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Online Screening of X-System Music Playlists Using an Integrative Wellbeing Model Informed by the Theory of Autopoiesis

PETIA SICE[ID], **GARRY ELVIN**[ID], **CHIRINE RIACHY**[ID], **YILUN SHANG**[ID], **SUZANNAH OGWU, AND CORINNA ZINK**
Department of Computer and Information Sciences, Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne NE2 1XE, U.K.
Corresponding author: Petia Sice (petia.sice@northumbria.ac.uk)

ABSTRACT Research suggests that music has a powerful effect on the human mind and body. This article explores the impact of music as an intervention. For this purpose, the X-System technology is used to curate relaxing and enlivening music playlists designed to positively impact wellbeing and emotional state during the COVID-19 pandemic. A wellbeing model grounded in autopoietic theory of self-organisation in living systems is developed to inform the evaluation of the impact of the intervention and ensure the reliability of the data. More specifically, data quality is enhanced by focusing the participants' awareness on their immediate embodied experience of physical, emotional and relational wellbeing and sense of pleasure/displeasure prior to and after listening to a preferred playlist. The statistical analysis shows significant positive changes in emotional wellbeing, valence and sense of meaning ($p < 0.001$) with a medium effect size. It also reveals a statistically significant change for physical wellbeing ($p = 0.009$) with a small effect size. With the relaxing playlists leading to decrease in arousal levels and the enlivening playlists to an increase in activation, it is also concluded that appropriately curated playlists may be able to lead the listener to positive relaxation or activation states or indeed to positive mood change that may have health benefits.

INDEX TERMS Activation, autopoiesis, intervention, listening, music, music valence, wellbeing, X-system.

I. INTRODUCTION

This study was initiated to provide an integrative model and tools for monitoring the impact of a music intervention on wellbeing and emotional state. The intervention was designed using X-System technology to curate playlists for a positive impact on wellbeing and emotion, in response to the COVID-19 crisis, March-June 2020. X-System is a technology developed by a private limited company registered with Companies House in Whiteley UK, with a research facility in Edinburgh. The X-System music playlists curation is derived from an informatics model of the musical brain [1]. The playlists are designed to entrain emotion, mood, and general physiological state. An integrative model, i.e. 'the wellbeing pyramid', grounded in the theory of autopoiesis and Varela's later work on neurophenomenology, was used in designing the research study for monitoring the impact of

listening to X-System playlists on the listeners wellbeing and emotions [2]–[5].

The paper is divided into five parts: review of impact of music listening and applications on wellbeing; introduction to X-System; reflection on autopoietic theory and the model of wellbeing; evaluation of the X-System music intervention informed by the model; discussion, conclusion and limitations of the research.

A. MUSIC LISTENING, APPLICATIONS AND WELLBEING
Advances in music neuroscience, music therapy and music medicine have shown that music may have a powerful effect on the human mind and body. These effects range from relaxation and enlivenment to controlling mood, reducing anxiety, alleviating pain and more [6]–[8].

This study was initiated in response to the COVID-19 pandemic. In this context, a focused literature review was conducted to assess the impact of music listening interventions on wellbeing and behaviour in stressful circumstances. Reviews of literature in the area of arts and mental health suggest that

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music is one of the most useful tools available that may play a vital role in helping to deal with the behavioural problems of mental health [9]. Listening to music may bring significant decreases in agitated behaviour, and the effect may last for an hour after the listening experience [10]. Preferred music is particularly effective [11] and may significantly reduce aggressive behaviour. In one study, 80% of patients showed significant decreases in aggressive behaviour and increased cooperation with caregivers [12]. Improvements have been recorded in sleeping patterns [13], in mental health rehabilitation where music has been used as a complement to medication [14], [15], in anxiety levels and communication [16], and in social functioning [17]. The role of music in generating sympathy and empathy has been investigated in depth in the theory of communicative musicality [18]. The research was initially based on the study of the musical prosodic qualities of mother-infant communication [18], [19]. Research in affective neuroscience suggests that this "musical" experience of emotional communication, sympathy and movement between mothers and babies is linked to the activation of a variety of cortical and subcortical neural and neuroendocrine systems such as opiate and dopamine circuits, oxytocin, norepinephrine, the HPA axis and secretory immunoglobulin [20]. These empathetic activations continue into adult life. On a neurophysiological level, it has been postulated that music induces relaxation or arousal through its impact on autonomic and central nervous responses [21], [22]. Music triggers the limbic system, a section of the brain that plays an important role in the regulation of emotional responses, to release endorphins; these neurotransmitters play an important role in enhancing a sense of wellbeing [23], [24].

A systematic Cochrane Library review conducted by Joke Bradt and Cheryl Dileoin in 2014 [6] concludes that music listening may have a beneficial effect on anxiety in mechanically ventilated patients. The review furthermore suggests that music listening consistently reduces respiratory rate and systolic blood pressure. Music listening interventions could potentially be used for COVID-19 sufferers and may provide a viable anxiety management option in high stress situations.

More recent studies have confirmed the findings of the 2014 Cochrane review. For example, in a paper by Lee *et al.* from March 2017, beneficial effects of music in reducing anxiety among patients on ventilation were measured through cortisol levels, heart rate, heart rate variability and psychometrics [25]. Analysis showed that those in a group who listened to music had significantly better scores for all post-test measures ($p < 0.02$) than those in a control group, except for diastolic blood pressure.

Music interventions are low cost and easily administered, thus health services may want to use music to reduce stress and anxiety for patients and users. A recent work by Schriewer *et al.* [26] reflects on the opportunity of converting music streaming services into adjunct therapies acknowledging that a growing number of services and smartphone applications targeting emotions through music are becoming available, such as Amazon Prime Music,

Apple Music, Google Play Music, Spotify, or SoundCloud playing a variety of songs on-demand via the Internet. The user can select music stations based on specific songs or the mood of a song [26]. Current applications use several approaches including streaming mood-related playlists, providing mood-tagging options for users' own libraries, and playing soundscapes to promote relaxation [27]. A few have been explicitly designed to address mental health, emotion regulation and wellbeing. Examples include, eScape, Stress-free and X-System. The eScape mobile app teaches people how to identify and manage emotions using music, while targeting unhealthy music use [27]. Stress-free provides a tool for stress determination and treatment through computer music generation [28]. To our knowledge, X-System is the only application that uses a model of the musical brain and body to predict the level of relaxation or excitement of a piece of music [1].

A problem with music applications is that it is unclear what they actually do to categorise and recommend music [29]. Thus, it is important, that before creating novel music libraries and streaming playlists for specific wellbeing purposes, individual pieces of music are validated for their physiological responses. X-System provides a computational approach to the automatic categorisation of music by its effects on the human mind and body.

B. X-SYSTEM

X-System is an innovative computational approach to the automatic categorisation of music of all human cultures and other sound sources, by its effects on physiology and mental state. These effects may include modulation and regulation of emotion (in particular arousal), mood, and autonomic and endocrine response. The automatic categorisation process is based on the Innate Neurophysiological Response to Music (INRM) model [1]. The model is concerned primarily with low and mid-brain processing of music in areas where responses are largely innate and "universal".

The INRM model tracks the pathway of neurophysiological response to sound and music from the cochlea to the primal acoustic and musical processing areas of the auditory brainstem and then on to the convergence of musical and emotional responses in the mid-brain. It continues with the recruitment of the premotor cortex and other organs in the response to rhythm, and traces detailed pitch and rhythmic analysis in the temporal lobes. INRM finally follows these cortical and subcortical neural pathways to the musical/emotional centres of the limbic system, and onwards to activation of the autonomic nervous system and pathways related to neurotransmission and endocrine release.

X-System algorithms are based both directly and indirectly on these biological processes, and include cochlear modelling (the basilar membrane), turbulence, volume and sharpness (auditory brainstem and limbic response) [30]–[33], fundamental detection and harmonicity (Heschl's gyrus and related limbic systems) [34]–[36], and rhythmicity including autocorrelation (premotor cortex and temporal lobes) [37].

These models are constantly tested and refined by linear regressions and neural network processing related to both subjective/psychometric and physiological data.

X-System categorisations derived from INRM analysis may be used to stream music to listeners in sequences designed to entrain emotion, mood and general neurophysiological state.

Tracks in MP3 format are uploaded to X-System's web app analyser, estimating where a piece of music lies on the arousal scale from relaxing to exciting. An example of X-system in action is provided in Appendix B.

C. AUTOPOIESIS AND THE DYNAMICS OF (WELL)BEING

This section articulates the framework and underpinning assumptions of the wellbeing evaluation model used in the experiment, with reference to the theory of autopoiesis [2]. This theory defines and describes the dynamics of living as an autopoietic system [2], i.e. a network of processes of production of components that: (i) through their interaction and transformations continuously regenerate the network of processes that produced them; and, (ii) constitute the entity as a concrete by specifying the topological domain of its realisation as such a network. Consequently, an autopoietic system that exists in a physical space can in general be thought of as a living system [2]. Autopoiesis is basic to the living individual. What happens to the individual is subservient to its autopoietic organisation, for as long as it exists the autopoietic organisation remains invariant. What this means, is that its identity, and therefore its emergent global properties, are generated through a process of self-organisation within its network of components. This process of self-organisation is conditioned by a two-way process of local-to-global and global-to-local causation [38], [39].

First, there is the local-to-global determination ('upward' causation) through which the entity, with its properties, emerges. Secondly, however, there is global-to-local determination ('downward' causation), where global characteristics constrain or direct local interactions between the components [39], [40]. Thus, the internal dynamics of the components (neuronal nets, metabolic nets and so on) generate and sustain the global properties of the autopoietic entity. At the same time, however, the global properties (body, mind, behaviour and so on) constrain and govern the activity of the individual components. The global properties are continuously emerging and are processes in themselves. This dialectic relationship between local and global levels is described in autopoietic theory as 'reciprocal causality' [39], [40]. For example, in organisms with a nervous system, the rules of interactions within the neuronal network are in reciprocal relationship with the overall activity of the autopoietic entity. To a very large extent, behaviour is a regulator of perception. That is to say, what the organism senses is a function of how it behaves, and how it behaves is a function of what it senses. 'Situated behaviour', thus, takes the form of coupling with the environment; where environmental perturbations trigger changes in the entity but do not determine them, because
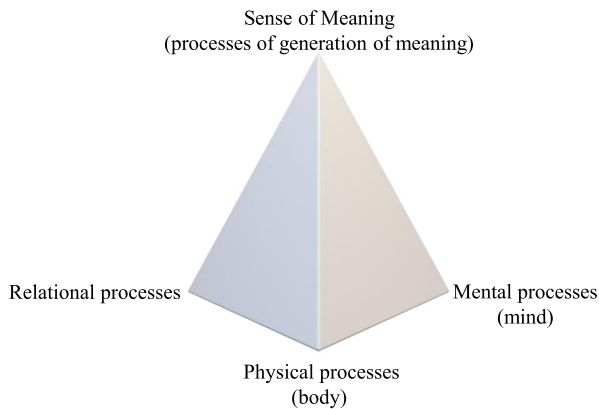
changes in autopoietic systems are necessarily subservient to conservation of organisation (identity). As observers we are in a position to distinguish the structure of an autopoietic system and the structure of the environment and observe them both changing in their mutual interaction. The important thing is that both the system and the environment undergo transformations through the process of coupling, referred to as 'structural coupling', and these transformations are determined by the structure of the transformed entity and not by the perturbation. In autopoietic entities with a nervous system, the coupling with the environment constrains and governs the neural and chemical dynamics [23], [38]–[40].

Thus, it is clear that the mode of coupling with the environment has two complementary dimensions: first, the living entity depends on its environment and defines itself through the interactions with that environment (these interactions are of the nature of macrophysical encounters such as sensory transduction or muscle movements). Secondly, yet no less importantly, coupling is only possible because these encounters are embraced from the perspective of the global properties of the living system itself.

What the autopoietic system does, due to its very mode of identity, is to constantly embrace the encounters (perturbations) with its environment and treat them from a perspective that is determined by its internal dynamics. What is meaningful to the organism is enacted from the perspective of an actively constituted identity, and thus, precisely given by its constitution as a circular process of self-production [2], [40]. The dialectics of the living are based on the necessary emergence of a meaning proper to the perspective of the cognitive self (for example one's perception), and on a coupling with the environment which refers to the necessary dependence of the self on its environment (for example socio-linguistic interactions). Consequently, the contents of human experience (how the world appears to us) depend crucially on the mutual embeddedness of the neuronal dynamics (embedded in the overall physical and chemical dynamics), the human agent as a unity with global properties (body, mind, self and so on) and the environment [38], [40].

There is reciprocal interrelatedness between the processes of body, mind and the process of relating to the environment, and these are embraced from the perspective of an actively constituted autopoietic identity, determining the sense of meaning attributed to the individual experience. Fig. 1 represents the interrelated dynamics of being.

What are the implications of understanding wellbeing from the perspective of the dynamics of being (Fig. 1)? If we go back to the core of the definition of autopoiesis as a network of processes of production of components that produces the components that through their interaction and transformations continuously regenerate the network of processes that produced them [2], it is clear that, to sustain living, these processes need to be reproduced without interruption [41], and that the living (autopoietic) system operates as a homeostatic system [42]. In Antonio Damasio's terms, homeostasis is the process of life regulation [43]. It is thus important to

Sense of Meaning
(processes of generation of meaning)

Relational processes

Mental processes
(mind)

Physical processes
(body)

FIGURE 1. The dynamics of (well)being.

clarify here, the word 'homeostasis' is used to indicate a dynamic process of organising resources to meet internal and external demands, not as a mere tendency to rigid equilibrium as perceived by some [43]. This is coherent with a complex systems perspective of an organism's function which suggests a dynamic relationship between system elements [41]; where patterns of organised variability are preserved in the face of continuously changing demands and the whole system has multiple points of stability. Thus, from an autopoietic perspective, the organism's wellbeing could be defined as maintaining physical, mental and relational homeostasis and meaning generation processes [44]. This definition is different from the hedonic (positive feeling) [45] and eudemonic (positive functioning) [46], [47] definitions of wellbeing. However, it encompasses their meaning, within a dynamic model of being (Fig. 1), acknowledging both positive feeling and homeostatic functioning. Feeling is an inherent part of the mental processes of being. Antonio Damasio makes a distinction between emotion and feeling, i.e. the definition of emotion is that of an unconscious reaction to any internal or external stimulus which activates neural patterns. Feeling emerges as a state of awareness of emotion, which simply senses the changes affecting the organism due to the emotional state [43]. Feelings thus support the process of homeostasis, alerting the organism to changes in state of being [43], [48]. Enhancing awareness of emotion, and thus of the quality of being, which is more subtle than awareness of exterior information [49], is part of the wellbeing process [50].

Awareness of experiences as they unfold is not only connected to emotion but also to accepting and witnessing present moment experiences and behaviours that may involve some or all of the following: sensations, bodily states (alert, quiet, pleasant, unpleasant), mental activity (thoughts, feelings, memory, intentions, beliefs, attitudes, etc.) and relational experience (connectedness to others, to our planet, to nature, etc.), sense of meaning and purpose [50]. This has important implications for understanding and evaluation/measurement of human experience. As the living (autopoietic) system is embodied and situated, measuring and monitoring for wellbeing requires an enquiry into the physical, mental and relational domains, interpreted

from the perspective of the living system itself [44]. This requirement is embedded in the wellbeing model ('pyramid of wellbeing') in Fig. 1. The model of wellbeing has previously been used in assessing the relationship between wellbeing and leadership capability [51], [52], and in the development of a protocol for interoceptive self-awareness in email communication [53]. In July 2020, the model was adopted by the Tees, Esk and Wear Valleys NHS Foundation Trust to inform the design of a staff wellbeing screening tool.

In the context of this study, the model implementation requires creating the conditions for encouraging interoception, i.e. accessing individual awareness and interpretation of personal experience in the present moment in the physical, emotional and relational domains [54]. The perceived benefit of this approach is collecting data with immediate reference to the embodied experience, interpreted by the participants themselves. This is consistent with the understanding of music listening as an embodied experience [55].

D. AIM AND OBJECTIVES OF THE STUDY
The majority of research studies investigating the impact of music on wellbeing have been experimental rather than interventional [56]. This research aims to explore the impact of music as an intervention. For this purpose, music playlists were curated using the X-System technology [1]: an informatic model of the musical brain, predicting neurophysiological response to order tracks in sequences, leading the user from their current state to a chosen state of mind and body. The playlists were uploaded to the Recovery College Online, Tees, Esk and Wear Valleys NHS Foundation Trust website.

The objectives of the study were twofold: 1) develop a method for evaluation based on 'the pyramid of wellbeing' outlined in the previous section; 2) apply the method to evaluate the impact of listening to X-System music playlists on wellbeing, valence and emotions.

II. METHODS AND RESULTS
For this study the effects of relaxing, enlivening and mood managing playlists (duration between 10 and 25 min) on the listeners' perception of wellbeing (Fig. 1), valence and emotional landscape were evaluated by assessing the change in these parameters before and after music listening. The choice of duration was based on studies of music, relaxation and mood change over recent decades [57], [58], where 20 minutes has been found to be the period required for significant cortisol reduction in relaxing circumstances [59] and 10 minutes has been found to be an effective period to achieve a relaxation and anxiety reduction effect [60].

Data was collected from online 'wellbeing diaries' kept by users of the Recovery College Online, Tees, Esk and Wear Valleys NHS Foundation Trust Music for Wellbeing website. The feasibility of a control group where participants observed a 10-minute silence was considered. However, participants from the feasibility trial reported extreme irritability (quote: 'I found it quite annoying waiting for something to happen'). In addition, there were ethical issues in establishing

non-participatory controls for an emergency intervention in trauma informed practice in a crisis situation, i.e. subjects being obliged to sit in silence at a time of high anxiety during the COVID-19 pandemic. Therefore, it was not possible to establish conventional control group. However, subjects were in some sense their own controls, an aspect of the study made possible by measurement "before and after" the intervention.

The autopoietic perspective adopted in this study, postulates that our experience of the world is born in our interactions with the environment and is validated by our embodiment. It was thus of utmost importance that the method of enquiry created conditions for paying attention and accessing immediate personal experience through a disciplined act of cultivating capacity 'of becoming aware' of the sources of this experience [4], [50]. Thus, a diary method was considered appropriate for this study [61]–[63]. It was designed to collect both quantitative and qualitative data. The quantitative data consisted of participants rating their own interpretation of their experience of wellbeing, before and after listening to a music playlist of their choice. The diary required the participant to reflect on their present experience, rating their perception of wellbeing according to the four dimensions of the wellbeing model in Fig. 1 and according to valence (pleasant/unpleasant experience) on a scale from −5 (poor) to 5 (excellent) and to leave short comments if they choose to do so. Participants were also encouraged to consider their state of being in the moment to promote greater clarity of their inner emotional landscape [64]. They were then asked to rate the intensity of the positive/negative emotions they might be experiencing (Appendix A). The ratings are associated with emotions felt by the individuals.

The mapping of emotions takes into account valence [65]. The mapping of emotions in the pleasant (positive)/ unpleasant (negative) categories is coherent with David Hawkins scale of experience [66] and literature on categorisation of basic emotions [66]–[68]. The categories and wording of emotions were selected by the authors in consultation with the wider team from the Tees, Esk and Wear Valleys NHS Foundation Trust and X-system, considering appropriateness for the context of the application, i.e. listening to music has been found to induce positive (pleasant) and negative (unpleasant) emotions [26], with low or high arousal levels [63], [64]. Positive emotions included: -low arousal level emotions: peace, love, safety; - high arousal level emotions: joy, motivation and enthusiasm. Negative emotions included: - low arousal level emotions: apathy, guilt, sadness; -high arousal level emotions: anxiety, fear and anger [26].

A. PARTICIPANTS

A Music for Wellbeing set of X-System playlists for supporting mental wellbeing during the time of the COVID-19 pandemic were uploaded on the Recovery College Online, Tees, Esk and Wear Valleys NHS Foundation Trust online platform. Listeners had a choice to fill in the wellbeing diary pre- and post-listening to a playlist of their choice. Out of 183 participants, 59 completed both the pre and post diary.

The approach to data cleaning involved excluding the entries with listening duration less than 10 minutes, thus 45 entries were considered for analysis.

The online platform was open access, participation in the evaluation was anonymous and voluntary, with explicit consent. Ethical approval was granted by Northumbria University, Newcastle, UK. Data on wellbeing and the valence profiles of individuals pre- and post-listening was collected and analysed. It was considered appropriate that no demographic data on individuals was collected in order to minimise service users effort in the context and timing of usage during the pandemic, as well as not to interfere with the listeners motivation to engage seamlessly in interoception. This choice was made in consultation with the wider team from the Tees, Esk and Wear Valleys NHS Foundation Trust and X-System. Google Analytics provided evidence of the countries from which the entries in the diary were completed: United Kingdom, Germany, China, Israel, United States, Spain, Albania, Belgium, Cyprus, and Finland.

TABLE 1. Mean scores before and after the intervention.

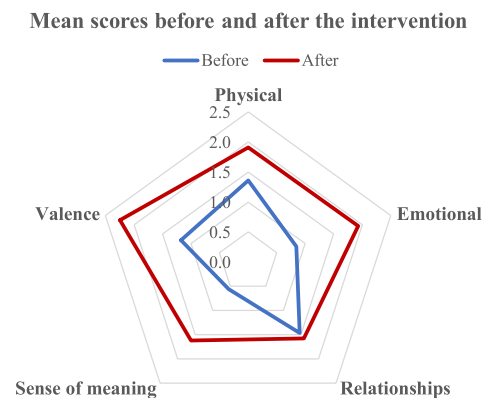|	Before	After	Change
Physical	1.36	1.91	0.56
Emotional	0.84	1.93	1.09
Relationships	1.47	1.58	0.11
Sense of Meaning	0.56	1.62	1.07
Valence	1.18	2.24	1.07

FIGURE 2. Mean scores before and after the intervention.

B. STATISTICAL ANALYSIS

IBM SPSS Statistics software (Version 26) and Microsoft Excel - Office 365 were used for the statistical analysis of the data. The mean scores for each of the four wellbeing dimensions and the valence before and after the intervention can be seen in Table 1. They show an increase for all the values post-intervention. The biggest increase is for the sense of meaning and for valence at 1.07, and the smallest is for relationships, 0.11. These values can better be seen in the radar chart in Fig. 2.

To evaluate whether these differences are statistically significant, the data is first tested for normality. For this purpose,

TABLE 2. Normality tests: test statistic and *p*-values. *p*-values less than 0.05 are in bold.

	Kolmogorov-Smirnov		Shapiro-Wilk	
	Test statistic	*p*	Test statistic	*p*
Physical	0.205	**<0.001**	0.921	**0.005**
Emotional	0.187	**<0.001**	0.941	**0.023**
Relationships	0.239	**<0.001**	0.917	**0.003**
Sense of meaning	0.184	**0.001**	0.870	**<0.001**
Valence	0.182	**0.001**	0.906	**0.001**

Kolmogorov-Smirnov and Shapiro-Wilk tests are conducted. The results are shown in Table 2. Both tests show that none of the variables is normally distributed. The normality of the data assumption being violated, it is inappropriate to use a parametric test such as the paired sample t-test. Therefore, the non-parametric one-tailed Wilcoxon signed rank test is alternatively applied to test whether the increases in values are statistically significant for any of the dimensions. Statistical significance is declared for a *p* value less than 0.05. The effect size is also evaluated using Rosenthal's *r* [69]. It is computed as $r = Z/\sqrt{N}$, where Z is the z-score of a statistical test and N is the total sample size. A small effect is associated with an *r* threshold of 0.10, a medium effect for $r = 0.30$, and a large effect for $r = 0.50$ [70]. The results are shown in Table 3.

TABLE 3. One-tailed Wilcoxon signed-rank test results: *z*-score (test statistic), *p*-values, and effect size *r*. *p*-values less than 0.05 are in bold.

	Test statistic	*p*	*r*
Physical	2.361	**0.009**	0.249
Emotional	4.063	**<0.001**	0.428
Relationships	0.532	0.297	0.056
Sense of meaning	3.875	**<0.001**	0.408
Valence	3.879	**<0.001**	0.409

The Wilcoxon signed rank test reveals statistically significant differences for physical wellbeing with a small effect size ($p = 0.009, r = 0.249$), emotional wellbeing with a medium effect size ($p < 0.001, r = 0.428$), sense of meaning with a medium effect size ($p < 0.001, r = 0.408$), and valence with a medium effect size ($p < 0.001, r = 0.409$). The differences in the relationships dimension are not significant.

TABLE 4. Pearson correlation coefficients between valence and various wellbeing dimensions. Values discussed in the text are in bold.

	Physical	Emotional	Relationships	Meaning	Valence
Physical	1.000	**0.600**	0.374	**0.330**	**0.514**
Emotional	0.600	1.000	0.566	0.532	**0.690**
Relationships	0.374	0.566	1.000	0.526	**0.441**
Meaning	0.330	0.532	0.526	1.000	**0.457**
Valence	0.514	0.690	0.441	0.457	1.000

C. CORRELATION BETWEEN WELLBEING VARIABLES

Pearson correlation coefficients between different wellbeing dimensions and the valence are presented in Table 4.

Among the four wellbeing dimensions, valence is the most correlated to emotional wellbeing ($\rho = 0.690$), followed by physical wellbeing ($\rho = 0.514$), sense of meaning ($\rho = 0.457$) and finally relationships ($\rho = 0.441$). The most highly correlated wellbeing dimensions are physical and emotional wellbeing ($\rho = 0.600$), and the least are physical wellbeing and sense of meaning ($\rho = 0.330$).

D. EMOTIONS ANALYSIS

Depending on whether the valence rating provided is positive or negative, the participant was asked to rate six associated emotions on a scale from 0 to 10 (low to high). Those associated with a negative valence are sadness, guilt, apathy, anger, fear and anxiety. Those associated with a positive valence are peace, love, safety, joy, motivation, and enthusiasm. Firstly, we examine the correlations between the six negative emotions and the six positive emotions using Pearson correlation coefficients. The results are shown in Tables 5 and 6, respectively. For the negative emotions, the most highly correlated are anxiety and fear ($\rho = 0.682$), and anger and fear ($\rho = 0.603$). Negative correlations, albeit very small, are found between anger and apathy ($\rho = -0.113$) and anger and guilt ($\rho = -0.059$). The lowest positive correlations are found between fear and apathy ($\rho = 0.092$), anxiety and apathy ($\rho = 0.121$), and anxiety and guilt ($\rho = 0.183$). For the positive emotions, most of them are highly positively correlated especially enthusiasm and motivation ($\rho = 0.864$), and enthusiasm and joy ($\rho = 0.851$).

TABLE 5. Pearson correlation coefficients for negative emotions. Values discussed in the text are in bold.

	Sadness	Guilt	Apathy	Anger	Fear	Anxiety
Sadness	1.000	0.227	0.458	0.279	0.500	0.324
Guilt	0.227	1.000	0.372	**-0.059**	0.305	**0.183**
Apathy	0.458	0.372	1.000	**-0.113**	**0.092**	**0.121**
Anger	0.279	-0.059	-0.113	1.000	**0.603**	0.433
Fear	0.500	0.305	0.092	0.603	1.000	0.682
Anxiety	0.324	0.183	0.121	0.433	**0.682**	1.000

TABLE 6. Pearson correlation coefficients for positive emotions. Values discussed in the text are in bold.

	Peace	Love	Safety	Joy	Motivation	Enthusiasm
Peace	1.000	0.648	0.754	0.600	0.591	0.665
Love	0.648	1.000	0.666	0.770	0.620	0.727
Safety	0.754	0.666	1.000	0.609	0.492	0.612
Joy	0.600	0.770	0.609	1.000	0.757	0.851
Motivation	0.591	0.620	0.492	0.757	1.000	0.864
Enthusiasm	0.665	0.727	0.612	**0.851**	**0.864**	1.000

Upon starting to use the service, participants are asked to choose between relaxing or enlivening playlists reflecting their current and desired states. Based on their choice of a playlist, they are divided in this analysis into two groups, 1) relax me, and 2) enliven me. On a valence axis the emotions are categorised into pleasant and unpleasant. This 2-dimensional configuration has been consistently identified and firmly established as the basic structure of affect in the
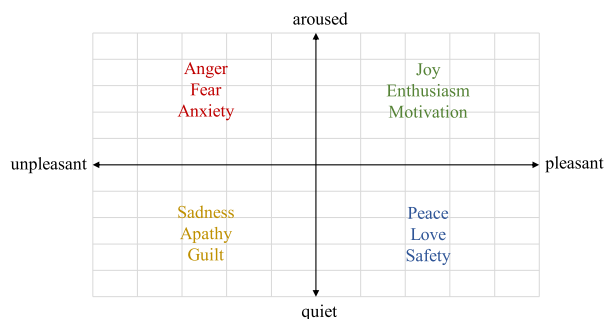
FIGURE 3. Valence and Arousal categorisation of emotions in this study.

FIGURE 4. Profile of the participants before and after music listening based on their choice of a relaxing playlist.

FIGURE 5. Profile of the participants before and after music listening based on their choice of an enlivening playlist.

West [65]. Emotions could also be represented within two bipolar dimensions, valence and arousal [71], [72] and could be mapped on the range of arousal (high to low) and valence (pleasure to displeasure) that is experienced during a particular emotion [68], [71], [72]. Some of the emotions indicate an aroused state and others a quiet/relaxed state (Fig. 3), they are divided in the following analysis into four groups, two groups with positive valence and two with negative valence on either the quiet or the aroused side.

However, emotions in different quadrants are not necessarily mutually exclusive, for instance a person can experience sadness and fear, peace and joy, etc. at the same time. There may be prevalent emotions but several emotions are experienced together [43], [66]. To place a person into one of these quadrants indicating which emotions are the most prevalent, we proceed to find the arousal/quietness level on a scale from -5 (quiet) to 5 (aroused) as follows:

1) Sadness, apathy, guilt, peace, love, and safety ratings are changed to negative values by taking their opposites. These emotions are associated with a quiet/calm state.

2) The scores for the displayed emotions for each person are then added. Each person rates 6 emotions (either positive or negative) on a scale from 0 to 10, out of which 3 are now on a scale from -10 to 0. Adding these will result in a range of values between -30 and 30.

3) These values are then re-coded between -5 and 5 indicating different levels of arousal as follows: $[-30, -23] \implies -5$; $[-22, -18] \implies -4$; $[-17, -13] \implies -3$; $[-12, -8] \implies -2$; $[-7, -3] \implies -1$; $[-2, 2] \implies 0$; $[3, 7] \implies 1$; $[8, 12] \implies 2$; $[13, 17] \implies 3$; $[18, 22] \implies 4$; $[23, 30] \implies 5$.

Using the participant's own valence rating with their computed arousal level and dividing the participants into the same 'relax me' and 'enliven me' groups as done previously, the scatter plots in Fig. 4 and 5 are obtained.

For the 'relax me' playlists group involving 16 participants, the first scatter plot shows that 4 out of 5 participants with unpleasant ratings moved into pleasant after listening to a playlist. Also, none of the participants displayed a positive arousal level after listening to a relaxing playlist as the range becomes restricted to $[-3, 0]$ compared to $[-3, 1]$ pre-intervention.
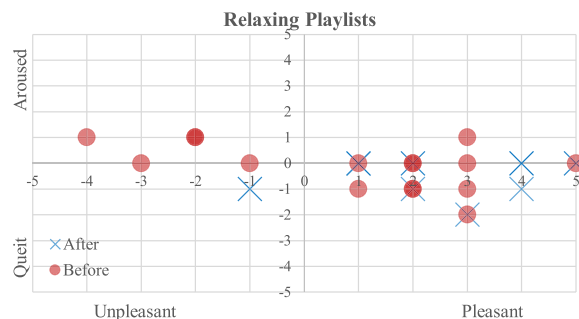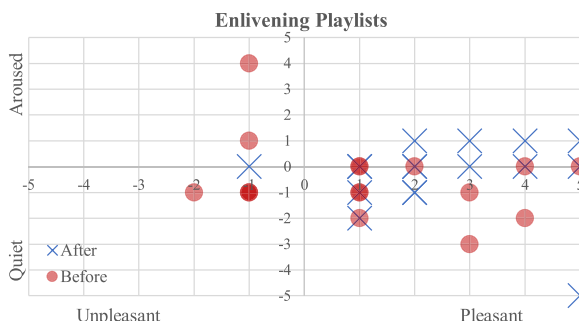
For the 'enliven me' group involving 17 participants, the second scatter plot shows that 5 out of 6 participants with unpleasant ratings moved into pleasant after a playlist. Apart from one (outlier) participant displaying an arousal level of -5 post-intervention, the arousal level pre-intervention ranged between -3 to 0 for participants with positive valence. This range moved up to $[-1, 1]$ with 4 participants above zero ratings after listening to an enlivening playlist.
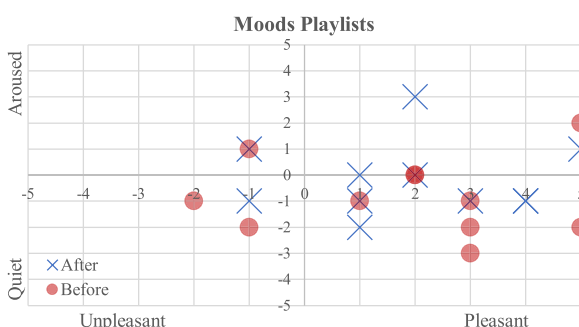

FIGURE 6. Profile of the participants before and after music listening based on their choice of a mood managing playlist.

In addition to relaxing and enlivening playlists, mood managing playlists were available for participants to choose from. They include 7 categories: self-care, staying relaxed, feeling better, feeling connected, motivation, solace and consolation, and the final category is spirituality, adventure and healing. 11 participants opted for one of these playlists from various categories. Given their small number, they are gathered in the same group, and their profiles are visualised in Fig. 6.

As expected, no clear pattern is identified in the corresponding scatter plot given the diversity of the playlists involved. It is also worth noting that one of the participants did not specify the playlist they listened to, thus they were excluded from this analysis.

The two-tailed Wilcoxon signed rank test is applied to the arousal variable to detect any differences before and after the music listening task. The results are shown in Table 7. The arousal level has decreased for the relaxing playlists while increasing for the enlivening and mood controlling playlists. However, none of the differences are statistically significant.

TABLE 7. Mean values and two-tailed Wilcoxon signed rank test results to compare the arousal level for relaxing, enlivening, and mood stabilising groups before and after the music intervention.

	Means		Test results	
	Before	After	p	r
Relaxing (n = 16)	-0.125	-0.375	0.331	-0.172
Enlivening (n = 17)	-0.529	-0.353	0.310	0.174
Mood stabilising (n = 11)	-0.818	-0.182	0.167	0.295

E. QUALITATIVE DATA

Participants were given the option to leave comments with regard to their physical, emotional and relational wellbeing, sense of meaning and positive and negative valence. Nineteen participants left comments. Example quotes from the comments are given in Table 8. The comments are categorised into themes (e.g. 'tired', 'apathetic', 'sad', etc.) by the authors.

Participants choosing enlivening playlists commented on feeling tired (P2E, P3E, P5E), apathetic and more down than usual (P1E, P5E), nervous (P3E), sad as they are disconnected with others (P4E, P6E), and struggling to get motivated (P6E, P1E). One participant reported being relaxed and positive (P7E). After music listening, the comments included: less apathetic, feeling better and more optimistic, better sense of meaning (P3E, P5E), working better after the music (P1E), anger while experiencing inner restlessness and tiredness before listening (P2E), impatience and annoyance while reporting feeling relaxed and positive before the music (P7E). One participant reported still tired (P2E), and another one reported feeling pain (P5E). Example quotes can be seen in Table 8.

Participants choosing relaxing playlists reported tiredness (P1R), pain and tension (P3R, P4R, P6R); heaviness (P2R), anxiety and worry (P1R, P5R, P6R), and difficulty in motivation (P6R). After music listening, participants reported no pain or discomfort (P3R, P6R), feeling calmer and lighter mood (P1R, P3R, P4R, P5R, P6R), and sadness (at not being able to see family P2R). Example quotes are shown in Table 8.

The moods playlist group reported discomfort and pain (P2M, P5M, P7M), anxiety and stress (P2M, P5M, P6M), sense of being lost, being disconnected, sadness (P1M, P3M, P4M), dissatisfaction and motivation issues (P8M).

After listening to 'mood' playlists the participants reported feeling better, less tired, less anxiety, more clarity, optimism (PM6, PM7, PM8), greater feeling of acceptance (PM7), more connected (P3M, P1M), anxiety (P2M) and apprehension (P3M). See Table 8 for some example quotes.

III. DISCUSSION

The analysis suggests that music positively influences wellbeing and emotions. The statistical tests show significant positive changes in physical and emotional wellbeing and in valence and sense of meaning, with a medium effect size for all but physical wellbeing for which the change was associated with a small effect size. There are a number of studies on the impact of music on emotions, however, there is no systematic work being performed on the impact of music on awareness of changes in wellbeing, including both visceral awareness (body sensation) and emotion [48], [73].

In this study, awareness of body was built in the design of the wellbeing diary. The design was informed by the 'pyramid of wellbeing' model, focusing and enhancing participants awareness of bodily sensations, emotions and the level of pleasure/displeasure of experience. This study reports a significant, positive impact of listening to music playlists, curated by X-System technology, on both physical and emotional wellbeing with participants reporting reduction in discomfort, stiffness and pain, as well as reduction in anxiety, inducing more positive emotions and facilitating self-regulation [74].

It is important to communicate the high correlation (Pearson coefficient 0.6) between changes in emotional and physical wellbeing (Tables 5 & 6) thus acknowledging that the emotional and physiological aspects of wellbeing are interrelated. This is also confirmed by a high correlation between changes in valence (pleasant vs unpleasant experience) and physical and emotional wellbeing (Pearson coefficients 0.514 and 0.690). Sense of meaning is highly correlated to emotional wellbeing, while low correlation is observed between sense of meaning and physical wellbeing. This is to some extent surprising as emotional wellbeing is strongly correlated with physical wellbeing. Other studies report similar findings i.e. Flensborg-Madsen *et al.* report low correlation between sense of coherence (meaning) and health, but high correlation between emotional wellbeing and sense of meaning [75]. From a perspective of autopoiesis, perception of wellbeing is a non linear process and the interrelatedness of different aspects of wellbeing emerges in context. This study was conducted during a pandemic with social distancing rules in place, which may have had an effect on the participants perception of sense of meaning and that may explain the results.

Changes in relational wellbeing (sense of connectedness) at $p = 0.297$, $r = 0.0056$ were not found to be significant (Table 3). Two factors may have played a role in reporting a low impact on relational wellbeing. The music was streamed online to an individual listener, rather than to an audience and/or live. The study was undertaken during the pandemic

TABLE 8. Example quotes given by participants for different types of playlists.

	Before	After
Relaxing	- Feeling tired all the time P1R - Stressed, anxious P5R - Pain and tension P6R - I know that housework will make my house nicer to live in but enthusiasm is in rather short supply! P4R	- Feeling calmer P5R - less anxious P1R - not much discomfort, relaxed P3R - No pain or discomfort P6R
Enlivening	- I'm very tired and my eyes are red from working at the computer 12 hours in a row…'P2E - Pain in back hip and neck P5E - Really struggling to get motivated. I know work is piling up and deadlines are approaching. Breaking promises to myself which isn't good P6E	- More enthusiastic more positive about the meaningfulness P5E - Pain in spine, discomfort in hips P5E - Getting down to work better after the music P1E - I'm very tired P2E
Mood managing	- I feel disconnected P3M - Sadness futility P4M - A few muscle aches. Quite low energy … lacklustre P7M - I enjoy my work but I don't feel like I'm really doing what I want. Family life is hard work even though I love them P8M	- I feel slightly more connected P3M - Greater feeling of acceptance P7M - I said tired before but I do think I feel a bit more rejuvenated P8M - I thought it was a bit of joke before but I think I just feel different in a good way a but more positive P8M

lockdown and music streaming alone would not have been perceived as impacting relational wellbeing.

The analysis suggests that the emotions are highly correlated. The results are coherent with studies reporting that people do not just experience one emotion, one or more may be prevalent [43], [65], [76]. Other studies propose that the accuracy that one exhibits when differentiating between emotions and the accuracy of emotion labels depend on the emotional granularity one is capable of and the available emotion words. When emotional granularity is low it is likely that one may cluster several emotions together [43]. Other studies propose that individual differences in the neural underpinnings of conscious internal sensitivity to visceral activity, termed interoceptive awareness, are related to emotion awareness [77]. In this study, the 'pyramid of wellbeing' model and the diary approach to the evaluation of impact, support an enhanced awareness of embodied state and thus a capacity for greater emotional granularity.

Participants listening to enlivening and mood playlists observed increased motivation and sense of meaning, and overall positive change in emotion and valence, but a lower effect on diminishing tiredness and discomfort, compared to the relaxing playlists. Participants choosing relaxing playlists report less anxiety and increased sense of meaning and motivation, as well as change in physical discomfort: tiredness, pain and tension are significantly diminished or disappear after listening. The decrease in the arousal level shown by these participants is consistent with Porges' polyvagal theory [78]–[80] where an increase in the relaxation response is correlated with parasympathetic system activation, promoting internal conditions for rest, digest and healing.

The arousal level decreased for the relaxing playlists while increasing for the enlivening and mood playlists. However, none of the differences are statistically significant (Table 7). Further research is needed to investigate whether appropriately curated playlists may be able to lead the listener to positive relaxation or activation states.

IV. LIMITATIONS

This was a study conducted during the time of the COVID-19 pandemic which presents several limitations that need to be addressed in future work. One limitation is the demographic information about the participants. Future investigation should include a larger sample with participants who are more thoroughly representative of different age groups and other demographic factors. Another limitation is the limited qualitative data. Future research would benefit from encouraging participants to share their experience in free text, to allow for cross-reference between quantitative measures and individual perception of wellbeing and emotion. The playlists used in the study had a predefined duration as discussed in the beginning of Section II. The effect of playlist duration was not within the scope of this study but could be considered in future research. In addition, further development of the evaluation tools to allow for a more intuitive graphical user interface, would avoid any potential ambiguities in interpreting emotion labels and improve accuracy in the measurement of the arousal level derived from emotions' ratings.

V. CONCLUSION

Listening to X-System music entrainment playlists was found to have a positive impact on physical and emotional wellbeing, valence and sense of meaning. The changes that

these entrainments produced were measurable and significant with a medium effect size for emotional wellbeing, valence and sense of meaning, and small effect size for physical wellbeing. The participants' comments confirmed positive emotional change and decrease in physical discomfort. This suggests there are potential health benefits to music listening and the need for further research into the impact of music on health.

The X-System relaxing playlists led to a decrease in arousal levels and the enlivening playlists to an increase in activation. Although these particular changes were not significant, the direction of change was as predicted by X-System. Predictions of valence were significant. Thus, appropriately curated and calibrated music playlists may be able to lead the listener by entrainment to positive relaxation, to activation states or indeed to positive mood change that may have health benefits.

The wellbeing model and diary approach used in the evaluation allowed for monitoring change, i.e. before and after music listening. The quality of the data was enhanced by: focusing the participants awareness on their immediate embodied experience of physical, emotional and relational wellbeing and sense of pleasure/displeasure, while requesting that they rate and interpret the experience themselves. It would be beneficial to further develop the wellbeing diary to enhance quality of observation through explicit reference to openness and objectivity, i.e. observing kindness to self while witnessing present moment experience. In addition, development of a more intuitive graphical user interface would allow for a seamless connection to experience bypassing language articulation.
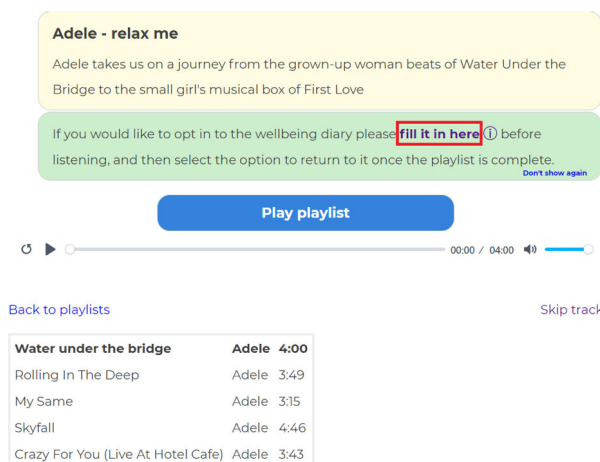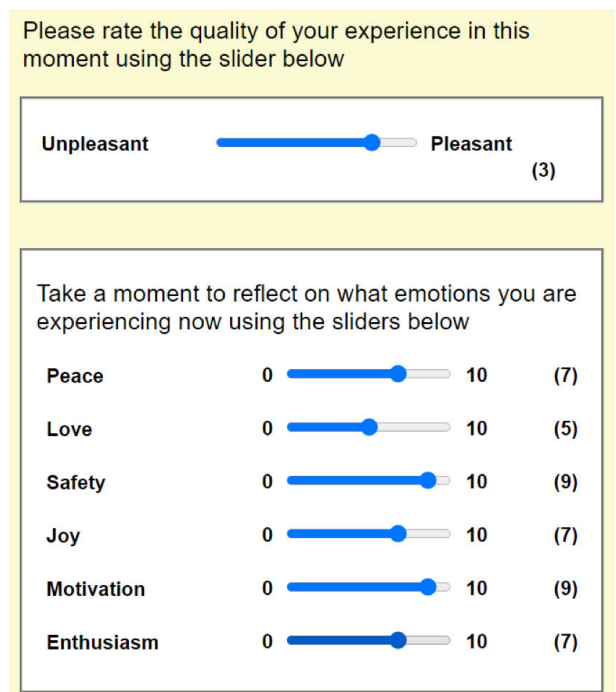

FIGURE 7. An example Music for Wellbeing – Recovery College Online music playlist. Users have the option to follow the highlighted link to the Wellbeing diary. Doing so leads the user onto the screens shown in Fig. 8 and 9 which are designed to measure the user's wellbeing prior to listening to the music.

APPENDIX A

This appendix includes examples from the wellbeing diary page on the Music for Wellbeing website - Recovery College Online, used to collect the data (Fig. 7, 8, 9, and 10).
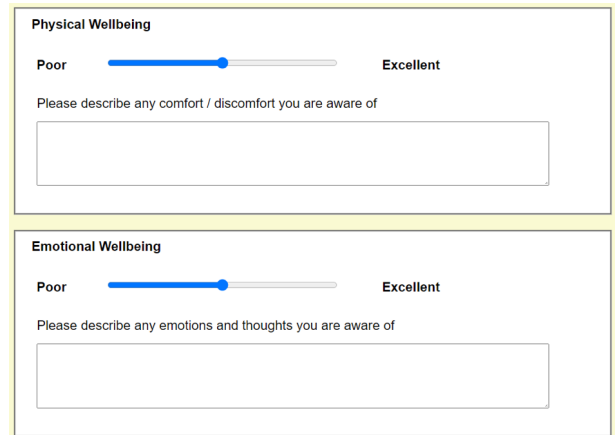
FIGURE 8. An example from the Wellbeing diary page intended to collect user data on their sense of wellbeing.

FIGURE 9. An example from the Wellbeing diary page intended to collect data on how they are feeling. Following this, the user is directed back to particular music playlist they had selected in Music for Wellbeing site which will automatically start.
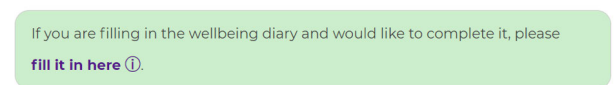
FIGURE 10. When the playlist has finished, the message and link shown here are displayed. Following the link takes the user back on the Wellbeing diary where they can complete and enter the data required in the pages shown in Fig. 8 and 9 again. This facilitates measuring of the user's wellbeing after listening to the music.

APPENDIX B

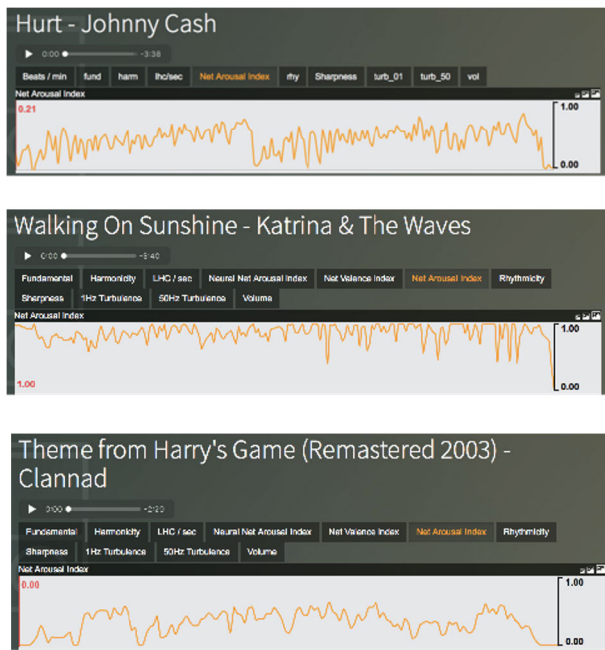This appendix includes examples of songs' analysis generated by X-System software (Fig. 11).

FIGURE 11. Examples of 3 songs analysed by X-System.

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PETIA SICE received the Ph.D. degree in complex systems sciences. She is currently an Associate Professor with the Department of Computer and Information Sciences, Northumbria University, specializing in wellbeing informatics. Her research interest includes interpreting and applying insights from complexity theory for facilitating positive transformation in individuals and organizations. She is also a Convenor of the U.K. EPSRC Systems Practice and Managing Complexity (SPMC) and a Senior Associate Editor of the *International Journal of Systems and Society*.

YILUN SHANG received the B.S. and Ph.D. degrees in mathematics from Shanghai Jiao Tong University. He is currently an Associate Professor of computer sciences with Northumbria University. His main research interest includes complex networks and systems. He was a recipient of the 2016 Dimitrie Pompeiu Prize, the 2018 Energies Best Paper Award, 2019 MDPI Top Reviewer Award, and the 2019 IEEE Access Outstanding Associate Editor Award. He has served as an Editor for some international journals, including *Scientific Reports* (Nature), *Frontiers in Physics*, the *KSII Transactions on Internet and Information Systems*, and the *European Journal of Pure and Applied Mathematics*.

GARRY ELVIN received the B.Sc. and M.Phil. degrees in computer science. He is currently a Principal Lecturer with the Department of Computing and Information Sciences, Northumbria University, U.K. His work focuses on social computing applications and mental health and includes Ph.D. studies on supporting student mental health online in student populations. He has over 20 years' experience in web development.

SUZANNAH OGWU received the B.Sc. degree in information and communication technology, the M.Sc. degree in information management, and the Ph.D. degree in developing technology for self-awareness in virtual communication. She is currently a Research Assistant and an Assistant Lecturer with the Department of Computing and Information Sciences, Northumbria University, Newcastle, U.K.

CHIRINE RIACHY received the B.Sc. degree in pure mathematics from Lebanese University, Lebanon, the master's degree in computational mathematics from the University of Balamand, Lebanon, and the Ph.D. degree in machine learning and computer vision from Northumbria University, U.K. She is currently a Senior Research Assistant with Northumbria University. Her research interest includes data science.

CORINNA ZINK received the B.A. degree in business from Rheinische Fachhochschule, Germany, and the M.Sc. degree in information science (data analytics) from Northumbria University, Newcastle, U.K. She is currently the Medical Data Scientist of the University Hospital, RWTH Aachen, Germany.

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