significant difference on synchronization performance between exercise types?

2. **Synchronization between heterogeneous devices:** Do exercise types of a leader or followers have significant impact on synchronization performance? Will a pair with homogeneous exercise show better performance than that with heterogeneous exercises?
3. **User experience:** What kind of affordance does our system provide to users through interpersonal synchrony? Are there any differences on user experiences, e.g., intrinsic motivation, engagement, entitativity and attentional focus, between two synchronization mechanisms?

We answer these research questions by conducting three different experiments specifically focusing these questions. In the rest of this section, we first share the design of the three experiments and then report the results and findings.

Experimental Design 1

The first experiment is performed mainly to see the effectiveness of the proposed system in synchronization. We select two rhythm presentation methods, i.e., audio-visual rhythmic cue with a frequency rate gauge and the case only with a frequency rate gauge, and measure the workloads as seen by the exercisers and the accuracy of synchronization.

Participants and Apparatus

For this study, 40 participants (19 females and 21 males) were recruited on campus from the age group of 18 to 28. All of them had (corrected-to-) normal vision and hearing. During the recruitment, we announced that the participants should specify one exercise type in which they are skillful enough, among the four exercise types we stated earlier. As a result, we set four exercise-specific groups and each group consists of ten participants. The participants went through a training session for about 5 to 20 minutes in order to familiarize themselves with the way to naturally change their exercising speed. During the training session, we measured the preferred range of repetition frequency (f_{min_i} , f_{max_i}) for each participant.

To detect the exercise rhythm of two players in a pair, we used the smart shoes and vests, and the sensor-enabled stationary cycles that we described earlier. We chose off-the-shelf hula hoops and jump ropes. The dimension of a hula-hoop is about 95cm in diameter, and 500g in weight. The jump rope is about 100g in weight (including handles and a rope) and the maximum length of this rope is 270cm. We used FITEX-670U stationary cycles in which we attached the rhythm detectors. Lastly we used Frevola-T7A interactive treadmills which adjust the speed automatically on the basis of the players' current running paces [1]. To provide audio-visual information, we used 23-inch LCD screens (resolution of 1920x1080) and Samsung HS3000

stereo Bluetooth headsets. The headsets are utilized to provide auditory stimulation as well as a shared voice channel between two participants in a pair.

Tasks

We made two types of experimental tasks which are different in rhythm presentation methods: (1) an audio-visual rhythmic cue with a frequency rate gauge (Figure 5a) and (2) the case only with a frequency rate gauge (Figure 5b). Participants experienced each type of tasks for five times subsequently, and the sequence of the task types is counter-balanced.

For each task, a participant receives a workout program including five representative frequencies, namely 10%, 30%, 50%, 70%, and 90% point in the preferred repetition frequency range (f_{min_i} , f_{max_i}). The workout program is designed to have 2 minutes of total duration, consisting of 8 sections, each with 15 seconds. Each section has one of the representative frequencies, and the participant is informed of the frequency information through the rhythmic cue and/or the frequency rate gauge. We carefully randomized the frequency rates over the sections, while letting the participants experience all frequency rates. Also, we had the participants to experience all possible frequency transitions (i.e., $\pm 20\%$, $\pm 40\%$, $\pm 60\%$ and $\pm 80\%$) at least once in a workout program. (As this experiment investigates the effectiveness of rhythmic cues in synchronization, it was originally designed to be performed for pairs of exercisers, namely a leader and a follower. However, with the initial design, it was difficult to sort out the effectiveness clearly since the results were affected by the leaders' stability as well as the followers' synchronization efforts. This current design is a revised version to sort out and focus on the synchronization efforts, in which each follower attempts to synchronize to the system providing the leader's frequencies.)

After performing each task, participants were asked to answer a questionnaire for subjective workload assessments. We used the NASA-TLX (Task Load Index) [16]. It consists of six items: Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort Level and Frustration Level. Because the task explicitly defines the duration, we omitted Temporal Demands and used other five items. Each item has a five-point Likert scale, ranging from Very Low (1) to Very High (5). We also logged the exercise data and calculated *degree of asynchrony* [10] (DoA), defined as the sum of the differences between each participant's current frequency rate and the target frequency rate over a time period.

Experimental Design 2

This experiment is performed to see the effectiveness of the rhythmic cue over different exercise types.

Participants and Apparatus

Similar to the first experiment, 20 participants (8 female and 12 male) were recruited on campus from the age group of 18 to 29. To closely examine differences on user

experiences between different exercise types, we chose two exercise types, stationary cycle and hula hoop, which have different characteristics in terms of the controllability to follow a given frequency rate, and shows the best and worst performance, respectively. (See the result of the first experiment.) We set two exercise-specific groups and each group consists of ten participants. We also let the participants go through a training session and measured the preferred frequency ranges. We used the same devices in this experiment as we used in the first experiment.

Tasks

In this experiment, we focus on followers' experiences and accuracies when using different exercise types. Therefore, we made two types of tasks which are different in a leader's exercise type, i.e., stationary cycle and hula hoop. All participants experienced each type of the leader's exercise for five times subsequently, and the sequence of the leader's exercise types is counter-balanced.

To control the variability on the leader's skillfulness, condition and stamina effect, we used pre-recorded workout programs obtained from the first experiment. During the first experiment, we precisely recorded all of the frequency changes of participants with timestamps during tasks. We carefully examined the recorded files and chose five representative ones for hula hoop and stationary cycle. These representative log files, namely pre-recorded workout programs, have the most similar characteristics with the exercise types, in terms of degree of asynchrony (DoA) values. In this experiment, we implemented a recorded log-file playback application and let participants to follow the pre-recorded workout programs. Duration of a program is two minutes, as they are recorded from the first experiment. After performing each task, participants were asked to answer the same questionnaires (5 items from NASA-TLX), and we logged the exercise data and calculated DoA values.

Experimental Design 3

The goal of this experiment is to understand the user experiences with two different assistive mechanisms by using various psychology metrics.

Participants and Apparatus

For this study, 7 pairs of students, 14 students in total (6 female and 8 male), were recruited on campus from the age group of 19 to 28 (average: 23.3, SD: 2.97). To mimic realistic social exergame scenarios, we encouraged the participants to join the study with people whom they were familiar with. We let the participants go through a training session and measured the preferred frequency range as we did in the two previous experiments. We also used the same devices as in the previous experiments. After the training session, each participant went into different exercise rooms that are about 50 meters apart.

Tasks

We let participants experience two roles (i.e., leader and follower) with two different rhythm presentation methods:

(1) audio-visual rhythm cue, and (2) the gauge only. The sequence of the task types is counter-balanced. We went through a pilot test with two pairs of participants to validate the experiment configuration. Reflecting a feedback to enhance the social presence of the leader, we decided to use low frequency sounds of drum beats.

Each task session lasts 5 minutes and is composed of sub-sessions (each with 150 seconds). In the beginning of a task, a random participant takes the role of a leader and the other does the role of a follower. At the end of the first sub-session, our software automatically switches the roles and announces that their roles have just been changed. We did not provide any workout program to the participants to create realistic exergame environments; e.g., naturally discussing their workout plans and freely synchronizing their pace.

Since the goal of this experiment is to understand the user experiences, we decided to consider a scenario where two exercisers are working out on stationary cycles. We used the same devices in this experiment as we used in the first experiment. In addition, we used stereo headsets to provide a shared voice channel between two participants in a pair.

After performing each task, the participants were asked to answer a set of questionnaires including intrinsic motivation, focused attention, engagement, entitativity and perceived exertion rate. The details of the questionnaires will be presented in the following sub-section. After the questionnaire, we conducted a semi-structured interview to collect participants' experiences, including leader/follower roles, and rhythm representation.

Survey Metrics

The Intrinsic Motivation Inventory (IMI) [39] was used to assess participants' subjective experience related to a target activity. IMI has been widely used in user studies related to intrinsic motivation and self-regulation. Using this instrument, we mainly examined the following factors, namely interest/enjoyment (7 items), perceived competence (6 items), and felt pressure/tension (5 items).

Engagement Survey Instrument (ESI) was used to measure engagement or a quality of user experience [31]. Only the factors/items relevant to our study are used for evaluation: namely, focused attention (7 items), usability (7 items), endurance (4 items), and involvement (3 items).

The Attention Focus Questionnaire (AFQ) consists of 30-items of various attention behaviors that are rated on a seven-point scale after each session. The AFQ has three factors: (1) association that are task-related mental strategies (11 items; e.g. "monitoring specific body sensations", "focusing on staying loose and relaxed"), dissociation that are task-unrelated mental strategies (12 items; e.g. "singing a song in your head", "focusing on the outside environment"), and distress (7 items; e.g. "wishing the task would end", "thinking about how much you want to quit").

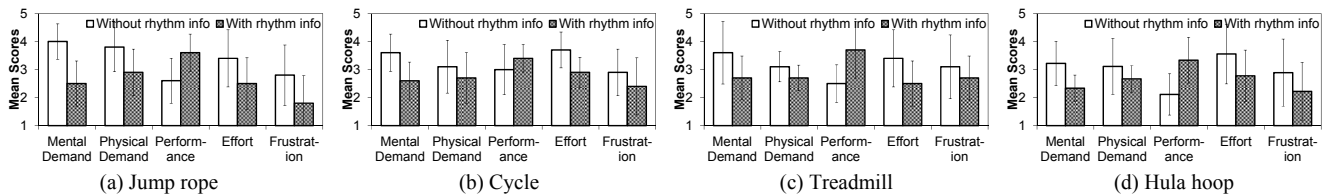


Figure 6. NASA-TLX questionnaire scores for each exercise type

	Mental demand	Physical demand	Performance	Effort	Frustration
(a) Exercise type - main effect, $F(3,72)$	$F=1.174, p=0.326$	$F=1.419, p=0.244$	$F=1.191, p=0.319$	$F=0.75, p=0.526$	$F=1.11, p=0.350$
(b) Cue type - main effect, $F(1,72)$	$F=37.878, p<0.001$ ***	$F=9.037, p=0.004$ **	$F=29.064, p<0.001$ ***	$F=17.11, p<0.001$ ***	$F=7.605, p=0.007$ **
(c) Interaction effect, $F(3,72)$	$F=0.574, p=0.634$	$F=0.423, p=0.737$	$F=1.242, p=0.301$	$F=0.02, p=0.996$	$F=0.315, p=0.814$

Table 1. Two-way ANOVA result (exercise type and cue type) on NASA-TLX questionnaire scores

The Borg Scale, a simple method of rating perceived exertion (RPE) has been widely used to gauge an individual's level of intensity in sports training. We use a RPE version with a 15-point scale that ranges from 6 to 20 where 7 is “very, very light” and 19 is “very, very hard.” Researchers showed that there is a strong correlation between RPE and physiological variables (e.g., 0.8-0.9 on heart rates) [8].

We measure entitativity (perception as a social unit) and rapport (an affective state of mutual attention and positivity) using Entitativity questionnaire (4 items) by Postmes et al. [35], and Rapport questionnaire (5 items) adapted from Puccinelli et al. [36]. Examples of entitativity items include feeling as a unit and acting in unison, and those of rapport items include feeling coordinated with each other and being aware of each other.

Experiment Results 1

The main effect of different cue types was found in all NASA-TLX subscales (See Table 1). The results show that when compared with the gauge, the rhythmic cue helped reduce the perceived task workloads of the participants. It is interesting to see that the rhythmic cue also decreases the perceived physical demand. Several users state why they gave high ratings on physical demand after performing the gauge task; the participants overly used their muscle to maintain constant speed when following the gauge. (It is important to note that the results are based on the subjective measures reported by users. The study at the current stage does not aim at providing rather objective measurement of the exercise intensities.) As for the Performance, users commented that they synchronized their body movements with the rhythm sound, and this gave the feeling they could perform better with the rhythmic cue. We also see the effect of the exercise type, but the result was not statistically significant.

We also tried to measure the accuracy of synchronization via degree of asynchrony (DoA) between the target speed (leader) and the following speed (follower). The result shows that the two cue types did not show significant differences over DoA. (See Table 2b) We further tested DoA over different exercise types. (See Table 2a), and main effect was found. The cycle shows the lowest value of DoA, and the hula hoop, the highest. For deeper analysis, we divided the synchronization times into two phases, i.e., the

adaptation and the retainment phase. We divided the duration of 15 seconds into two halves, considering the first half as the adaptation phase, and the second half the retainment phase. From this analysis as well, the cycle showed the best performance in both adaptation and retainment phases. For the adaptation phase, the other three exercises, jump roping, running, and hula hooping, showed similar DoA. For the retainment phase, cycling showed the best performance, jump roping and treadmill running being in the middle, and hula hooping the worst.

Players generally liked the case with the rhythm cue. Most of them felt easier and more comfortable in the case. They expressed many different reasons for their preference with the rhythm. Players mentioned that the rhythm helps concentration, gives the feeling of being together, gives more fun, is more intuitive, and is easier to check their own speed and to adapt, etc.

“I can easily prepare my breath by matching it with the rhythm, however, without it, it is easy to lose the breath”. [P3]

“With the gauge, I should have paid constant attention to maintain my tempo, and hence constant mental strain. I was not sure if I was doing well. With the rhythm, my objective became simpler; I needed to simply match my rope hitting the floor with the rhythm. In the beginning, I paid attention to both audio and visual rhythm. However, once I became in sync with the rhythm, I concentrate only on the sound”. [P11]

“I often lose my concentration. Without rhythm I become constantly blank. The rhythm helps concentration”. [P4]

However, several participants also indicated negative points of the rhythm.

“I needed to pay more attention with the rhythm since there is more information to process”. [P6]

“With the rhythm I felt much more comfortable. However, it still leaves slight obsession” [P10]

“The rhythm sound was sharp. While more comfortable, the sound gave stress when out of sync”. [P2]

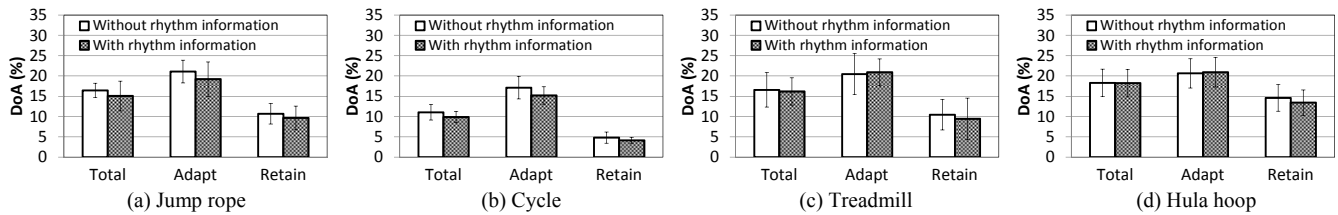


Figure 7. Degree of Asynchrony (DoA) values for each exercise type

	DoA (Total)	DoA (Adapt)	DoA (Retain)
(a) Exercise type - main effect, $F(3,72)$	$F=24.177, p<0.001$ ***	$F=7.704, p<0.001$ ***	$F=31.577, p<0.001$ ***
(b) Cue type - main effect, $F(1,72)$	$F=1.209, p=0.275$	$F=0.957, p=0.331$	$F=1.877, p=0.175$
(c) Interaction effect, $F(3,72)$	$F=0.210, p=0.889$	$F=0.667, p=0.575$	$F=0.022, p=0.996$

Table 2. Two-way ANOVA result (exercise type and cue type) on DoA values

Experiment Results 2

Table 3 shows the results for TLX questions and the DoA. We tested the answers with 2-way ANOVA. For the Mental Demand, the main effects were found neither from followers' nor leaders' exercise types. As for the Physical Demand, the main effect was found for the follower's type; following with hula hoop shows lower values than when following with cycles ($F(1,36)=9.081, p<.01$). For the Performance, on the contrary, the main effect was found for leader types. The perceived performance of cyclists was highly affected by leaders' exercise type, whereas that of hula hoopers was not: the leaders' effect: $F(1,36)=22.253, p<.001$, the followers' effect: $F(1,36)=4.846, p<.05$. Hula hoopers also expressed difficulties as followers. It is interesting that a user (cyclist 3) commented the following:

"I could follow well, but it was difficult because the leader changed his speed (frequency) too often". [P8]

However, in this case, the interaction effect is significant: $F(1,36)=8.011, p<.01$. In the case of cyclists, Figure 7 (left) clearly shows this effect: homogeneous configuration (cycle-cycle) performs much better than heterogeneous configuration (hula hoop-cycle).

As for Effort, the main effect was not found, but the average Effort value is quite higher than that in Experiment 1. Several people commented that it was quite 'stressful' and requires more effort since the target value was continuously changing. This in part explains why Mental Load does not show statistically significant differences.

As for Frustration, following hula hoop's rhythm is more difficult than following cycle's rhythm ($F(1,36)=5.769, p<0.05$).

As for DoA, the main effect was found with the followers' exercise type ($F(1,36)=89.641, p<.001$). It was also affected by leaders' exercise type ($F(1,36)=5.786, p<.05$). The cycle followers can quickly adapt to the changes regardless of leader's exercise type (Figure 7(right)). In contrast, the hula hoop followers are less responsive (lower controllability as predicted in Experiment 1, see Figure 7), meaning that their DoA is much greater than that of cyclists.

From the experiment, we conclude that a leader's exercise type (e.g., cycle vs. hula hoop) is a critical factor on the perceived workload. This is also supported by the results of exit interviews; most of the participants answered that they

prefer synchronizing with a leader with less speed fluctuation. The results of average error rates in Experiment 1 show that the highest and lowest speed fluctuation is given as hula hoops and cycles, respectively. The controllability of an exercise device (i.e., lower fluctuation or error) does not always guarantee lower perceived workload; when the followers use highly controllable devices, a leader's fluctuation level determines the followers' perceived physical workload. For followers with highly controllable devices, homogeneous exercise configuration always results in better perceived workloads (e.g., C-C > H-C); in contrast, for the followers with less controllable devices, homogeneous exercise configuration does not always result in better perceived workloads (e.g., H-H < C-H) due to the aforementioned reasons.

Experiment Results 3

We conducted reliability analysis on IMI, ESI, AFQ, Entitativity, and Rapport questionnaires. The Cronbach's alpha was 0.729, 0.954, 0.806, 0.925, and 0.932, respectively. It is widely accepted that when the Cronbach's alpha value is greater than 0.7, the results are assumed to be very reliable.

In IMI, the subscale of interest/enjoyment and competence were statistically significant ($t(13)=2.76, p<0.01$, $t(13)=2.66, p<0.01$, respectively). Note that some of the Interest/enjoyment items include "enjoyed doing this activity", "was fun to do"; some of the Competence items include "pretty good at this activity", "satisfied with my performance", etc. The subscale of pressure/tension (e.g., feel nervous, anxious, pressured, etc.) was not statistically significant, but its average value is slightly lower. This subscale is quite related to NASA-TLX's mental workload that was not statistically significant either.

In ESI, the subscales of focused attention, endurance and involvement were statistically significant ($t(13)=2.14, p<0.05$, $t(13)=2.35, p<0.05$, $t(13)=2.25, p<0.05$ respectively). Focused attention measures how much a participant focused on the activity; endurance measures whether the participants are likely to recommend this activity to others; involvements measures the participants' perceived feeling drawn to the activity. The perceived usability was not statistically significant ($t(13)=1.73, p=0.054$), but the average value of the rhythm cue was

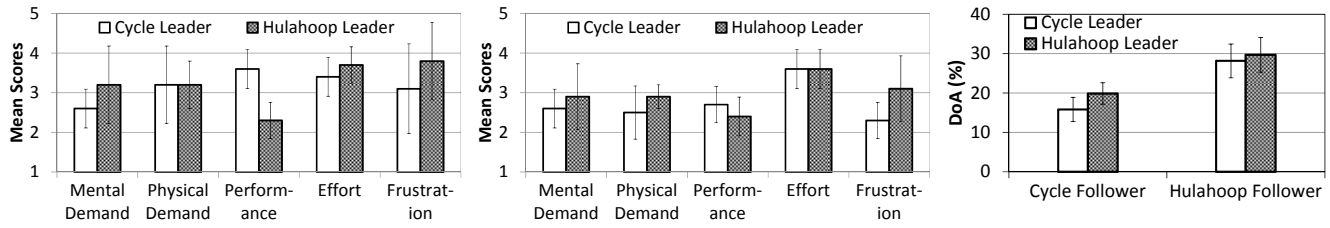


Figure 8: NASA-TLX questionnaire scores of cyclist followers (left) and hula hooper followers (center), and DoA values (right)

	DoA	Mental demand	Physical demand	Performance	Effort	Frustration
(a) Leader type - main effect, F(1,36)	F=5.786, p=0.021 *	F=3.329, p=0.076	F=0.363, p=0.551	F=22.253, p<0.001 ***	F=0.095, p=0.760	F=5.769, p=0.022 *
(b) Follower type - main effect, F(1,36)	F=89.641, p<0.001 ***	F=0.041, p=0.851	F=9.081, p=0.005 **	F=4.846, p=0.034 *	F=0.095, p=0.760	F=2.077, p=0.158
(c) Interaction effect, F(1,36)	F=1.139, p=0.293	F=0.041, p=0.851	F=1.009, p=0.322	F=8.011, p=0.008 **	F=0.853, p=0.362	F=0.026, p=0.874

Table 3 Two-way ANOVA result (exercise type and cue type) on DoA values and NASA-TLX questionnaire scores

slightly greater than that of the gauge cue. In general, the participants believe that the rhythm cue helps better engage in the paced exergames.

In AFQ, only distress subscale was statistically significant ($t(13)=-2.38, p<0.05$). This result is in line with NASA-TLX values, meaning that interpersonal synchrony with a rhythm cue is less demanding. The association subscale was not statistically significant; participants were able to equally concentrate on the task related items in both cases. The dissociation (or distraction) subscale was not statistically significant either, but it appears that the rhythm cue were able to slightly lower potential distraction.

RPE measures the perceived exertion, and the result shows that a rhythm cue’s RPE is lower than a gauge cue’s RPE ($t=-1.99, p<0.05$). Due to lower distress factor (AFQ, distress subscale) and task workloads (NASA-TLX), participants may feel that perceived exertion would be lower with a rhythm cue.

Finally, the results of social aspects, namely entitativity and rapport were not statistically significant ($t(13)=0.54, p=0.299, t(13)=-0.036, p=0.486$). Nonetheless, the rhythm cue has a slightly higher entitativity value on average partly due to coordinated movements. Interestingly, when we ask the participants to compare the results with the case where only real-time videos are available (without any of these assistive mechanisms), we find that the levels of entitativity and rapport were much lower than assistive mechanisms for interpersonal synchrony. In other words, tightly coupled collaboration in the virtual game can potentially provide enough rapport/entitativity, regardless whether participants are in complete synchronization (in-phase).

Post-experiment Interview Results

We conducted post-experiment interviews to (1) study the different user experiences depending on the roles, i.e., the leader and the follower, and to (2) understand the effects from the use of the gauge alone, and plus the rhythm.

Overall, we could observe quite even votes on both roles in terms of user preference; 7 participants preferred playing as a leader, 6 as a follower, and 1 equally liked both. Most of the preferences on being a leader came from its relative

simplicity, mental freedom, and feeling of comfort. The participants’ comments elaborate those such as

“I like playing as a leader because I feel free and independent”. [P10] and

“I understand that I was supposed to give guidance to the followers, but I soon found myself doing exercise at my own pace”. [P5]

We received minor opinions stating the difficulties of being a leader as well, such as

“Every single moment, I kept focusing on giving my follower proper exercise speeds and fun. That’s why I frequently changed my pace, but it made me soon exhausted”. [P11] and

“I feel pressure in the leader’s responsibility to guide the follower”. [P14]

On the other hand, notable comments on being a follower were regarding the feeling of achievement and the effectiveness of workouts, such as

“I think being a follower gives me more fun, because I feel I’m fulfilling some goals especially with the rhythmical cues”. [P7] and

“I feel I’m doing more exercises when I play as a follower”. [P6]

Interestingly, two participants preferred being a follower mainly because they felt more comfortable when simply following the leader’s guidance, while many responded that being a follower was more difficult as it required extra attention to meet the guidance.

In either role, the participants mostly agreed that the conversation was quite beneficial. Notably, we could hear from two participants respectively that,

“Talking to each other makes me forget the pain of exercise. Even I got the sympathy that I am not the only one feeling hard, which encouraged me a lot”. [P7] and

“At first it was weird for me to play separately from each other. But as I keep talking to him and pacing with him, I was no longer aware of such a feeling”. [P8]

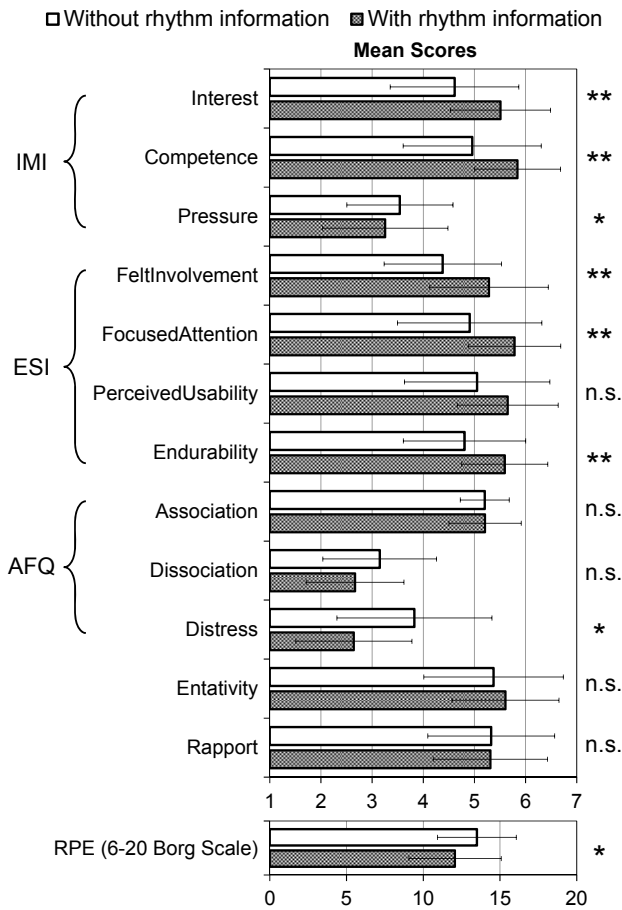


Figure 9. Mean scores of questionnaires for two cue types

From the comparative interviews regarding the gauge and the rhythm, we could understand that using the rhythm effectively facilitated easier plays, while notably, solely using the gauge stimulated unique fun originating from the higher challenges. Many leaders agreed that, with rhythms, they felt that their followers did better in keeping the paces closely. Similarly, many followers stated that the rhythms made it very simple to follow the leader’s guidance. A brief comparison was that,

“The gauge is like something I watch and then follow, but the rhythm is just what I feel!” [P14]

A participant elaborated,

“With listening to the rhythms, I found myself already got synchronized. (...) With the gauge alone, I had to concentrate on it and think more”. [P1]

However, we also received a few noteworthy opinions regarding the fun in using the gauge alone, such as

“Without the rhythms, my follower asked me more questions. Well, eventually it was very interesting that we could talk a lot to each other”. [P7] and

“I think keeping eyes on the gauge was more intuitive for me to find out the leader’s intent”. [P11]

It was interesting to observe the opposing effects of using the rhythms. A participant commented,

“It was a great fun to me when I get the exact sync with the rhythmical sounds. But it was so annoying when I was out of beats!” [P3]

A pair of participants gave very different comments; one said,

“I felt more comfortable to have signs to which I can conform” [P12]

But the other said,

“I felt more comfortable to have only the gauge, because the rhythms are more like extra information for me to keep aware of”. [P10]

DISCUSSION

The user study results show that when compared with speed gauge cues, the rhythm cues lower the perceived workloads (NASA-TLX) with less distress (AFQ) and have positive impacts on perceived competence (IMI), performance (NASA-TLX), and involvement (EQ). We think that the mental and physical workloads will be an important factor on game performance and user experience, and should be thoughtfully considered in exergame design. Exergame players frequently perform multiple tasks simultaneously. A game is often designed with multiple different gaming devices (e.g., various game items, map structure, game rules) on top of a core game mechanic (e.g., exercising speed and interpersonal synchrony), which interact with each other, creating and enriching additional fun factors and new gaming experiences. For example, a player may concurrently perform one task of controlling exercise interfaces (e.g., maintaining synchrony), and another task of keeping track of game plays (e.g., making decisions on what items to take in a game) under a highly competitive situation. These tasks make players experience divided attention and impose continuous demands on the attention, potentially resulting in *dual-task interference*; performance gains on one task will come at the cost of performance deterioration on the other [51]. This relationship implies that lowering the mental and physical workloads of synchrony may have a positive effect on game performance and user experience, and allows more freedom to explore in game design. It is part of our future work to thoroughly investigate the impact of dual-task interference in exergame design; one way is to design a set of experiments in which participants perform elementary cognitive tasks relevant to exergame design (e.g., recall, pattern recognition, spatial awareness, perception/reaction) while continuously maneuvering exertion interfaces (e.g., adaptation, retainment tasks).

ExerSync provides a useful tool for gamifying existing group exercises/sports where leader-follower roles are rather clear, and interpersonal synchrony is important. Several game design scenarios include enabling online group exercises such as virtual rowing/spinning classes, and designing collaborative/competitive games out of group exercises with diverse exercising modalities. For example, in the design of a boat racing game, a virtual coxswain

(leader) guides the rest of rowers (followers), and there could be multiple teams competing with one another.

As briefly mentioned earlier, a rhythm of body movements has two key factors, namely speed and phase. So far existing exergames use only exercise speed as game input from exercise devices. While we have not tested its feasibility, we discuss how phase information can be used as an additional game input. Interestingly, there are few convincing game design scenarios where the phase information can be used. For instance, in rowing, it is obvious that in order to achieve maximum speed, the crew must perfectly synchronize their rowing strokes (i.e., in-phase synchronization). In this case, the physics of rowing should be incorporated in the exergame design such that detailed rowing strokes dynamically determine boat movements.

For efficient rhythm coordination, the leader should be aware of the rhythm of followers. In the current design, the leader can only monitor the follower's status from the speed gauge. Yet, this activity would be cognitively demanding as the size of a group increases—there will be too many speed bars in a gauge. It is part of our future work to design intuitive and scalable mechanisms for delivering group status information. In a boat racing game, a good alternative would be animating each crew's rowing strokes such that the leader can instantly tell whether the crew members are performing well.

When knowing that both players are exercising with difference devices, some of our participants felt that interpersonal synchrony with heterogeneous exercises provides less social support than that with homogeneous exercises. One way of improving social affordance is to introduce a virtual avatar that animates translated rhythm; e.g., the rhythmic movements of a cyclist can be translated into a virtual avatar running on a treadmill at the cyclist's speed. An alternative method would be designing a game scenario that provides immersive social experience; in a boat racing game, we allow the crew members to directly maneuver the rowing strokes of virtual avatars.

In ExerSync, the software architecture of synchronization is based on a client-server model as in network time synchronization (NTP) [24], where exercise gamers (clients) exchange messages through the game server. Each cycle of a leader's rhythm (or gait phase) has a sequence number, and this rhythm information is broadcast to the followers with arbitrary network latency. The game server coordinates the rhythm responses from the followers on the basis of sequence numbers such that the leader can have a consistent view. In ExerSync, the worst case end-to-end round trip time (RTT) along the path of leader-server-follower is critical for group synchronization; e.g., a follower with one way latency of 150ms (comparable to 3G network latency) will always see a leader's rhythm generated 150ms ago. Fortunately, in ExerSync the time scale of interpersonal synchronization is usually much greater than that of network latency, and thus, players

would be less sensitive to the network latency. In most exercises, changing a rhythm takes at least few seconds; e.g., cycles take around 2-3 seconds, and hula hoops take around 4-5 seconds. We believe that the network configuration of our user studies was no significant impact on user experiences since we used campus wireless LAN whose worst case RTT was smaller than 10ms. It is part of our future work to systematically investigate user experience under different network delay/jitter conditions in a controlled environment using Dummynet [22].

LIMITATION

The participants of user studies were mostly drawn from the university population (average age: 21.7, SD: 3.06). We recruit the study participants through campus bulletin boards and participants' referrals, indicating that the experiments involve equipment-based exercises, and the participants should be comfortable with maneuvering a chosen exercise device. This homogeneous selection of participants (who are likely young and fit) can provide an internal validity of experiments, but this would restrict the generalizability of findings. Whether our main findings are transferrable to other populations remains to be determined.

Given that only short-term experiments were carried out, we cannot determine whether ExerSync usage influences the long-term motivation. Yet, our user study results show the positive effects such as lowering the mental/physical load and distress, improving interest/enjoyment and competence, which may lead to improved long-term motivation. As reasonable as this interpretation may seem, direct confirmation requires a longitudinal study.

As it is currently, our primary interest lies in investigating the effectiveness of a rhythm cue in synchronization under group exercise environments. Our study currently does not investigate the exercise benefits of interpersonal synchrony (e.g., improved endurance, burnt calories). To this reason, the user studies are mostly composed of a series of short exercise sessions where each session takes about two minutes to complete. In the user study with five minute sessions, we asked the participants to report rating of perceived exertion (RPE) to roughly see whether the exercise amount differs between rhythm cue and speed gauge conditions—RPE is a good metric as it is highly correlated with heart rates [8]. The results show that RPE values were statistically significant, and there may be some difference between these conditions. A thorough investigation must be followed to validate whether there are the exercise benefits of interpersonal synchrony (e.g., running exhaustive tasks).

CONCLUSION

We proposed the ExerSync platform that supports various assistive mechanisms of facilitating interpersonal synchrony and handles inter-person and -device heterogeneity. In this paper, we detailed the core components of ExerSync, namely Exercise Rhythm Extractor, Rhythm Translator, and Audio-visual Rhythm. For rhythm extraction, we analyzed four kinds of repetitive

aerobic exercises, namely rope jumping, hula hooping, stationary cycling and treadmill running and designed novel mechanisms for extracting major phases within the movement cycles. Rhythm translation mechanisms are based on a leader-directed model of group synchronization for fast convergence and efficiently handle inter-person and -device heterogeneity. The extracted rhythm of the leader is broadcast to the followers using thoughtfully designed audio/visual rhythm cues such that they can effectively coordinate their movement cycles. We built the prototype platform and validated the feasibility and effectiveness of synchronizing rhythm via extensive user studies.

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REFERENCES

- Ahn, M., Kwon, S., Park, B., Cho, K., Choe, S., Hwang, I., Jang, H., Park, J., Rhee, Y., and Song, J. Running or gaming. *In Proceedings of the International Conference on Advances in Computer Entertainment Technology*, ACM (2009), 345-348.
- Ainsworth, B., et al. Compendium of physical activities: an update of activity codes and met intensities. *Medicine & Science in Sports & Exercise* 32, 9 (2000), S498.
- Akoumianakis, D., Vellis, G., Milolidakis, I., Kotsalis, D., and Alexandraki, C. Distributed collective practices in collaborative music performance. *In Proceedings of the 3rd international conference on Digital Interactive Media in Entertainment and Arts*, ACM (2008), 368-375.
- Alexandraki, C., and Akoumianakis, D. Exploring new perspectives in network music performance: The diamouses framework. *Computer Music Journal* 34, 2 (2010), 66-83.
- Arias, P., and Cudeiro, J. Effects of rhythmic sensory stimulation (auditory, visual) on gait in parkinson's disease patients. *Experimental Brain Research* 186, 4 (2008), 589-601.
- Ashton-James, C., Van-Baaren, R., Chartrand, T., Decety, J., and Karremans, J. Mimicry and me: The impact of mimicry on self-construal. *Social Cognition* 25, 4 (2007), 518-535.
- Bernieri, F. Coordinated movement and rapport in teacher-student interactions. *Journal of Nonverbal behavior* 12, 2 (1988), 120-138.
- Borg, G.A. and others. Psychophysical bases of perceived exertion. *Med sci sport exerc.* 14, 5 (1982), 377-381.
- Carroll, E., Lottridge, D., Latulipe, C., Singh, V., and Word, M. Bodies in critique: a technological intervention in the dance production process. *In Proceedings of the CSCW 2012*.
- Chen, Y., Repp, B., and Patel, A. Spectral decomposition of variability in synchronization and continuation tapping: Comparisons between auditory and visual pacing and feedback conditions. *Human Movement Science* 21, 4 (2002), 515-532.
- Cluff, T., Robertson, D., and Balasubramaniam, R. Kinetics of hula hooping: An inverse dynamics analysis. *Human movement science* 27, 4 (2008), 622-635.
- Fraser, S.N. and Spink, K.S. Examining the role of social support and group cohesion in exercise compliance. *Journal of behavioral medicine*.25.3, (2002), 233-249.
- Gavin, J., McBrearty, M., and Seguin D. The psychology of exercise, IDEA Health & Fitness Source. 3. 2 (2006).
- George, B. Visual metronome, 1987. US Patent 4,649,794.
- Haidt, J., Seder, J., and Kesebir, S. Hive psychology, happiness, and public policy. *The Journal of Legal Studies* 37, S2 (2008), S133-S156.
- Hart, S., and Staveland, L. Development of nasa-tlx (task load index): Results of empirical and theoretical research. *Human mental workload 1* (1988), 139-183.
- Hove, M., and Risen, J. It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition* 27, 6 (2009), 949-960.
- Karageorghis, et al. Psychophysical and ergogenic effects of synchronous music during treadmill walking. *Journal of sport & exercise psychology*.31, (2009), 18-36.
- Karvitz, L. Exercise Motivation: What Starts and Keeps People Exercising? <http://www.unm.edu/~lkravitz/Article%20folder/ExerciseMot.pdf>, (2011).
- Lakens, D. If they move in sync, they must feel in sync: Movement synchrony leads to attributions of rapport and entitativity. *Social Cognition*. 29. 1, (2011), 1-14.
- Lee, B. Jump Rope Training-2nd Edition. 2010. <http://www.humankinetics.com/excerpts/excerpts/learn-three-phases-of-rope-jumping>.
- Luigi Rizzo. The Dummynet project. <http://info.iet.unipi.it/~luigi/dummynet/> (2009).
- McNeill, W. Keeping together in time: Dance and drill in human history. Harvard Univ Pr, 1997.
- Mills, D.L. Internet time synchronization: The network time protocol. *Communications, IEEE Transactions on*.39.10(1991) 1482-1493.
- Miles, L., Nind, L., and Macrae, C. The rhythm of rapport: Interpersonal synchrony and social perception. *Journal of experimental social psychology* 45, 3 (2009), 585-589.

26. Mueller, F., Stevens, G., Thorogood, A., O'Brien, S., and Wulf, V. Sports over a distance. *Personal and Ubiquitous Computing* 11, 8 (2007), 633-645.
27. Mueller, F., Vetere, F. and Gibbs, M. The Design of Networked Exertion Games. *J. of Virtual Reality and Broadcasting*.5.13, (2008).
28. Mueller, F., Vetere, F., Gibbs, M., Edge, D., Agamanolis, S., and Sheridan, J. Jogging over a distance between europe and australia. In *Proceedings of the 23rd annual ACM symposium on User interface software and technology*, ACM (2010), 189-198.
29. Mueller, F., Vetere, F., Gibbs, M., Edge, D., Agamanolis, S., Sheridan, J., and Heer, J. Balancing exertion experiences. In *Proceedings of the 2012 ACM CHI*, ACM (2012), 1853-1862.
30. O'Brien, S., and Mueller, F. Jogging the distance. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM (2007), 523-526.
31. O'Brien, H.L., Toms, E.G., Kelloway, E.K. and Kelly, E. Developing and evaluating a reliable measure of user engagement. *Proc. of the American Society for Information Science and Technology*, 2008
32. Park, T., Hwang, I., Lee, U., Lee, S., Yoo, C., Lee, Y., Jang, H., Choe, S., Park, S., and Song, J. Exerlink: enabling pervasive social exergames with heterogeneous exercise devices. In *Proceedings of the ACM MobiSys*, ACM (2012), 15-28.
33. Park, T., Yoo, C., Choe, S., Park, B., and Song, J. Transforming solitary exercises into social exergames. In *Proceedings of the ACM CSCW 2012*, ACM (2012), 863-866.
34. Pikovsky, A., Rosenblum, M., and Kurths, J. *Synchronization: A universal concept in nonlinear sciences.* Cambridge Univ Pr, 2003.
35. Postmes, Social Identity Formation and Team Performance. University of Groningen (2008).
36. Puccinelli, N.M., and Tickle-Degnen, L. Knowing too much about others: Moderators of the relationship between eavesdropping and rapport in social interaction. *Journal of Nonverbal Behavior*. 28. 4 (2004), 223-243.
37. Reidsma, D., Nijholt, A., and Bos, P. Temporal interaction between an artificial orchestra conductor and human musicians. *Computers in Entertainment (CIE)* 6, 4 (2008), 53.
38. Repp, B., and Penel, A. Rhythmic movement is attracted more strongly to auditory than to visual rhythms. *Psychological Research* 68, 4 (2004), 252-270.
39. Ryan, R.M. Control and information in the intrapersonal sphere: An extension of cognitive evaluation theory. *Journal of personality and social psychology*. 43. 3 (1982), 450.
40. Schmidt, R.C., Bienvenu, M. Fitzpatrick, P.A and Amazeen, P.G. A comparison of intra-and interpersonal interlimb coordination: coordination breakdowns and coupling strength. *J. of Experimental Psychology : Human perception and Performance*.24.3, (1998), 884.
41. Schmidt, R.C. and Turvey, M.T Phase-entrainment dynamics of visually coupled rhythmic movements. *Biological cybernetics*.70.4, (1994), 369-376.
42. Schmidt, R., and Richardson, M. Dynamics of interpersonal coordination. *Coordination: Neural, behavioral and social dynamics* (2008), 281-308.
43. Stach, T. Graham, T.C. Yim, J. and Rhodes, R.E. Heart rate control of exercise video games. *Proceedings of Graphics interface 2009*, Canadian Information Processing Society, (2009), 125-132.
44. Stach, T. and Graham, T. Exploring haptic feedback in exergames. *Human-Computer Interaction—INTERACT 2011*. (2011), 18-35.
45. Stein, N. Jumping rope vs. kettlebells, 2011. <http://www.livestr ong.com/article/552088-jumping-rope-vs-kettlebells/>.
46. Stel, M. Effects of mimicking: acting prosocially by being emotionally moved, 2007. <http://onlinelibrary.wiley.com/doi/10.1002/ejsp.472/abstract>.
47. U.S. Department of Health and Services, *Physical activity and health: a report of the Surgeon General*. (1996).
48. Valdesolo, P., and DeSteno, D. Synchrony and the social tuning of compassion. *Emotion* 11, 2 (2011), 262.
49. van Baaren. *Mimicry and pro-social behavior*, 2004. <http://pss.sagepub.com/content/15/1/71.short>.
50. Weir, J. How to calculate calories burned with a hula hoop, 2011. <http://www.livestrong.com/article/89945-calculate-calories-burned-hula-hoop/>.
51. Wickens, C.D. The structure of attentional resources. *Attention and performance*.8 (1980).
52. Wilson, A., Snapp-Childs, W., Coats, R., and Bingham, G. Learning a coordinated rhythmic movement with task-appropriate coordination feedback. *Experimental brain research* 205, 4 (2010), 513-520.
53. Wilson, D., et al. Multilevel selection theory and major evolutionary transitions implications for psychological science. *Current Directions in Psychological Science* 17, 1 (2008), 6-9.
54. Wiltermuth, S., and Heath, C. Synchrony and cooperation. *Psychological Science* 20, 1 (2009), 1
55. Yim, J. and Graham, TC. *Proceedings of The 2007 conference on Future Play*. ACM, (2007), 166-173.
56. Zehr, E., Balter, J., Ferris, D., Hundza, S., Loadman, P., and Stoloff, R. Neural regulation of rhythmic arm and leg movement is conserved across human locomotor tasks. *The Journal of Physiology* 582, 1(2007), 209-227.
57. Zhao, N. Full-featured pedometer design realized with 3-axis digital accelerometer, 2010. http://www.analog.com/static/imported-files/tech_articles/pedometer.pdf.