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Tour de Tune - Auditory-game-motor synchronisation in Exergames

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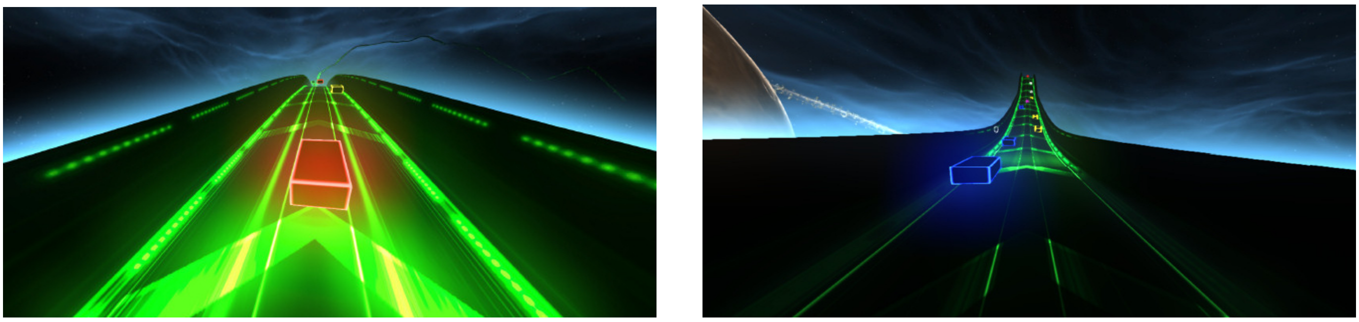

Figure 1: *A section of the cycling track generated from an intense music track. The track pulsates with the rhythm of the music and contains boxes (pick-ups) collectable by the player. The entire track is "lit up" if a player cycles with or above the beat of the music (top). If the player cycles below the beat of the music the lit up section moves ahead of the player (bottom).*

Abstract

Exergaming has been heralded as a promising approach to increase physical activity in hard-to-reach populations such as sedentary young adults. By combining physical activity with entertainment, researchers and developers hope that the excitement and immersion provided by a computer game will result in increased motivation and dissociation from the discomfort of physical exercise. A different approach to improve physical activity is the use of music. Music, in particular if synchronised with the rhythm of exercise, has been shown to increase performance and decrease the amount of perceived effort for the same performance. So far little research has been done on the combined effect of music and gameplay in exergaming.
In this paper we investigate the effect of game-music synchronisation for an immersive exergame. We present a simple yet effective music analysis algorithm, and a novel exergame enabling synchronisation of gameplay with the music's intensity. Our results indicate that our exergame significantly increases enjoyment and motivation compared to music alone. It slightly increases performance, but also increases perceived effort. We did not find any significant differences between gameplay synchronised and not synchronised with the music. Our results confirm the positive effects of music while exercising, but suggest that gameplay might have a bigger effect on exergame effectiveness, and more research on the interaction between gameplay and music needs to be done.

CCS Concepts

•***Computing methodologies*** → ***Virtual reality;*** •***Human-centered computing*** → *Virtual reality;* •***Applied computing*** → *Computer games; Health informatics; Sound and music computing;*

1. Introduction

Insufficient physical activity is a primary cause of most common chronic conditions such as obesity, type 2 diabetes, coronary heart disease, hypertension, stroke, cognitive dysfunction, depression and anxiety, and many others [BRL12]. Significant ongoing research is exploring novel ways to increase physical activity in at-risk populations, such as sedentary young adults [BOB11].

One approach is the use of dissociation to reduce thoughts and realisation of the physical discomfort and fatigue of the body while exercising [LWE09]. Music has been shown to achieve dissoci-

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ation and increased enjoyment, even when physical effort is increased, whereas watching videos alone (without music) had no effect [JKE14].

Exergaming is experiencing increasing interest as an effective approach for increasing physical activity [GCPP15]. However, little work has been done investigating the effect of game-music interaction on exergames' effectiveness. In this paper we present a novel approach where the gameplay (track and rewards) is synthesised from the music. We investigate whether exergaming is more effective than music alone, and whether synchronisation between music and gameplay increases effectiveness.

2. Related Work

2.1. Effect of Music on Exercise Performance

Several authors report positive effects of music on exercise performance of untrained individuals. Brownley et al. found that music has a positive effect on untrained individuals, but a negative effect on trained runners [BMH95]. Trained runners use internal cues to monitor heart rate and exertion to be able to perform better while untrained individuals do enjoy the external distraction that music provides. Soltani and Salesi report that treadmill users exposed to audio ran further than those who weren't [SS13]. Stork et al. found that music enhances performance and perceived enjoyment of sprint interval exercise [SKGM15]. Karageorghis and Priest [KP08] report that music can influence exercise performance in five ways: dissociation, arousal regulation, synchronisation, acquisition of motor skills, and attainment of flow.

One important concept relevant to our research is the synchronisation of organisms to an external perceived rhythm - specifically, when integration between auditory and motor systems leasd to time-organised movement patterns in response to rhythm [CSW05]. Exercising with synchronous music reduces oxygen consumption and increases exercise performance when compared with asynchronous music and no music [SK06, KP12]. One suggested explanation is that synchronisation of repetitive movement cycles with music increases motor movement accuracy, leading to improved energy efficiency and work output [CBT15].

Of all components of rhythm, tempo is generally considered to give the most significant response [BNvR13]. Music exerts a general arousal effect on human heart rate, which might be regulated by tempo [vDSS*17]. Karageorghis et al. found that for treadmill walking exercises medium to fast tempo songs (120-140 bpm) were preferred, with fast tempo songs most popular for high intensity exercises (75% of heart rate reserve) [KJL06]. For treadmill running exercises Edworthy and Waring reported that tempo has a stronger effect than loudness, with the greatest increase in running speed occuring with fast, loud music [EW06]. Similar results were obtained by Oliver and Flores-Mangas who found that for a mobile exergame, which selects songs based on desired heart rate, run speed was related to a song's tempo [OFM06]. Kosogi et al. suggest that adjustment to tempo depends on users' familiarity with the tune [KSS*14]. Another important component of rhythm for exercises is syncopation, which occurs if rhythmic emphasis is placed off the main beat (often referred to as "groove") [Kar16].

2.2. Effect of Music on Exercising in VR Environments

Several authors have studied the effect of music when doing exercises in a virtual environment. Mestre et al. [MDM11] studied the effects of virtual reality (using a pre-recorded video) on enjoyment and dissociation during exercise on an exercise bicycle. The authors found that using a video increased dissociation from exercising, but motivation reduced quickly if the video was not accompanied with music. The authors speculated that this effect was due to the novelty of the music, which made subsequent runs of the same track different due to variations in the music.

Using a similar set-up Jones et al. [JKE14] found that both music and music-and-video were effective for dissociation and increasing enjoyment, but that video by itself was not particularly effective, and in fact resulted in the lowest mean heart rate. The video used in the study displayed a tranquil park cycle route, and did not vary in time with the cycling speed, i.e. there was no synchronisation present.

Some music-driven games have been very successful. The most famous example is arguably Dance Dance Revolution (DDR) [Hoy06], where players have to hit lit tiles with the rhythm of the music. Taylor et al. report that DDR has one of the highest energy expenditure of reviewed activity-promoting gaming systems and meets ACSM guidelines for physical activity [TMS*11]. However, such rhythm games do not extend to common exercises (cycling, walking and running), are often easy to cheat, and do not promote specific health outcomes. VR Exergames with specific health outcomes have been proposed [GCPP15], but none of them uses music to drive gameplay.

3. Design

In order to test the effect of game-music synchronisation, we developed an immersive exergame called *Tour de Tune*. The game is played on an exerbike while wearing a head-mounted display (see figure 2). The game's objective is to traverse a futuristic cycling track, and score as many points as possible by collecting pick-ups (collectable items represented as boxes distributed along the track). Pedalling is translated into a motion along the track, whereas position between the track's boundaries can be changed by leaning left and right. The cycling track and the locations of pick-ups are generated from a music file that the user can supply. The use of game elements requiring response to a visual or audio stimulus, and the fact that gameplay changes with different music tracks, has been designed to hold users' long-term attention [Sun13].

3.1. Music Analysis

In our application we want the virtual track's gradient to increase with the "intensity" of a song. We define intensity as the combination of tempo and music style, i.e. a rock song, such as "We will rock you" from Queen has a high intensity, even though its tempo is quite slow. The Fourier transform is a popular tool for time-frequency analysis, but is not suitable for our application since it only gives the strength of waves with frequencies which are an integer multiple of the sample rate n. To understand this limitation consider the difference in frequency between semitones:

$$2^{1/12} - 1 \approx 5.946\% \qquad (1)$$

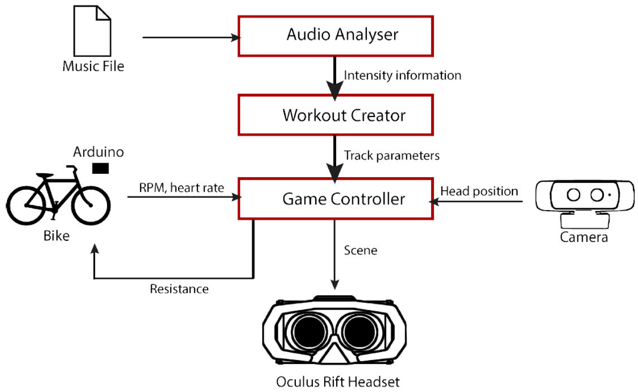

Figure 2: *Architectural Overview of* Tour de Tune.

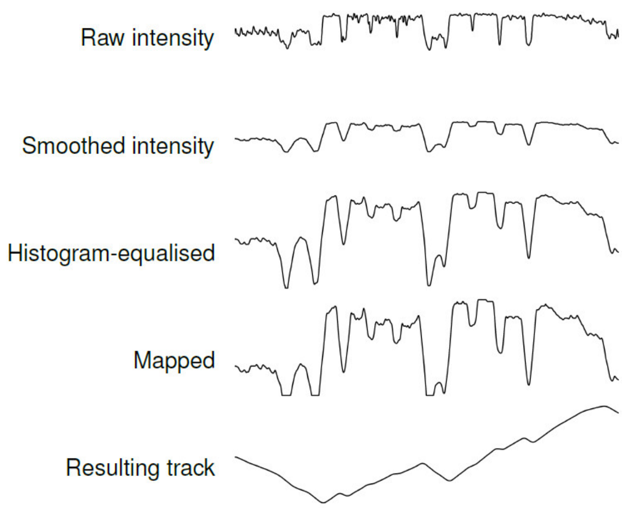

Figure 3: *Intermediate results of the algorithm for computing track gradient from a music track.*

Assuming a sample rate of 44100kHz, which is typical of a music recording, and assuming that the window size of the Fourier transform is 30Hz (1470 samples at 44100kHz), the difference between adjacent frequencies in the resulting frequency domain is 30Hz. This is smaller than the difference between semitones until between D5 and D#5 - below this point, rounding the Fourier transformed sample to the nearest semitone may not yield the correct semitone, and some more complex analysis would be required to accurately determine the correct note. In fact, D5 is in the middle range of musical notes, so this limitation severely affects the ability to detect the notes of bass lines.

We do not need to be able to reconstruct the original signal from the detected notes, hence our solution for detecting notes is to use a damped harmonic resonator tuned to each note, which is driven by the audio signal. The damping coefficient is tuned to attenuate the vibration at a rate proportional to the frequency of the note. This tuning means that the accuracy of the note frequency detection is effectively constant across the notes. The trade-off is poorer temporal accuracy with bass notes, because the sampling window is effectively wider for notes with a longer wavelength. This can be mitigated by choosing a damping coefficient which gives a window size just wide enough to accurately determine the note. The narrower the window, the better the temporal accuracy but the poorer the frequency accuracy. Using the resonator approach yields a runtime of $O(n \times m)$ for n samples and m notes, which is efficient enough to be performed in real time.

Percussion instruments, such as drums, tend to have a loud initial attack in their sound, with many frequencies excited at once. We detect the onset of such instruments by calculating the spectral flux using the L_1 norm and linear magnitude [Dix06].

Using these concepts we define the intensity as the weighted sum of the amplitude and "drum factor". This simple approach has the following desirable properties:

- Loud songs are more "intense" than quiet songs.
- Harmonic songs with a small range of notes, such as lullabies, are less "intense" than songs with wider frequency responses, such as heavy metal - even if equalised to the same amplitude.
- Songs with a higher tempo are more "intense" than songs with a lower tempo.

3.2. Track Generation

Research suggests that listening to intense music makes an intense workout more enjoyable - and vice versa, when listening to intense music, workout intensity can increase without a corresponding increase in perceived effort [SKGM15, BNvR13, KP12]. We hence procedurally generate a track where the gradient correlates with the intensity of music. An increased gradient results in an increased resistance of the exerbike and hence requires more effort from users. This approach to content creation is similar to that taken by the music games *Audiosurf* [Aud] and *Riffracer* [FOA]. A positive side effect of this game design is that track layout changes with each music track. This type of variation appeals to the *need for competence*, one of the mechanisms proposed by self-determination theory as a motivation for game-play [PRR10].

The track's gradient is computed from a music track as indicated in figure 3: First the music's intensity is computed using the algorithm described in subsection 3.1. The resulting data is then smoothed using a low pass filter. In order to account for different songs having different distributions of intensity, we perform histogram equalisation on the intensity values. Finally, the intensity values are converted to the cycling track's height profile using the equation

$$I_{mapped} = I^2_{equalised} - I_{offset} \tag{2}$$

where I_{offset} defines the intensity value corresponding to flat sections of the track. In order to achieve a smooth curve, height values are computed at half second intervals and interpolated using a B-Spline curve. We choose cubic B-Splines since they have C^2 continuity, are easy to compute, and each curve segment fulfils the convex hull property, i.e. in contrast to, say, Catmull-Rom splines, the curve segments always lie between the highest and lowest control point [WT04]. An example is shown in figure 1.

A potential problem in virtual reality applications is simulation sickness, e.g. due to sensory disconnect. This problem has been observed in exergames using tracks with ramps, in which case there is a conflict between users' visual perception (inclined position) and inertia perception (horizontal position) [SWL*15]. We address this problem by increasing gradients smoothly and by not providing a ground plane in our visual environment, i.e. the track is essentially floating in space. In our subsequent user study none of the participants reported any form of discomfort.

3.3. Music-dependent Game Elements

Aside from influencing the height profile of the cycling track, the music influences other parts of the game as well. For instance, the pick-ups (collectable items) are placed at the same rate as the song's beats-per-minute (BPM). The BPM also determines the players' target pedalling speed. The closer the player's pedalling cadence is to the song's BPM, the higher the score awarded for collecting a pick-up (represented by a box). The intention is to encourage the player to focus on the music, with the goal of drawing attention away from any feelings of tiredness or exertion.

As a final visual cue, the track itself glows with a spectrogram of the song. Drum beats cause this glow to pulsate and other features of the music cause various patterns (see figure 1). Again, the goal is to increase dissociation from the physical discomfort of exercises.

Since exercising with the beat of music can be particularly beneficial [KP12] we visually indicate this relationship. If a player is pedalling with or above the beat of the music, the track looks as indicated in the left image of figure 1. If the player's pedalling speed drops below the beat of the music, the lit up section of the track moves ahead of the player (right image of figure 1) giving a strong sense of "falling behind".

4. Implementation

Our prototype was implemented using the game engine Unity 5.2, due to its excellent documentation, active user community, supported hardware (e.g. Oculus Rift), native plug-ins, and free license for private use.

For the user study we used a PC with NVidia GTX 780 graphics card and a Lifefitness 95CI Upright Exercise Bike. The bike supports the CSAFE (Communications Specification for Fitness Equipment) standard, allowing the bike to communicate information such as speed and user heart rate to the computer.

Resistance was provided through the exercycle's inbuilt resistance mechanism, controlled by an Arduino micro controller. The Arduino was connected to the PC, and to the buttons on the exercycle which control the resistance. When changes in the track's gradient cause the resistance to change, the Arduino triggers button presses on the bike's console to increase or decrease the resistance. The head-mounted display used was an Oculus Rift DK2 and players' movements (leaning left and right) were tracked using a Creative Senz3D depth camera (see figure 2).

5. Evaluation

We performed a user study to investigate how the game affects performance, as well as whether synchronising the gameplay with the music has any effect.

5.1. Methodology

Our user study used three conditions, which were permuted using the Latin Square method to avoid bias from training effects or exhaustion:

1. Exergame synchronised with music (synch)
2. Exergame not in synch with music (asynch)
3. Exercycle with music only (music)

Before the exercise sessions participants supplied information about their fitness and virtual reality experience, as well as filling in the *Sports Orientation Questionnaire* (SOQ) [GD88]. Each user was asked to select two songs (maximum total length 10 minutes) that they found to be motivating.

In each condition, the participants cycled on an exercycle for the duration of the two songs, which were played in the same order each time. For the music condition, the participants pedalled on the exercycle while listening to the two songs they had selected. For the synch condition, the two songs were used to generate the cycling track. The participant wore a head-mounted display and headphones, and cycled along the track. Finally, the asynch condition was identical to the synch condition, except that the track was generated using the song's intensity profile in reverse order. This produced a track of the same length and difficulty, but there was no longer a correlation between the pick-up placement rate and song BPM, and the intensity of the song was no longer correlated with the gradient of the track.

After each condition, the participants filled out a questionnaire consisting of 11 questions selected from the *Intrinsic Motivation Inventory* (IMI) [Rya82], with 3 additional Likert scale questions about exhaustion and motivation, and a further 4 questions about the user's perception of the game level for the exergame conditions. The questionnaires concluded with open-ended questions to invite discussion about the three conditions. From the questionnaires, numerical values for perceived effort and perceived enjoyment were calculated by averaging the numerical responses for the questions categorised as pertaining to effort and enjoyment respectively

5.2. Hypotheses

We used the following hypotheses:

- **H1**: Both exergame conditions will have higher ratings of enjoyment than the music-only condition.
- **H2**: Both exergame conditions will have lower perceived effort than the music-only condition due to the dissociative effects of exergames.
- **H3**: The music-synchronised version of the exergame will be rated as more enjoyable and have a lower perceived effort than the unsynchronised version.

5.3. Participant Demographics

11 participants took part in the user study (9 male, 2 female). The age of the participants ranged from 20-26, with the mean and median age being 21.8 and 22, respectively. All but two participants had a "normal weight" according to the Body Mass Index (BMI) scale. The remaining two participants had an "overweight" BMI

Table 1: *Significance of differences for the three conditions "music and no game" (**M**), "game synchronised with music" (**S**), and "game not synchronised with music" (**A**)*

	M vs. A	M vs. S	A vs. S
Distance	$M < A$	$M < S$	$A > S$
p-value	0.153	0.504	**0.032**
Calories	$M < A$	$M < S$	$A > S$
p-value	0.098	0.354	0.132
Heart rate	$M < A$	$M < S$	$A > S$
p-value	0.389	0.365	0.885
Enjoyment	$M < A$	$M < S$	$A > S$
p-value	**0.001**	**0.001**	0.231
Motivation	$M < A$	$M < S$	$A > S$
p-value	**0.004**	**0.023**	0.207
Perceived effort	$M < A$	$M < S$	$A > S$
p-value	**0.005**	**0.035**	0.637

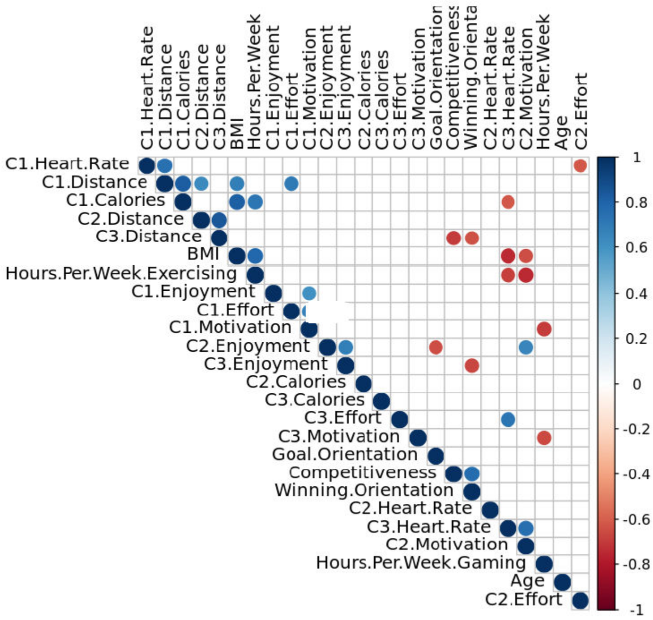

Figure 4: *Correlation Analysis with p-value* < 0.05. *The variables preceded by C1-C3 refer to data measured during the conditions C1-C3: 'Distance' is the in-game distance, 'Calories' is the calorie burned data as computed by the exercise bike, 'Heart rate' the heart rate as measured by the bike's in-built sensors, and 'Enjoyment', 'Motivation' and 'Effort' are Likert-scale data from the post-condition questionnaires. 'Goal orientation', 'Winning orientation' and 'Competitiveness' are measures obtained from the SOQ questionnaire and the remaining variables were obtained from the demographics questionnaire.*

measurement, however, both reported a high level of physical activity per week. The mean and median BMI was 23.3 and 23, respectively. Six of the 11 participants exercised for 2-4 hours each week, with three indicating no exercise and one reporting one hour of exercise per week. One participant reported in excess of 15 hours of exercise per week. The average self-assessed fitness level of the participants was 5 on a scale of 1-10 with 10 meaning very, very fit and 1 meaning very, very unfit. Seven participants reported to listening to music while exercising. Eight of the 11 participants played video games for more than five hours per week. Five of the 11 participants had previously played exergames and five had previously used an Oculus Rift.

6. Results

6.1. Pair-wise Comparison of Conditions

A Wilcoxon signed-rank test was performed to compare the measurements and questionnaire variables across each pair of conditions. The results are shown in table 1 with statistically-significant differences ($\alpha < 0.05$) displayed in bold.

Both exergaming conditions were rated significantly more enjoyable than exercising with music only. On a 7-level Likert scale (-3 to +3) music only had a mean enjoyment of 0 (neutral), whereas for the game synchronised and not synchronised with the music the results were 1.5 and 2.0, respectively. The results support hypothesis **H1**.

Both exergaming conditions resulted in a significantly higher perceived effort (IMI scale) than using music only. On a 7-level Likert scale (-3 to +3) music only had a mean perceived effort of -0.5 (roughly neutral), whereas for the game synchronised and not synchronised with the music the results were 1.4 and 1.6, respectively. The results are interesting since distance travelled, calories burned and heart rate were higher, but not significantly higher, in the gaming conditions. This means, perceived effort increased even though exercise performance did not increase.

Our results suggest that hypothesis **H2** is not true. In fact, the results suggest that the opposite is the case, i.e. exergaming increases perceived effort compared to exercising with music only.

Table 1 indicates that synchronising the game with the music has no significant effect on enjoyment and perceived effort and hence we found no evidence to support hypothesis **H3**. In fact, for all variables values were slightly higher, and in case of "distance" significantly higher, for the asynchronous condition.

6.2. Correlation Analysis

A correlation analysis was performed using all variables measured with our questionnaires and equipment for the three conditions. The results are displayed in figure 4. The colour of a circle indicates the Pearson's r rank correlation coefficients for the corresponding pairs of variables (for colour coding see legend on the right of the figure). Values with a p-value greater than 0.05 have been omitted. The values on the diagonal indicate variables compared to themselves and can be ignored.

For the music-only condition we can see a positive correlation between the distance travelled and the participants' BMI, heart rate, calories burned, and perceived effort. For the gaming conditions this correlation was not observed.

For the asynch condition we found a negative correlation between enjoyment and “Goal Orientation”.

For the synch condition we found a negative correlation between distance travelled and “Competitiveness” and “Winning Orientation”, i.e. competitive participants performed worse. In addition winning oriented players felt less enjoyment. Possible explanations are that competitive participants missed a competing player, or that they found the game a distraction from the exercises (note that the SOQ measures competitiveness in sports and not in gaming).

6.3. Discussion

Our results suggest that our exergame increases players’ motivation and enjoyment compared to exercising with music only. This is regardless of whether the music is synchronised with the gameplay or not.

The use of our exergame seemed to slightly increase performance (distance travelled and calories burned) and it significantly increased perceived effort compared to the music-only condition. This suggests that exergames might counteract the positive effect of music on perceived exertion for low-to-moderate and high intensity exercises [CE17]. One explanation for this might be the additional cognitive load required for exergaming [Lyo15].

However, this should not be considered an argument against exergaming, since exergaming has been shown to have a higher benefit on cognitive function than comparable exercises [AAB*12]. Furthermore, cognitive training stimulates different parts of the brain than physical training [CAS*16]. So the additional effort of playing an exergame, might result in a larger health benefit than traditional exercises. Also, the fact that enjoyment and motivation are significantly higher during the exergaming conditions is important since it helps to increase exercise compliance [LOS*99, EB08, DJB14, GR15, HTPM16].

We could not find any significant differences (except for “distance”) between the exergame synchronised and not synchronised with music. Possible reasons for this are that the gameplay was a larger motivator than the music (as indicated in table 1) and hence players always tried to get the largest score possible regardless of the intensity of the music and gradient of the track. Another reason might be that users could select their own music tracks - we noticed that all music tracks were moderately to very intense, i.e. there were few, if any, flat or declining sections in the resulting cycling tracks.

It is interesting, though, that all variables were slightly higher, and in case of “distance” significantly higher, for the asynchronous condition. It is possible that asynchronous music is advantageous in the sense that it boosts players performance during periods where game play lacks excitement. The significant higher distance for the asynchronous condition might be due to the fact that applying a constant amount of effort during flat and steep sections of the track results in a higher distance than applying a low effort during flat sections and a high effort during steep sections.

6.4. Limitations

Our user study suffers from several limitations. The number of participants in our user study was low (eleven) and spanned a limited set of demographics. Some of our results might be due to novelty effects (e.g. using a head-mounted display) and no long-term study has been performed. The songs chosen in the user study were selected by the users and were all moderately to highly intense. The track for the asynchronous condition was created by reversing the intensity profile of a music track. Many songs start slowly and get more intense over time. Hence the reversed intensity profile results in steeper gradients at the beginning, which might be perceived as harder. Furthermore, since the cycling session was limited to six minutes, the track in the asynchronous condition might actually have a higher overall gradient for the session.

Finally, many users reported that it was difficult to collect the pick-ups, i.e. they had to hit them almost in the centre, and sometimes it was difficult to change direction fast enough to pick up items on opposite sides of the track.

7. Conclusion and Future Work

Our results indicate that a suitably designed music-driven exergame can considerably improve exercise enjoyment and motivation compared to exercises with music only. We also found a (not significant) higher performance, and a significantly higher perceived effort. While no longitudinal study was done, we consider the results encouraging and that music-driven exergames can combine positive effects of both music and gaming for encouraging physical activity.

We did not find any significant difference between gameplay synchronised and not synchronised with the music. This might be due to multiple limitations of our study as described above. However, it could also indicate that gameplay has a significantly higher effect on motivation and performance than music. Our music dependent game elements described in subsection 3.3 were designed to encourage cycling with the beat of the music. However, while there was a strong indication of players “falling behind the beat”, there was no strong visual cue if players were cycling faster than the music beat. This was done intentionally since the primary purpose of an exergame is to encourage and not limit physical activity (same as for using music alone). The results suggest that researchers and developers need to put more effort into better understanding the relationship of different gameplay elements on the effectiveness of exergames.

In future work we will investigate the relationship of gameplay and music on auditory-game-motor synchronisation in more detail and compare the effects of synchronised gameplay and synchronised music separately for different music tracks. In addition we would like to investigate the interplay of music and gameplay with other motivational strategies such as virtual trainers and self-competition (e.g. [SBC*16]).

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References

[AAB*12] ANDERSON-HANLEY C., ARCIERO P. J., BRICKMAN A. M., NIMON J. P., OKUMA N., WESTEN S. C., MERZ M. E., PENCE

B. D., Woods J. A., Kramer A. F., Zimmermane E. A.: Sedentary behaviour interventions in young people: a meta-analysis. *American Journal of Preventive Medicine 42*, 2 (2012), 109–119. 6

[Aud] Audiosurf LLC: Audiosurf hompage. (last accessed 7th September 2017). URL: http://www.audio-surf.com. 3

[BMH95] Brownley K., McMurray R., Hackney A.: Effects of music on physiological and affective responses to graded treadmill exercise in trained and untrained runners. *International Journal of Psychophysiology 19*, 3 (1995), 193–201. doi:10.1016/0167-8760(95)00007-F. 2

[BNvR13] Bood R. J., Nijssen M., van der Kamp J., Roerdink M.: The power of auditory-motor synchronization in sports: Enhancing running performance by coupling cadence with the right beats. *PLoS One 8*, 8 (2013), 1–8. 2, 3

[BOB11] Biddle S. J. H., O'Connell S., Braithwaite R. E.: Sedentary behaviour interventions in young people: a meta-analysis. *British Journal of Sports Medicine 45*, 11 (2011), 937–942. 1

[BRL12] Booth F. W., Roberts C. K., Laye M. J.: Lack of exercise is a major cause of chronic diseases. *Comprehensive Physiology 2*, 2 (2012), 1143–1211. 1

[CAS*16] Chapman S. B., Aslan S., Spence J. S., Keebler M. W., DeFina L. F., Didehbani N., Perez A. M., Lu H., D'Esposito M.: Distinct brain and behavioral benefits from cognitive vs. physical training: A randomized trial in aging adults. *Frontiers in Human Neuroscience 10* (2016). 6

[CBT15] Clark I. N., Baker F., Taylor N.: The modulating effects of music listening on health-related exercise and physical activity in adults: a systematic review and narrative synthesis. *Nordic Journal of Music Therapy 25*, 1 (2015), 1–29. 2

[CE17] Chow E. C., Etnier J. L.: Effects of music and video on perceived exertion during high-intensity exercise. *Journal of Sport and Health Science 6*, 1 (Mar. 2017), 81–88. doi:http://dx.doi.org/10.1016/j.jshs.2015.12.007. 6

[CSW05] Clayton M., Sager R., Will U.: In time with the music: the concept of entrainment and its significance for ethnomusicology. *European Meetings in Ethnomusicology 11 (ESEM Counterpoint) 1* (2005), 1–82. 2

[Dix06] Dixon S.: Onset detection revisited. In *Proceedings of the 9th international conference on digital audio effects (DAFx-06)* (Sept. 2006), pp. 133–137. URL: http://www.dafx.ca/proceedings/papers/p_133.pdf. 3

[DJB14] Dishman R. K., Jackson A. S., Bray M. S.: Self-regulation of exercise behavior in the TIGER study. *Annals of Behavioral Medicine 48*, 1 (Aug 2014), 80–91. URL: https://doi.org/10.1007/s12160-013-9573-8, doi:10.1007/s12160-013-9573-8. 6

[EB08] Ebben W., Brudzynski L.: Motivations and barriers to exercise among college students. *Journal of Exercise Physiology Online 11*, 5 (Oct. 2008), 1–11. 6

[EW06] Edworthy J., Waring H.: The effects of music tempo and loudness level on treadmill exercise. *Ergonomics 49*, 15 (Dec. 2006), 1597–1610. 2

[FOA] FOAM Entertainment: Riffracer homepage. (last accessed 7th September 2017). URL: http://www.riffracer.com. 3

[GCPP15] Gao Z., Chen S., Pasco D., Pope Z.: A meta-analysis of active video games on health outcomes among children and adolescents. *Obesity Reviews 16*, 9 (Sept. 2015), 783–794. 2

[GD88] Gill D. L., Deeter T. E.: Development of the sport orientation questionnaire. *Research Quarterly for Exercise and Sport 59*, 3 (1988), 191–202. 4

[GR15] Goh D. H.-L., Razikin K.: Is gamification effective in motivating exercise? In *Human-Computer Interaction: Interaction Technologies (Proceedings HCI International)* (2015), Kurosu M., (Ed.), Springer International Publishing, pp. 608–617. URL: https://doi.org/10.1007/978-3-319-20916-6_56, doi:10.1007/978-3-319-20916-6_56. 6

[Hoy06] Hoysniemi J.: International survey on the dance dance revolution game. *Computers in Entertainment 4*, 2 (Apr. 2006). 2

[HTPM16] Heisz J. J., Tejada M. G. M., Paolucci E. M., Muir C.: Enjoyment for high-intensity interval exercise increases during the first six weeks of training: Implications for promoting exercise adherence in sedentary adults. *PLOS ONE 11*, 12 (Dec. 2016), 1–10. URL: https://doi.org/10.1371/journal.pone.0168534, doi:10.1371/journal.pone.0168534. 6

[JKE14] Jones L., Karageorghis C. I., Ekkekakis P.: Can high-intensity exercise be more pleasant?: attentional dissociation using music and video. *Journal of Sport and Exercise Psychology 36*, 5 (2014), 528–541. 2

[Kar16] Karageorghis C.: *Applying Music in Exercise and Sport*. Human Kinetics, 2016. 2

[KJL06] Karageorghis C., Jones L., Low D. C.: Relationship between exercise heart rate and music tempo preference. *Research Quarterly for Exercise and Sport 77*, 2 (June 2006), 240–250. 2

[KP08] Karageorghis C., Priest D.-L.: Music in sport and exercise : An update on research and application. *The Sport Journal 11*, 3 (2008). 2

[KP12] Karageorghis C., Priest D.-L.: Music in the exercise domain: a review and synthesis (part ii). *International Review of Sport and Exercise Psychology 5*, 1 (2012), 67–84. 2, 3, 4

[KSS*14] Kosugi N., Shimizu S., Sasaki S., Diep N. T. N., Kiyoki Y.: Music retrieval and adjustment technique to support and motivate ergotherapy and daily exercises. In *Proceedings of the 16th International Conference on Information Integration and Web-based Applications & Services (iiWAS '14)* (2014), ACM, pp. 385–394. URL: http://doi.acm.org/10.1145/2684200.2684313, doi:10.1145/2684200.2684313. 2

[LOS*99] Leslie E., Owen N., Salmon J., Bauman A., Sallis J. F., Lo S. K.: Insufficiently active australian college students: Perceived personal, social, and environmental influences. *Preventive Medicine 28*, 1 (1999), 20–27. URL: http://www.sciencedirect.com/science/article/pii/S0091743598903759, doi:http://dx.doi.org/10.1006/pmed.1998.0375. 6

[LWE09] Lind E., Welch A. S., Ekkekakis P.: Do 'Mind over Muscle' Strategies Work? Examining the Effects of Attentional Association and Dissociation on Exertional, Affective and Physiological Responses to Exercise. *Sports Medicine 39*, 9 (2009), 743–764. 2

[Lyo15] Lyons E. J.: Cultivating engagement and enjoyment in exergames using feedback, challenge, and rewards. *Games for Health Journal 4*, 1 (Feb. 2015), 12–18. 6

[MDM11] Mestre D. R., Dagonneau V., Mercier C.-S.: Does virtual reality enhance exercise performance, enjoyment, and dissociation? an exploratory study on a stationary bike apparatus. *Presence: Teleoperators and Virtual Environments 20*, 1 (Feb. 2011), 1–14. doi:10.1162/pres_a_00031. 2

[OFM06] Oliver N., Flores-Mangas F.: MPTrain: A mobile, music and physiology-based personal trainer. In *Proceedings of the 8th Conference on Human-computer Interaction with Mobile Devices and Services (MobileHCI '06)* (2006), ACM, pp. 21–28. doi:10.1145/1152215.1152221. 2

[PRR10] Przybylski A. K., Rigby C. S., Ryan R. M.: A motivational model of video game engagement. *Review of General Psychology 14*, 2 (2010), 154–166. 3

[Rya82] 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), 48–57. 4

[SBC*16] SHAW L. A., BUCKLEY J., CORBALLIS P. M., LUTTEROTH C., WÜNSCHE B. C.: Competition and cooperation with virtual players in an exergame. *PeerJ Computer Science 2* (Oct. 2016), e92. URL: https://doi.org/10.7717/peerj-cs.92, doi:10.7717/peerj-cs.92. 7

[SK06] SIMPSON S. D., KARAGEORGHIS C. I.: Effects of synchronous music on 400-metre sprint performance. *Journal of Sports Sciences 24* (2006), 1095–1102. 2

[SKGM15] STORK M. J., KWAN M. Y., GIBALA M. J., MARTIN GINIS K. A.: Music enhances performance and perceived enjoyment of sprint interval exercise. *Medicine and Science in Sports and Exercise 47*, 5 (May 2015), 1052–1060. doi:10.1249/MSS.0000000000000494. 2, 3

[SS13] SOLTANI P., SALESI M.: Effects of exergame and music on acute exercise responses to graded treadmill running. *Games for Health: Research, Development, and Clinical Applications 2*, 2 (2013), 75–80. 2

[Sun13] SUN H.: Impact of exergames on physical activity and motivation in elementary school students: A follow-up study. *Journal of Sport and Health Science 2*, 3 (2013), 138–145. 2

[SWL*15] SHAW L. A., WÜNSCHE B. C., LUTTEROTH C., MARKS S., CALLIES R.: Challenges in virtual reality exergame design. In *16th Australasian User Interface Conference (AUIC 2015)* (Sydney, Australia, 2015), Marks S., Blagojevic R., (Eds.), vol. 162 of *CRPIT*, ACS, pp. 61–68. URL: http://crpit.com/confpapers/CRPITV162Shaw.pdf. 4

[TMS*11] TAYLOR M. J. D., MCCORMICK D., SHAWIS T., IMPSON R., GRIFFIN M.: Activity-promoting gaming systems in exercise and rehabilitation. *Journal of Rehabilitation Research & Development 48*, 10 (2011), 1171–1186. 2

[vDSS*17] VAN DYCK E., SIX J., SOYER E., DENYS M., BARDIJN I., LEMAN M.: Adopting a music-to-heart rate alignment strategy to measure the impact of music and its tempo on human heart rate. *Musicae Scientiae* (2017), 1–15. doi:10.1177/1029864917700706. 2

[WT04] WÜNSCHE B. C., TEMPERO E.: A comparison and evaluation of interpolation methods for visualising discrete 2d survey data. In *Proceedings of the 2004 Australasian Symposium on Information Visualisation (invis au '04)* (2004), pp. 1–7. URL: http://crpit.com/abstracts/CRPITV35Wuensche1.html. 4