SoundRunner: Out of the Starting Blocks

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SoundRunner

Out of the Starting Blocks

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ABSTRACT

This paper presents a project in the art-science nexus. SoundRunner is a platform that exploits the potential of electroacoustic music to create an interactive sound- and music-making experience. The project investigates how data on running performance can be harnessed in real time to drive musical creation. A range of psychological indices (and associated analyses) is used to assess the effects of the SoundRunner platform on runners. Driven by health and well-being imperatives, the project served to augment running experience with unique sound and music. The paper discusses implications regarding running performance and the further technological development of SoundRunner.

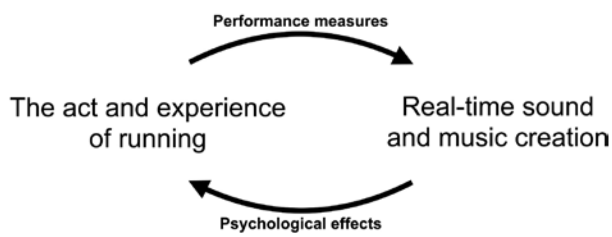

Fig. 1. The core concept of SoundRunner. (© David G. Berezan)

A MEETING OF ART AND SCIENCE

SoundRunner is an arts-led collaboration between the first author (an electroacoustic music composer) and the second author (a sport scientist). The core aim of the project was to develop an interactive aural experience for the runner, in which sound and music adapt in real time to running performance. SoundRunner provides auditory incentives to participate in and improve running performance, in addition to nudging individuals toward a more active lifestyle. A glossary can be found in Supplemental Materials 1.

The authors' research explores how a runner's performance, attainment of goals, or adherence to session targets can directly influence sonic and musical parameters. We also investigate the runner's empowerment as music-maker, in terms of how the interactive sound and music experience influences physiological and psychological parameters of running performance. Thus, the exploration of dynamic bidirectional relationships (runner performance upon music creation, music creation upon runner performance) is a central pillar of the project (Fig. 1).

While researchers in the field of sport sciences have investigated the effects of music on athletic performance [1–3], it has largely been confined to forms of music that are traditionally applied within the context of exercise and sport training (e.g. rock, pop, and dance music). Other work has also explored real-time tempo alterations of preexisting commercial music in response to changes in running cadence (steps per minute) [4–6], generative musical processes primarily based on cadence and heart rate [7], and the sonification of additional running data, including location [8].

Platforms linking music and running (e.g. Tempo Run and Tempo Magic) select or dynamically adjust the tempo (beats per minute, bpm) of precomposed, conventional music tracks to match a runner's cadence. Other sound-based aids to fitness motivation have included narrative-based game play (e.g. Zombies, Run!), the JYMMiN system of real-time modulation of repeating/looping sounds in response to transduction of exercise machine movement [9], and the moBeat system of MIDI-based music creation in aerobic exercise [10]. The DJ-Running mobile application provides music recommendations to the user, based on locative and emotion-related data [11].

Other research [12,13] focused on measurements of running gait and posture to articulate modifications and augmentations of preexisting music tracks, with the goal of enhancing running technique. The treadmill-based D-Jogger system supports a range of music alignment strategies for walking- and running-related goals [14]. Specifically, this system manipulates the timing differences between salient musical and movement-related rhythms (i.e. beats and footfalls) through adaptation of the musical period and phase. It

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has been suggested that the motivational qualities of music and related music-structural features (e.g. rhythmic accentuation) could improve energy expenditure through rendering running cadence more symmetrical and regular [15].

The use of electroacoustic music in SoundRunner is distinct from the commercial music traditionally associated with running, which adds a novel dimension. Moreover, the unique sonic possibilities and musical forms of electroacoustic music render it an ideal medium for exploring interactive audio experiences. SoundRunner is inherently flexible, and its lack of stylistic or generic expectations/restrictions affords maximum freedom to explore how sound might enhance the running experience.

The project is situated within approaches to interactive music that include the application of sonification procedures (e.g. *SoundBikes* [16]), biometric mapping systems (e.g. the use of physiological interfaces [17]), generative processes (e.g. *Heartbeats* [18]), and the embodiment of sound (e.g. *Bodycoder* [19,20]). Furthermore, David Rokeby's *Very Nervous System* (1982–1991), Cobi van Tonder's *Skatesonic* (2006), and Atau Tanaka's *BioMuse* (1992) are examples of artistic works that resonate with the concepts that underlie SoundRunner.

We configured the SoundRunner user experience to be inherently dynamic, interactive, and creative, resulting in different music upon each use. The runner's activity serves as a creative input, effectively empowering the runner as music composer and creator. SoundRunner explores the use of many musical parameters within the interactivity, not just relying on pulse and pace—the traditional foci among musical qualities that might enhance running performance—but also relying on much more subtle elements, that include timbre and frequency content.

Our ultimate aim is for SoundRunner to function as a fully mobile app-based experience, untethered from the treadmill and studio, allowing the music produced to be locative [21] (i.e. tied to specific running locations or location types). We also aim for the app to have functionality for use among groups of runners using phone networking, wherein the group's combined effort is used to produce the interactive responses influencing the music, so that, for example, one person falling off the pace has an impact on the shared auditory experience.

ATHLETIC–SONIC INTERACTIVITY

SoundRunner facilitates experiences wherein musical and sonic development informs the runner of key performance-related indicators. In addition, a variety of engaging sonic and musical experiences are created that tie into the runner's performance (Fig. 2). Harnessing real-time running performance data to inform sonic and musical processes can, for example, allow the sound and music to adopt a warmer timbral character as the runner reaches their optimal pace. As a runner progresses through a planned period of running, structural attributes of the music/sound world can change accordingly (e.g. sequences of rhythmic patterns, introductions of new sets of sounds). Certain sonic and musical "rewards" can be reserved for the attainment of performance-related goals (e.g. a key distance or duration milestone pertaining to a given training session). In effect, the runner navigates a musical form throughout their running session.

The primary forms of running performance data that we are investigating include cadence, pace, distance, duration, elevation gain, and heart rate (HR). These are monitored as both constant and variable parameters, as well as through

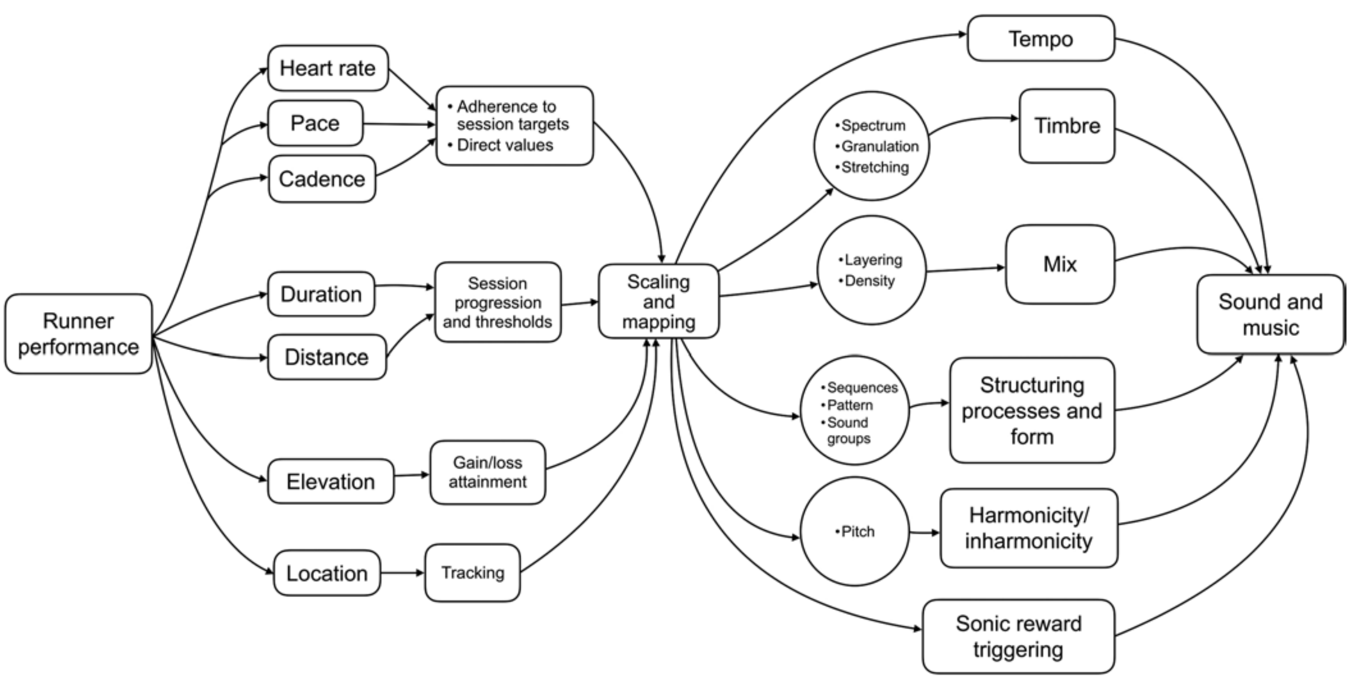

Fig. 2. Overview of real-time running, sound, and music interaction aims for SoundRunner. (© David G. Berezan)

evaluation against set session thresholds and target adherence. The main sonic and musical parameters/processes that are deployed include constant tempo adjustment, variations in mix and layering, sequencing of patterns, spectral articulation, and sound triggering. Given the platform's flexibility, we can explore a wide range of creative performance-music mappings. For example, sound could become increasingly disjointed through processes of granulation as a form of aural feedback under certain training conditions.

A distinction is made in the music-exercise literature between *active synchronization* and *passive synchronization* [22]. The former, which is well established in the practices of athletes, entails the runner consciously synchronizing their stride rate with the rhythmic qualities of music. The latter entails a process in which a digital interface adapts the tempo of music in real time or assigns a track at a tempo to match the stride rate of the runner (cf. Bart Moens and Marc Leman's notion of "spontaneous synchronization" [23]). There is a dearth of research into passive synchronization given that it is a relatively new phenomenon, enabled by technological advances. Accordingly, we sought further understanding of passive synchronization through the medium of the SoundRunner platform.

PILOT STUDY

In 2019 we conducted a pilot study that laid the groundwork for the research by developing a framework to investigate approaches to runner performance data collection and real-time sound- and music-making. The study occurred in the electroacoustic studios at the University of Manchester using a Matrix T1xe running treadmill. We accessed performance data (e.g. distance, duration, HR, pace) in real time using the FitLinxx protocol [24] from the treadmill CSAFE (Communications Specification for Fitness Equipment) serial port, which was connected to a receiving laptop (MacBook Pro, 2.3 GHz Intel Core i5, 8 GB memory) and Max software (version 8). We measured running cadence using a contact microphone attached to the treadmill chassis, as well as amplitude threshold detection and beat analysis in Max. The Max environment allowed for data preparation, analysis, and mapping onto sound and music generation.

We applied a rescaling procedure to performance data (as required), and mapped these data onto a range of sonic and musical parameters. Rescaling was determined by the numerical needs of the sonic parameter concerned. For example, running duration progression was evaluated in terms of percentage of completion of a set duration goal (e.g. to run for 20 min). Mapping the duration onto a global frequency equalization (e.g. high-shelf filter) in a meaningful manner (i.e. audible, musical, and impactful) required the range of running distance completed (expressed in the range 0.0–1.0) to be rescaled and mapped onto a range (for example) of filter gain articulation ranging between -10 and +10 dB, so that as the runner neared the end of their planned session, the musical mix became gradually brighter in terms of its spectral profile.

We selected bespoke sounds as the building blocks for the arising musical/sonic experience: short and percussive sounds, running-related body sounds (breath, steps, vocal utterances), sustained drones, and animated textures of varied lengths. We implemented real-time adjustments (constant control/variation and threshold triggering) of sound and music, and the platform's interactive capabilities led to music that arose through: (1) the sequencing of sound events (with variable tempo) in changing juxtapositions of patterns, (2) the dynamic layering of sonic texture, (3) the articulation of frequency content and pitch, and (4) the different mappings of performance data to the musical parameters. Supplemental Materials 2 includes audio examples of the musical and sonic outcomes of the pilot study.

For the purposes of the pilot study (Fig. 3), we recruited 12 volunteer participants (all males) to investigate the psychological and physiological effects of real-time mapping of running cadence to the tempo of the main underlying sound engine. The study had institutional ethics approval (ref. #2019-7644-11895), and we sought informed consent from each participant. Participants (M_{age} = 20.1 years, SD_{age} = 1.0 years; M_{height} = 1.79 m, SD_{height} = .04 m; M_{mass} = 71.04 kg, SD_{mass} = 6.83 kg; M_{BMI} = 22.1, SD_{BMI} = 2.3) were members of student running communities in the Greater Manchester area, U.K.

An experimental protocol with full counterbalancing of conditions was applied, wherein each participant was administered a series of 5-min running trials. All trials took place during a single visit to a sound studio that was fitted with a treadmill and safety mats. The trials comprised: (1) a habituation to familiarize the participant with experimental procedures and calibrate the treadmill belt velocity to elicit a predetermined target HR (65% HR reserve; i.e. a moderate running intensity), (2) a control condition wherein no music/sound was generated, (3) a synchronous running condition wherein cadence was mapped to alter musical tempo, and (4) an asynchronous running condition wherein cadence was not mapped to musical tempo (tempo was subtly varied to ensure asynchronicity). We included an additional post-experimental running session to explore the wider sound and music capabilities of the system. Attainment of duration thresholds influenced structuring processes, while indicators of running duration determined frequency articulations of sonic elements.

At specified intervals before, during, and after each control, synchronous, and asynchronous condition, we administered a series of psychological self-report measures to evaluate the participant's subjective experience (Supplemental Materials 3 provides a brief description of each measure, along with associated references). Specifically, before, immediately after, and at intervals during the running task (2:30 min and 4:30 min), we administered the 11-point Feeling Scale, to assess in-task affective valence (i.e. exercise-related pleasure/displeasure on a scale from −5 [*Very bad*] to +5 [*Very good*]), and the Felt Arousal Scale, to assess in-task affective arousal (i.e. exercise-related activation on a scale from 1 [*Low arousal*] to 6 [*High arousal*]).

At two intervals during the task (2:30 min and 4:30 min), we administered the 11-point Rating of Perceived Exertion (RPE) scale (a psychophysical index of perceived exertion

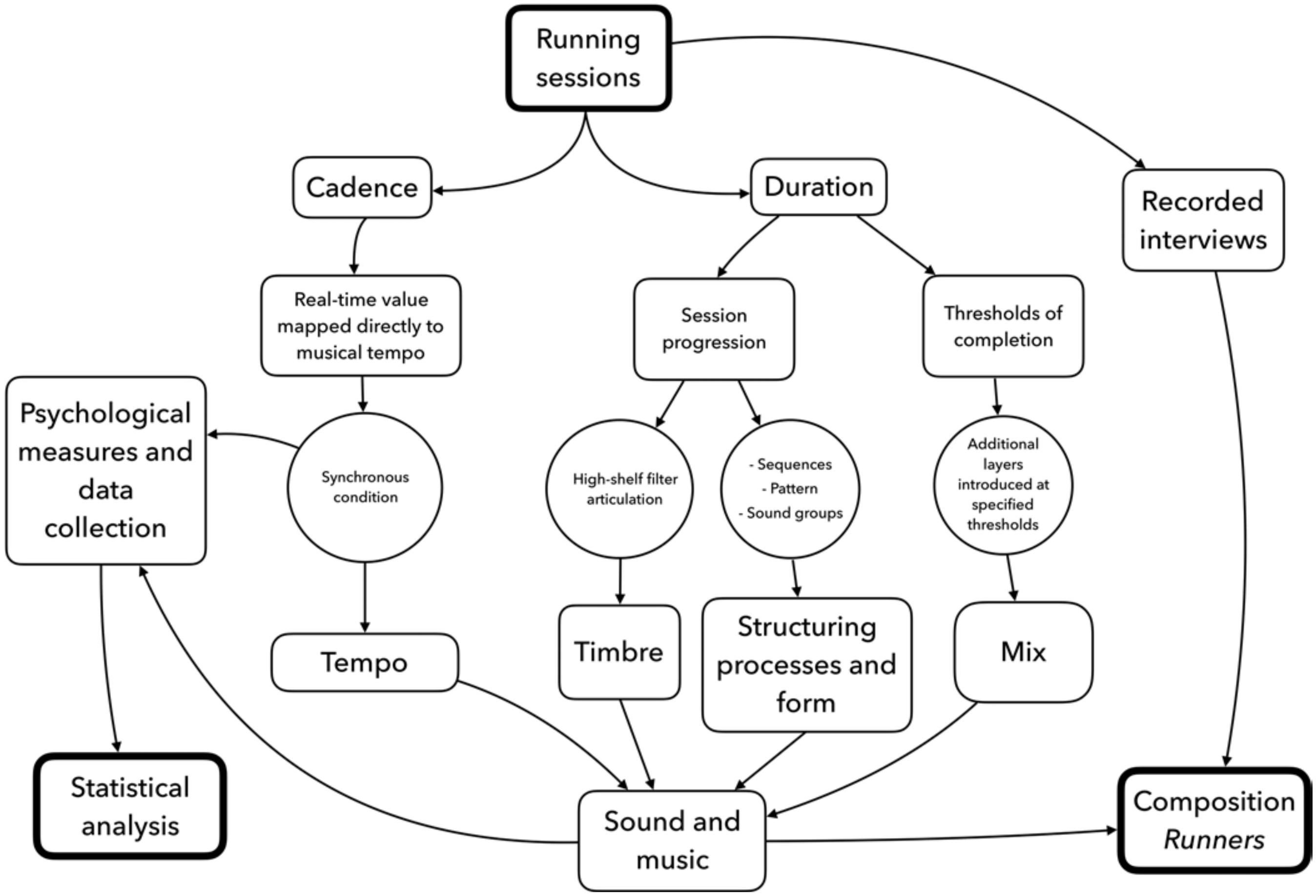

Fig. 3. SoundRunner pilot study implementation and investigation. (© David G. Berezan)

on a scale from 0 [*Nothing at all*] to 10 [*Extremely strong*]), the State Attention Scale to assess in-the-moment associative (inward/task relevant) and dissociative (outward/task irrelevant) focus on a scale from 0 (*Internal focus*) to 100 (*External focus*), and the 11-point Situational Motivation Scale on a scale from 0 (*Not at all motivated*) to 10 (*Extremely motivated*).

Immediately after the task, we administered a 10-point music-liking item attached to a scale from 1 (*I did not like it at all*) to 10 (*I liked it very much*); the Physical Activity Enjoyment Scale (PACES), which contains 18 items attached to a 7-point bipolar scale (e.g. I dislike it—I like it) preceded by the instruction "Rate how you feel at the moment about the physical activity you have been doing"; and remembered pleasure (measured using a 200-mm visual analog scale). We did not administer the music-liking item at the end of the no-music control trial. We monitored HR throughout each 5-min running trial at 1-min intervals, starting with Minute 1 and ending at Minute 6 (i.e. during active recovery).

We analyzed the affective valence and affective arousal scores using 3 (Condition) × 3 (Timepoint) analyses of covariance (ANCOVAs), with the mean pretask valence or arousal score included as a covariate in each analysis, respectively. This served to factor out statistically the participants' preexisting affective state, thus enabling a more accurate assessment of how the three conditions influenced core affect. We analyzed RPE, state attention, and situational motivation scores using 3 (Condition) × 2 (Timepoint) analyses of variance (ANOVAs), and HR using a 3 (Condition) × 6 (Timepoint) ANOVA.

In terms of post-task measures, we used a paired-samples t test to examine differences in music liking between the synchronous and asynchronous music conditions. We computed one-way repeated-measures (RM) ANOVAs to analyze the PACES score and remembered pleasure. We set alpha at $p < .05$ for all analyses, and made Bonferroni adjustments for pairwise comparisons.

Pilot Study Results

Supplemental Materials 3 includes all details pertaining to data screening and diagnostics, as well as a detailed description of the results along with descriptive statistics, inferential statistics, and effects sizes. We provide a brief outline of the key findings herein.

Core Affect

The 3 (Condition) × 3 (Timepoint) interaction for affective valence was significant and associated with a large effect size ($\eta_p^2 = .28$). Confidence intervals (see x-axis in Color Plate D) indicated that in the asynchronous condition at Timepoint 2 (4:30 min) and Timepoint 3 (post-task), affective valence scores were higher when compared to Timepoint 1 (2:30 min). There was a main effect of condition and timepoint, both associated with large effect sizes ($\eta_p^2 = .28$ and $\eta_p^2 = .35$, respectively). The former did not show any significant differences among conditions in follow-up pairwise comparisons (*p*s > .05), while the latter indicated a significant difference between Timepoint 1 and Timepoint 2, wherein affective valence scores increased. The two-way Condition × Timepoint interaction for affective arousal was nonsignificant (see *y*-axis in Color Plate D), as were the main effects of condition and timepoint.

In-Task Measures

The 3 (Condition) × 2 (Timepoint) interaction for RPE was nonsignificant, as were the main effects of condition and timepoint. The analysis for state attention indicated similar findings. The *p* value for timepoint, however, was borderline nonsignificant and associated with a large effect size ($\eta_p^2 = .31$), which is indicative of a shift toward greater associative focus as the running trial progressed (Supplemental Materials 3, Table 1). Nonsignificant findings also emerged for situational motivation. The *p* value for the two-way interaction was borderline nonsignificant and associated with a large effect size ($\eta_p^2 = .26$), which is indicative of a dip in situational motivation from Timepoint 1 to Timepoint 2 in the control condition only (Supplemental Materials 3, Table 1).

Post-Task Measures

The paired-samples *t* test that we used to compare liking scores between synchronous and asynchronous music conditions showed no significant difference. The RM ANOVA that we used to compare PACES scores (exercise enjoyment) across conditions indicated no significant differences. Similarly, the RM ANOVA for remembered pleasure showed no differences, although there was a mild trend toward higher pleasure in the two music conditions when compared to control (Supplemental Materials 3, Table 1).

Heart Rate (Work Intensity Manipulation Check)

The 3 (Condition) × 6 (Timepoint) interaction for HR was nonsignificant, as was the main effect of condition. The main effect of timepoint was significant and showed that HR rose gradually from pretask to the end of the running task, and then fell sharply during active recovery ($M_{\text{Timepoint}}\ 1 = 144.8$, $M_{\text{Timepoint}}\ 2 = 156.9$, $M_{\text{Timepoint}}\ 3 = 158.1$, $M_{\text{Timepoint}}\ 4 = 161.5$, $M_{\text{Timepoint}}\ 5 = 162.1$, and $M_{\text{Timepoint}}\ 6 = 103.6$). This suggests that we manipulated exercise intensity effectively, as mean HRs correspond with 65% HR reserve for healthy young adults and are consistent across conditions.

REFLECTIVE AND DOCUMENTARY ARTISTIC OUTCOMES

The first author recorded pre- and postsession interviews of each pilot study participant to provide material for the composition of a 41-min electroacoustic composition (*Runners*, 2022). The interview subject matter related to personal experiences with running, perspectives on the experience of sound, and reflections upon the sound and music interactivity experienced by participants. The first author subsequently recorded his own spoken narrative element reflecting upon his personal history with running.

Participants' remarks during the interviews illustrated their perceived physiological and psychological benefits when empowered as a music-maker by SoundRunner. For example, Participant 4 said, "The timbre and instrumentation of the music reminded me of the experience of running, maybe outdoors or on a treadmill, so that sort of helped to internalize everything." Participant 3, who had not experienced prior musical training, noted, "I found the running easier when the music was playing. I could channel into it and be more aware of it, and think less about my breathing or my legs."

Other work composed in the electroacoustic medium has referenced dynamic human activity and outdoor pursuit (e.g. skateboarding in Guillaume Dujat's *Tune of Crackle*, 2020), as well as the act and sounds of running (e.g. Rick Nance's *Cross Country Runner*, 2004). *Runners* focuses and comments on running through the exploration of places, spaces, body, breath, memory, kit, struggle, and achievement. Field recordings collected by the first author were used to create contrasting sound environments and spaces (urban settings, natural areas, and trails). He made footfall recordings using DPA 4060 miniature microphones attached to his shoes. The microphones captured the sounds of impact on varied surfaces (e.g. trail and road), as well as tactile sounds associated with the shoe material (e.g. sole, lining, and laces).

The first author varied these sounds through electroacoustic transformations, creating dynamic rhythmic patterns, articulated musical phrases (e.g. attacks and terminations), and spatial details in the stereo image (e.g. approach, departure, and horizontal trajectories). Breath sounds not only contributed additional sonic lines of musical pulse but also reinforced human presence and athletic effort. The work formed a narrative structure that was bookended by the first author's comments regarding initial aspirations to run a marathon and experiences as a runner during the COVID-19 pandemic leading into his 17th marathon in 2022. Individual sections feature the voices of pilot study participants and the wider collection of sounds and musical extracts, referencing first encounters, benefits, experiences, locations, music, and sounds of running.

Runners premiered at the MANTIS Festival of Electroacoustic Music and EASTN-DC Matte (R)ealities Festival (5 March 2022) and was preselected in the 2022 Phonurgia Nova Awards, Paris. It constitutes the second running-related work composed by the first author following his 2019 audiovisual work *Run*. Kenawa Films created a short promotional film that documents the rationale and experience of the SoundRunner pilot study [25].

KEY SCIENTIFIC OUTCOMES

The scientific component of the project entailed a pilot study with 12 young adult male runners. We computed statistical analyses to identify key trends, but with such a small sample, statistical significance is unlikely to emerge [26]. Accordingly, in expounding the key outcomes, we will focus primarily on effect sizes (i.e. the η_p^2 values), which indicate the percentage of variance in a dependent variable that is accounted for by the independent variable manipulation. For example, in the two-way interaction effect on affective valence, $\eta_p^2 = .28$ indicates that the interaction accounts for 28% of the variance (or differences) in affective valence. This is considered to be a large effect.

Starting with core affect, the only significant findings to emerge in the pilot study were for affective valence (i.e. the participant's perceived pleasure; Color Plate D). We recorded the highest affective valence scores in the asynchronous music condition at Timepoint 2 and Timepoint 3. Interestingly, no differences emerged in terms of the Condition × Timepoint interaction between the synchronous music condition and control (Color Plate D). The music manipulation had a medium effect on affective arousal ($\eta_p^2 = .09$), which was far from statistical significance (Supplemental Materials 3).

Collectively, the core affect findings hint at the possibility that the passive synchronous application of music heightened participants' exercise consciousness (cf. [27]) through accentuating their footfall. Ostensibly, the rhythmic emphasis on stride rate can draw the runner's attention to their effort through a sensory feedback loop. This might explain why the presence of music in this mode did not elicit the marked benefits for affective valence that are commonly reported by researchers who have examined active synchronization during treadmill exercise [28,29].

The in-task measures (RPE, state attention, and situational motivation) did not appear to be as sensitive to music manipulation as reported in past studies that delivered conventional prerecorded music [30]. As expected, RPE scores increased slightly during the submaximal running task, and there was a nonsignificant shift toward higher levels of associative (i.e. an inward/task-focused) attention (Supplemental Materials 3, Table 1). The situational motivation scores remained relatively stable in the two music conditions when compared to control, where there was a slight dip at Timepoint 2 (Supplemental Materials 3, Table 1). This finding is akin to those of previous studies that have assessed situational motivation in repetitive exercise tasks [31,32].

The post-task measures (music liking, exercise enjoyment [PACES], and remembered pleasure) revealed no differences either between the two music conditions or between each of the music conditions and control. The soundmapping (synchronous music condition) appeared to have no bearing on participants' aesthetic appreciation of the music. The present pilot study entailed a relatively brief, submaximal exercise bout on the treadmill, while much of past work entailing treadmill-based exercise has employed highly fatiguing or exhaustive tasks [33,34]. A protocol that entails a longer running task (i.e. > 10 min) would enable researchers to assess whether the form of passive synchronization that SoundRunner facilitates might engender an ergogenic (i.e. work-enhancing) effect.

THE ROAD AHEAD

Our ongoing research project will focus on higher levels of sonic and musical sophistication that the electroacoustic medium enables, including timbral and spectral qualities of sounds, structuring processes of musical and sonic units, and dynamic form. We will recruit larger cohorts of participants, representing diverse backgrounds and levels of running experience, to develop the SoundRunner concept further.

Our main long-term objective for SoundRunner is for it to function as a mobile platform, using a smartphone and bespoke app, wherein the underlying technology is transparent and does not encumber natural athletic movement in diverse settings. The mobile app will harness fitness data available through smartphone technology (GPS, accelerometers, etc.) and Pure Data (or similar) to replicate the interactive aural experience developed in-studio with a treadmill, but with the added potential of location-based soundmapping (e.g. locative audio) and a networked "ensemble" mode for groups of runners.

We will develop several different stylistic modes to provide a diverse choice of musical and sonic options for the user (ranging from electronic to more natural soundworlds). Moreover, we will investigate additional interactive functionality in terms of session durations (i.e. exploring the limits of functionality, formal design, and user engagement across a range of shorter-to-longer duration running sessions). This will enable us to explore whether we might harness SoundRunner for ergogenic effects in running, as well as the magnitude of such effects.

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35 The numbers in each geometric shape that represents a data point (estimated marginal mean) denote the relevant timepoint (Timepoint 1, 2, and 3). The synchronous music Timepoint 1 and asynchronous music Timepoint 1 estimated marginal means are the same, so the former data point is obscured although the associated 95% confidence intervals are visible. Means are covariate adjusted.

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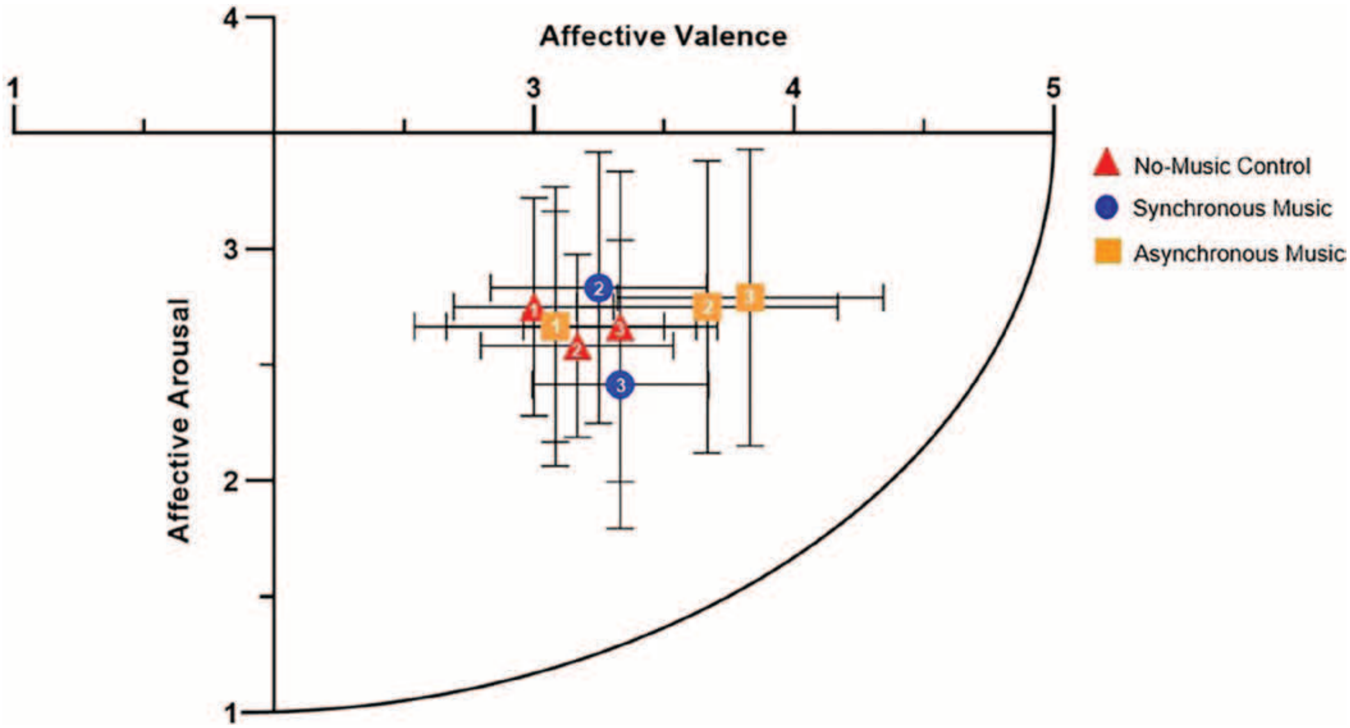
COLOR PLATE D: **SOUNDRUNNER: OUT OF THE STARTING BLOCKS**



A circumplex-like plot of mean scores for affective valence (*x*-axis) and affective arousal (*y*-axis) with 95% confidence intervals (horizontal for valence and vertical for arousal) [35]. (© Costas I. Karageorghis) (See the article in this issue by David G. Berezan and Costas I. Karageorghis.)