Personalized Synchronous Running Music Remix Procedure for Novice Runners

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Abstract. Running music, which refers to background music for running, plays a crucial part in various mobile applications for running. Existing solutions for presenting running music cannot simultaneously address runners' preferences, physical conditions, and training goals, resulting in lower running efficiency, higher injury likelihood, and significant mental fatigue. We proposed a novel running music adaptation method to address this problem. Specifically, the adaptation starts with a trial run, where the runner's running statistics are sampled. Then, with parameters identified from the trial run, cadence goals are set accordingly. The song list provided by the runner is augmented with recommendation systems and later tagged, screened, sorted, and split. Finally, the music parts are rearranged and adjusted to match the cadence goals before being mixed with the training instructions. Unlike previous running music interventions, our method introduces a way to blend different music parts, giving runners unprecedented pleasure in running. Quantitative and qualitative results have shown that the crafted remix can reduce perceived effort, boost the pleasures, run more safely, and help the runners reach their second wind, providing novice runners with a passion for following the training programs.

Keywords: Digital art · Health · Preferred music · Synchronous music · Remix

1 Introduction

Music-related interventions have been an inseparable part of many athletes' daily and training routines for decades [1]. It is associated with almost all sports forms and is considered one of the most significant occurrences in athletic competitions [2]. Meanwhile, running is a popular physical activity worldwide, and music has always been a companion [3]. Listening to music before, during, or after exercise is common [4]. Runners with musical intervention usually find it easier to distract themselves from physical stress, maintain a steady pace, keep their spirits up, and thus stimulate overall performance [4, 28, 29, 31].

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B. Göbl et al. (Eds.): ICEC 2022, LNCS 13477, pp. 372–385, 2022.
https://doi.org/10.1007/978-3-031-20212-4_31

Despite the widespread adaptation to music-related interventions in running and music apps, existing solutions either lose sight of users' personal music choices or do not provide personalized training goals. Specifically, most running apps use a fixed, generic training music template - users cannot cut, select, customize, or even choose their songs, which is unsuitable for runners with various fitness levels. These solutions ignored the user's personalized indicators, but they are essential [23, 27]. On the other hand, most running apps provide music recommendations based on real-time performance measured by sensors [50, 51]. These experiences cannot be customized to users' real-time needs and cannot be combined with training goals, resulting in a low incentive effect [52].

Addressing the gaps, we contribute a synchronously running music remix scheme to help the novice runners reach their second wind [55]. The experimental results revealed that the music remixed through the scheme may raise running beginners' performance, motivate them, evoke a positive emotional response, and increase the enjoyment of running music to a greater extent than randomly selected synchronous music in existing applications. This is because the music remixed through the scheme can meet the runner's music preferences and adapt to the runner's cadence.

2 Related Work

2.1 Music, Health, and Sports

Second wind is a common phenomenon whereby a runner suddenly finds the strength to keep running instead of quitting. In the second wind, runners can reach the period of peak physical activity performance and conquer exercises that previously caused muscle fatigue, palpitations, and shortness of breath [55]. One explanation for the second wind is the switch from impaired anaerobic to normal oxidative metabolism [10].

Much literature holds that music is widely recognized and used for its positive psychological, physical, and psychophysiological properties [17]. First, from a psychological point of view, people often use music to regulate their emotions [7]. Music influences psychological aspects by arousing and stimulating emotions in daily life through induction mechanisms [6]. This includes the basic emotions of happiness, sadness, fear, and sameness [8, 9]. Moreover, music can reduce negative emotions and feelings such as fear, anxiety, and nervousness [12]. And it also promotes the effects of positive emotions [10]. At the physiological level, the health benefits of physical activity are well accepted. Statistics show that people who engaged in an average of 15 min of moderate-intensity exercise per day had significant health benefits compared to those who did not [16]. Meanwhile, listening to music during exercise is undoubtedly a way to make exercise more enjoyable and pleasant [18, 19, 32]. Furthermore, previous studies indicate that music can increase sports enjoyment and increase physical performance in various physical activities [13]. Additionally, listening to music has been shown to increase stamina and motivation [13–15]. Some studies have used music as therapy in the exercise environment, and music beats per minute (BPM) has also been considered an essential factor in exercise [17, 20, 21]. From the psychophysiological dimension, the enjoyment of exercise is thought to be a key determinant of exercise adherence [30]. And studies have shown that audiovisual stimuli can reduce feelings of perceived exertion [31] and increase feelings of pleasure. Moreover, music leads to dissociated thinking and altered attention, which improves athletic performance [28, 29].

2.2 Intervention of Music on Sports Performance

Previous research has proposed a model of musical intervention in the field of sports [33], which has referred to synchronous and asynchronous music [17, 21, 22]. It has been proposed that central pattern generators or pacemakers in the brain may respond to regulate and control the rhythm. In other words, humans naturally tend to synchronize their movements with musical rhythms [34, 41]. Synchronous music is often used in endurance-based sports, where synchronous music allows athletes to feel a stronger stimulus and work longer [17, 25, 35]. Experiments show that synchronous music has ergogenic effects on the treadmill and in the 400-m run [3, 24]. In running, synchronous music can make endurance activities more energy-efficient [36]. Synchronous music has been shown to reduce the energy cost of exercise because it increases neuromuscular metabolic efficiency [26].

In addition, music preference has been identified as an essential mediator of the functional benefits of listening to music during exercise [23]. In a variety of different forms of exercise, listening to preferred music has been shown to improve athletic performance [37–40]. Self-selected stimulating music appears to have an entrainment effect [27] and has been shown to improve resistance training performance [23], and familiar music may even elicit psychological and physiological responses without the athlete being aware of it [13].

3 Proposed Method

Based on the problem and related work, we propose a procedure for creating customized running music.

3.1 Trial Run

Trial runs are required to ensure that the running music fits the physical and health conditions of novice runners.

Trial Run Setup. For the trial run, novice runners are asked to wear comfortably. Before the test, runners do 3 min of warm-up exercises. They will then complete a base run on a 400 m standard track at a minimum speed of 9 min per kilometer. Runners run until their self-reported perceived exertion exceeds a score of 8 on the Borg's Perceived Exertion (RPE) scale CR-10 [42, 43], a scale ranging from 0 to 10.

Retrieval of Statistics. To obtain data from the test runs, runners will wear a commercial electronic sports wristband that integrates heart rate monitor (HRM), global positioning system (GPS), and accelerometer to measure heart rate (HR), pace, and cadence. The data should be sampled every 5 s to ensure granularity.

3.2 Data Analytic and Goal Establishment

All HR, pace, and cadence data collected during the test run will be smoothed by a moving average of $n = 6$ to perform the following analysis.

Parameter Identification. The term parameter refers to the observed statistical data of the test run. Three types of parameters should be observed: 1) Warm-up Point - the first starting point for the periods when HR oscillates in the range of ± 5 for 2 min, or the time when HR peaks if no such HR oscillation is observed; 2) Tiring Point - the starting point for all continuous 2-min periods when HR decreases by more than 5, or cadence decreases by more than 5, or pace decreases by 40 s per kilometer; 3) Platform Cadence - the cadence before each fatigue period.

Cadence Goals. Cadence goals *Ct* refer to the target cadence (steps/minute) for each second *t* of running. Cadence is 150 at *C0* and then increases linearly until it reaches the first platform cadence at the warm-up point. *Ct* will begin to decrease linearly 30 s before each Tiring Point, reaching *Ct* - 2.5 at the tiring point. *Ct* will never be lower than 155.

3.3 Music Retrieval and Pre-processing

Music Retrieval. A favorite song list is collected from the runner. Then similar songs will be retrieved from a music recommendation platform (e.g., Musiio). All collected music will be tagged (e.g., Pop, Korean, Male, Rap, Powerful) and downloaded.

Music Screening. To ensure the beat of each song matches the step and the song not to be stretched too much in the mixing process, songs with the following identity will be excluded: 1) BPM between 90 and 140; 2) BPM lower than 70; 3) Beat not obvious; 4) Syncopation too obvious. Then the songs will be sorted by BPM and grouped by tags and pitch.

Splitting. Each of the song is split into intro, verse, chorus, bridge, outro [53]. All collected audios are separated by four sources with DEMUCS [54], in particular, vocal, bass, drum, and other components.

3.4 Mixing

Music Rearrangement. Using the song list, generate the song sequence and rearrange all music parts according to cadence goals. For example, strong choruses are saved for the tiring point and low volume bridges are removed. Then, similar verses, choruses, and outros are swapped, layered, or repeated throughout the songs to keep the music engaging.

Speed Matching. To ensure that the BPM of the track matches the cadence goals, speed adjustment algorithms (e.g., iZotope Radius) are applied to the rearranged music track so that the BPM at time *t* matches the *Ct*.

Chaining and Adding Instructions. The beats for each song in the track are synchronized and matched to ensure consistency throughout the track. Then the metronome sound is superimposed over the beats. To refrain the runners from injury, voice instructions on postures, time, step, breathing, and stride are added to the track at specific time spans and fatigue points (see Appendix 1).

Mastering. Minimalist mastering operations are performed on the target track: Vocals are lowered when it is not on the beat; bass and drums are boosted when it is not obvious; volume is adjusted to a comfortable, consistent level. Finally, equalizers, compressors, and limiters are applied to the track to ensure that the dynamic and tonal balance is correct.

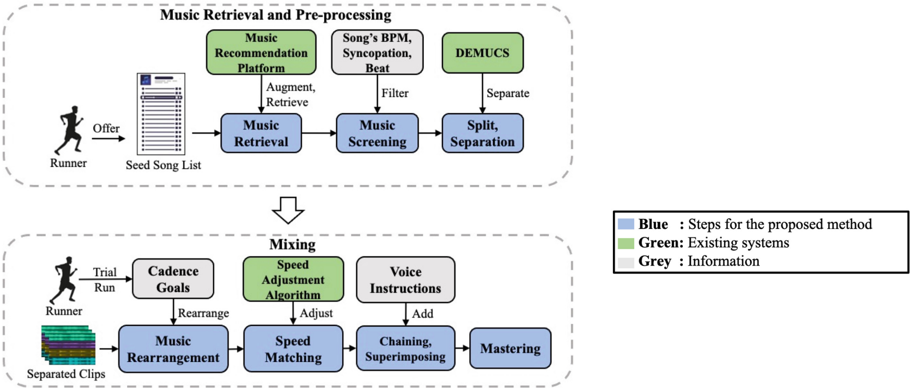

Fig. 1. The overview of proposed method processes

4 Experiment

4.1 Experiment Design

Participants. 12 Zhejiang University students (6 men, 6 women; $M = 23.83$ years) were recruited. They were all amateur runners who ran less than 4 times a month, half of whom hardly ran for years. They were aware of the importance of exercise and had a certain level of performance and fitness improvement goals (On a five-point scale, $M = 3.83$, $SD = 0.986$). The gender, age, height, and weight information are shown in Table 1. All participants provided informed consent before the experiment.

Equipment. Huawei Watch GT 2 was used to measure the participants' heart rate, distance, cadence, and pace during the tasks. It was proved that the measurements could be reliably made through the mainstream devices [45].

Table 1. Demographics of participants.

	Group 1 (n = 6)	Group 2 (n = 6)	Overall
Gender	$N_M = 3, N_F = 3$	$N_M = 3, N_F = 3$	$N_M = 6, N_F = 6$
Age (years)	23.17 ± 1.67	24.50 ± 0.76	23.83 ± 1.46
Height (cm)	168.33 ± 7.25	170.83 ± 6.28	169.58 ± 6.90
Weight (kg)	58.17 ± 7.27	60.67 ± 10.13	59.42 ± 8.90
BMI (km/m^2)	20.44 ± 1.24	20.61 ± 2.15	20.53 ± 1.76

Tasks and Groups. Participants were randomly divided into two groups. A repeated-measures design method was employed where both groups were asked to complete two running tasks. The tasks had three conditions, including no music (NM), personalized synchronous music (PSM) remixed in our procedure, and random synchronous music (RSM) recommended by QQ Music Running Radio. Both groups completed the first task under NM condition during the trial run. In the second task, participants in group 1 were conditioned on PSM, and those in group 2 were conditioned on RSM.

Test Setup. Running tasks were carried out on a 400 m circular track. While running, the runners are required to report their feelings. Participants were asked to maintain their eating and sleeping habits and avoid vigorous activities on their task day.

Measures. Total running distance, total running duration, average pace, and fastest pace were measured to evaluate running performance. The Feeling Scale (FS) and the Felt Arousal Scale (FAS) were used to measure Affective Valence and Arousal [42, 44]. The Physical Activity Enjoyment Scale (PACES) adaptation was included to quantify enjoyment ratings [46, 47]. Borg's rating of perceived exertion (RPE) scale was adapted to assess perceived exertion during running [42, 43]. Participants' heart rate (HR) was recorded continuously via wristband throughout the experiment. In addition, three single-item 5-point scales, including Music Liking, Music Motivation, and Music Dissociation, were adapted and used to evaluate runners' music experience [48, 49]. Semi-structured interviews were carried out for more information.

4.2 Procedure

Participants conducted a questionnaire prior to the experiment, which includes their basic information, running experience, running goals, and views on running music.

Before the first task, both groups of participants were informed about the detailed experimental procedure and the use of scales. Participants wore their wristband when they arrived. After a 3-min warm-up, participants began the first running task until their perceived exertion reached a score of 8. The first run was conducted under the conditions of NM. Participants had to report some subjective indicators during the run. After completing the run, participants filled out a questionnaire about the run.

The second running task was performed after participants had been fully rested for approximately 72 h. The procedure of the second task was similar to that of the first but under different conditions. Group 1 participants ran under the PSM condition, and Group 2 participants ran under the RSM condition. After completing the run, participants completed questionnaires and were given semi-structured interviews to obtain further information.

5 Results

5.1 Quantitative Analysis

Quantitative analysis was conducted using SPSS. Levene's test and Shapiro-Wilk test were used to evaluate the homogeneity of variance and the normality of the distribution. The analysis of variance with two-way repeated measures (RM-ANOVA) was conducted. A series of 2 (Condition: PSM, RSM) × 2 (Time: Task 1, Task 2) RM-ANOVA was conducted to determine whether significant differences existed between the two conditions throughout the tasks. For a more detailed comparison in task 2, a series of 2 (Condition: PSM, RSM) × 6 (Time: Arrival, Warm-up, First Half, Second Half, End, Post) RM-ANOVA was conducted. Independent samples t-test and Mann-Whitney test were used to compare participants' differences in Music Liking, Music Motivation, and Music Dissociation between the two conditions.

In contrast to no music, the results showed that both types of synchronous music enhanced beginner runners' performance, especially their total running distance and duration. Furthermore, compared to random synchronous music, personalized synchronous music had better effects in stimulating the beginner's running motivation, promoting positive emotions, and distracting attention, leading to better performance.

Above all, listening to synchronous music has a significant effect on the running performance of novice runners, especially in total running distance ($p = .043$, $\eta_p^2 = .348$) and duration ($p = .018$, $\eta_p^2 = .443$). Simple effects indicated that the changes between two tasks are more significant under the PSM condition ($p = .004$, $\eta_p^2 = .583$). Participants listening to PSM ran 7.48 min longer and for 0.82 km further on average than those listening to RSM in task 2.

There was no difference in pace and heart rate between groups. Participants' perceived exertion changed significantly over time but not across music types. Music conditions did not cause a measurable difference in RPE.

For the psychological response, both types of synchronous music may trigger positive emotions. The mean scores of affective valence and total PACES scores in task 2 were higher than those in task 1 (for FS, $p = .007$, $\eta_p^2 = .534$; for PACES, $p = .009$, $\eta_p^2 = .512$). The simple effect of FS through time on the PSM condition was more significant ($p = .001$, $\eta_p^2 = .665$), indicating the importance of music preference and adaption.

In addition, the results of the T-test and Mann-Whitney test showed that the scores of music experience, including Music Liking, Music Motivation, and Music Dissociation about PSM, were significantly higher than NSM.

5.2 Qualitative Analysis

We used grounded theory [56] to extract qualitative conclusions from Semi-structured interviews and questionnaires - 12 open coding were collected, then they were theorized into 4 axical coding. (See Appendix 3).

"*Music's effect towards running*" indicated that compared to the No Music condition, participants in both groups stated a more motivative, enjoyable, and relaxing running experience under the synchronized music condition.

For "*synchronized music's effect towards running*" and "*experiences towards synchronized music*", opinions are varied between the groups. Half of the RSM participants reported the feeling of inconsistency between the music beats and their cadence, while subjects in the PSM group felt the beat matched their cadence seamlessly. They also believed that the voice instructions regulated their postures and stride, while the beats and metronome sound provided them with reasonable cadence and pace control. The PSM group is confident that the music produced with our proposed method allowed them to avoid unnecessary injuries, got through the exhaustion of running, and reach their second wind. Furthermore, some of the RSM participants negatively viewed the songs in their running, and some indicated RSM's negative impact on mental feelings and cadence control. Nevertheless, runners in group the PSM group favored the music provided and were thrilled about the remix and transitions in their familiar songs, and it is possible that the preference consideration plays a key role in the improvements.

In the "*shifts in attention*" coding, we also revealed a shift in attention while running with PSM. We suspect that the role of PSM in the running may be phased - In the early stage of running, PSM mainly helps adjusting cadence, and the hearing enjoyment become dominate in PSM running experience. This conjecture deserves further study.

6 Discussion

This article presented a method for synchronous remixing of running music. This study features the contributions from several aspects: 1) We propose a running music customization scheme that simultaneously considers the music preference, the runner's physical condition, and the training goals. 2) This is the first running music customization scheme on the scale we are aware of and the first attempt to integrate remix - an art form - into running music. 3) We demonstrate through experiments that remix of playlists, cues, and metronomes can raise the interest levels in the running. 4) By proposing a novel method for presenting running music, we outperform existing running music platforms on runners' objective indicators. The results suggest that the music remixed can improve novice runners' performance, motivate them, elicit positive emotional responses, and increase their enjoyment of running music. This is because the PSM can respond to the runner's music preferences and adapt to the runner's cadence.

There are also some limitations: 1) The music remix is not a real-time generation. It assumes the status of the subsequent run based solely on the trial run, so it cannot change instructions based on real-time physical conditions. Future research may focus on adaptive remix music generated in real-time based on sensors. 2) All remixes are generated manually, which is delicate but involves high production costs and a large amount of time. Since our proposed method includes many qualified indicators, it offers the possibility of using batch playlist creation programs in the future. 3) Although the result shows that our experimental design is simple and effective, the specific method for setting cadence targets is relatively unscrupulous. Future studies may address generating more specific cadence goals according to different physical conditions.

Appendix 1. Power Words List

Power words (translated from Chinese)	Type	Key time point
Let's adjust our pace, get relaxed and start our [time] minutes of rhythmic running today! Let's start with a simple warm-up run!	General instruction	Warm-up point
If you're feeling okay but still struggling to keep up with the music, try leaning forward and taking smaller steps	Step instruction	Tiring point
Watch your breath! Your cadence is now [BPM] steps per minute. Two steps in and two steps out is the right rate! Remember, never breathe through your mouth!	Breathing instruction	Warm-up point
Now let's listen to something more energetic! Let's adjust the pace from [BPM] to [BPM] in the following [time] seconds! Follow the music!	Cheering words	Warm-up point
Remember to keep your body straight and stable! It is helpful to prevent injury in the long run!	Posture instructions	Warm-up point
Feeling okay? If you are feeling exhausted, try taking smaller steps, no need to rush, let's listen to more awesome songs together!	Step instructions	Tiring point
Bravo! Your steps match the rhythm like a clock! Run as if you are immersed in the music, you' re perfect! [favorite singer]'song is waiting for you!	Cheering words	Tiring point
You may feel tired now, but trust me, you're doing great! Let's focus on the music and try to forget about the physical exhaustion! Let's get through this phase and feel your second wind!	Cheering words	Tiring point
Remember to step as light as a hare! Don't dump your feet on the ground! This is good for your joint and can help you preserve your stamina!	Posture instruction	Tiring point
Your pace is now [BPM] steps per minute, stepping on the beats to give the run a more rhythmic feel and make it easier on your body!	Step instruction	Platform Cadence
Rotate Your Arms harder! Think of your arm as a pendulum swinging back and forth over your shoulder	Posture instruction	Platform Cadence
Take it easy! Don't strain your body! keep going! You are fabulous	Cheering words	Platform Cadence

Appendix 2. Descriptive Statistics for the Two Tasks

Measurements	Group 1 (NM + PSM)		Group 2 (NM + RSM)			Total
	Mean	SD	Mean	SD	Mean	SD
Distance 1	1.65 km	0.68	1.97 km	0.74	1.81	0.73
Distance2	2.66 km	1.11	1.84 km	0.75	2.25	1.04

(continued)

(*continued*)

Measurements	Group 1 (NM + PSM)		Group 2 (NM + RSM)			Total
	Mean	SD	Mean	SD	Mean	SD
Duration1	10.77 min	4.88	13.32 min	4.77	12.05	4.99
Duration2	20.08 min	7.43	12.60 min	5.13	16.34	7.40
aPace1	6.39 min/km	0.57	6.79 min/km	1.12	6.59	0.91
aPace2	7.11 min/km	0.78	6.87 min/km	1.39	6.99	1.14
fPace1	4.71min/km	0.48	4.74 min/km	4.70	4.73	0.63
fPace2	5.27 min/km	0.57	4.70 min/km	0.80	4.99	0.75
aHR1	167.33	5.50	168.17	7.80	167.75	6.76
aHR2	169.33	5.41	170.17	11.95	169.75	9.28
fHR1	180.33	4.92	185.67	5.59	183.00	184.75
fHR2	185.83	5.01	183.67	11.97	5.90	9.24
FS1	+ 0.36	2.18	+ 1.28	0.98	0.82	1.75
FS2	+ 2.56	1.17	+ 1.44	1.84	2.00	1.64
FAS1	3.98	0.69	3.54	1.00	3.74	0.89
FAS2	4.26	0.64	3.68	0.42	3.97	0.62
RPE1	4.96	0.82	4.06	0.95	4.51	0.99
RPE2	4.56	0.79	4.24	0.36	4.40	0.63
EE1	49.86	9.17	58.50	11.87	54.17	11.46
EE2	68.83	5.40	62.83	7.65	65.83	7.27
ML	4.50	0.50	2.83	1.07	3.67	1.18
MM	4.50	0.50	3.50	1.12	4.00	1.00
MD	4.33	0.47	3.00	0.82	3.67	0.94

Appendix 3. Qualitative Results

Axical coding	Open coding	PSM (Persons)	RSM (Persons)	Total (Persons)
Music's effect towards running	Music motivates me	6	6	12
	Music guides me	6	0	6
	Music makes my mood better	6	6	12
Synchronized Music's effect towards running	Instructions guided me	5	0	5
	Synchronized Music guided me	6	2	8

(*continued*)

(*continued*)

Axical coding	Open coding	PSM (Persons)	RSM (Persons)	Total (Persons)
	Synchronized Music not meet pace need	0	3	3
	Synchronized Music affects running	0	2	2
	Synchronized Music makes running safer	6	0	6
Experiences towards synchronized music	Synchronized Music is powerful	6	5	11
	Looking forward to the next song	3	0	3
	Synchronized Music is boring	0	4	4
	Synchronized Music is similar	0	2	2
	Synchronized Music help reach 2nd wind	4	1	5
	Liked the Synchronized Music	6	2	8
Shifts in attention	Attention shifts between instructions and enjoyment of the music	5	1	6

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