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Heart rate-based dynamic sound intervention – a pilot study

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Abstract
In this paper we present a pilot study on the prospects of working with dynamic sound intervention that adapts to physiological data. The study concerns an investigation of whether dynamic synth-based soundscape compositions, that adapt in tempo to the heart rate of a user, can lower and stabilize the heart rate faster than a 60 beats per minute (BPM) static synth-based soundscape composition. The assumption of the dynamic soundscapes is that if the tempo constantly decreases with either an adaptation of 10% or 2% below the actual heart rate, this will aid in bringing the user from a stressed to a more relaxed state (after 1 minute of physical/psychological exercise). To test the assumption, we included 46 test subjects in a repeated measures test with four different conditions of silence, static, and two variations of dynamic sound stimuli. The study furthermore includes short interviews on how the test subjects experienced the different conditions. Using the velocity of the decreasing heart rate as a measure, the influence of the four different conditions was estimated. The study cannot present any results of statistical significance between how fast the static and dynamic soundscapes decrease the heart rate. Qualitative insights from the interviews reveal how a majority of the test subjects found the characteristics of the soundscape composition relaxing and comfortable, while more varied responses were found in assessing the composition as exciting, boring, and vibrant. The paper discusses the findings and presents critical thoughts on what could be considered in a further development of a concept like this. Even though the study cannot reject the null hypothesis, the paper brings a new perspective to the area of working with sound intervention in health.

Keywords: Sound intervention, Physiological data, Generative soundscape composition, Adaptive sound

1 Introduction

This paper is an investigation on the possible effect of a heart rate-based dynamic sound intervention. Throughout the last decades thorough research has been conducted within music intervention in the health care sector, and this amongst other suggests an advantageous use of music when it comes to releasing stress amongst critically ill patients [1]. The hypotheses in this study is primarily shaped around questions regarding tempo of a soundscape composition. The idea of a correlation between the tempo of music and the heart rate is not a new scientific focus. Former studies have explored this with a clear confirmation on the close relation between the tempo of music and the heart rate [2,3,4,5]. A new perspective to add to this is a dynamic aspect of the development of tempo in the soundscape. One thing is to state that slow music will decrease the heart rate and in contrast fast music will increase the heart rate, but what about a soundscape that continuously adapts to meet the heart rate in trying to aid it decreasing? Could this have an even more fortunate role in bringing a patient from a stressed to a more relaxed state? The agenda in addressing this area of research is to explore whether you can detect any significant difference in static versus dynamic sound intervention. Preliminary studies with 8 test subjects on hypothesis 1 revealed indications about the conditions of soundscape intervention having an advantageous effect in decreasing the heart rate faster than no intervention. There was no tendency in relation to a difference between the static and dynamic sound intervention. These initial tests gave rise to a further investigation with an increased number of test subjects and a second hypothesis proposing an increased percentage gap between the heart rate and the tempo of the soundscape composition.

H_1: With a generative synth-based soundscape composition, that adapts to the heart rate of a user by setting the Tempo (BPM) 2 % below the measured heart rate, it is possible to lower and stabilize the heart rate faster than with a static synth-based soundscape composition or no intervention.

H_2: This hypothesis is similar to H_1 with exception of the tempo of the soundscape composition being 10% below the measured heart rate instead of 2%.

H_0: There is no difference to detect in how fast the heart rate is lowered and stabilized when you listen to the dynamic or static synth-based soundscape composition.

1.1 Project context

The project is a sub-project with connection to a larger context of investigating interactive sound zones in domestic and health care settings in a four-year long research project named Interactive Sound Zones for Better Living (ISOBEL) [6]. ISOBEL is a project in collaboration of the Danish companies Bang&Olufsen, SoundFocus, WaveCare and two departments of Aalborg University (Department of Electronic Systems/ Department of Computer Science). Due to an overall interest in exploring and developing new interaction techniques enabling dynamic sound zones, this minor project erupts as a pilot study to detect what could be an interesting field of heart rate-based sound intervention and possible inspiration for content within these sound zones. The purpose thus is to kickstart the process of exploring ways to work with dynamic sound content and how that might affect the user in both a physiological and perceptual manner.

2 Soundscape Composition

The synth-based soundscape composition is designed in the software programs Ableton and Max MSP specifically for the purpose of this context. It is characterized by self-generating elements that evolves on the basis of both fixed and random parameters. Due to studies about the pentatonic major scale being able to increase the parasympathetic tone [7], a fixed parameter is for the composition to stay within the major pentatonic C-scale. Due to the focus on detecting a correlation between sound and heart rate, the rhythmical aspect of the composition plays an important role in creating the perceptual synchronization between the current heart rate and musical tempo. A semi-random drum pattern is divided into three intervals with slight differences in the rhythm and number of subdivisions of the beat. This is to accommodate a pleasant and non-stressful feel in 130 as well as 50 BPM. The self-generating and random parameters in the composition, are an attempt to mimic characteristics found in nature sounds. *The Attention Restorative Theory* [8] suggest that nature can help us improve our mental health and one of the reasons has to do with the concept of *Soft Fascination,* which is about attending to inspiring patterns effortlessly while still being able to focus on other things. Nature sounds can at the same time possess captivating qualities and soothing effects [8]. The synth-based soundscape composition aims at balancing the expected and unexpected in how the evolvement of the sounds behave. This is to evoke some connotations to that same feeling of being both inspired and soothed.

Regarding the different functions of the soundscape being both static and dynamic, there are different conditions for the tempo. The static soundscape has a fixed tempo of 60 BPM, since findings indicate that music around 60 BPM can cause a synchronization between brain and music creating alpha brainwaves, which characterizes a relaxed state [9]. When the soundscape is dynamic, the composition evolves in accordance with the heart rate, by continuously being 2% or 10% lower than the real-time measured pulse. This adaptation of 2% or 10% is based on another study investigating the relation between increased acoustic tempo and elevation in the heart rate [3]. Here the increment of tempo was based on heart rate measurements from a baseline period and not continuous measurements of the current heart rate. Even though we apply this in a different real-time context, these findings have functioned as inspiration for determining the conditions for the adaptation between soundscape and heart rate. Since results from the abovementioned study indicate that the tempo of the music should neither be too close nor too far from the heart rate [3], the current study included two dynamic sound interventions with the different adaption conditions of 2% and 10%. In this way this study not only tested for an effect of the dynamic conditions compared to no intervention and the static condition, but also for how closely the tempo of the soundscape composition should follow the heart rate.

3 Experiment

An experiment was conducted to test the different hypotheses. Physiological data on the heart rate development during each phase was gathered. Furthermore, short interviews were carried out with the aim of addressing the perception of the four different conditions.

3.1 Test conditions

The test setup consisted of four different phases each including one of the four stimulus conditions: no intervention, static soundscape intervention and dynamic soundscape intervention with an adaption rate of 2% or 10% respectively. The sensor used to adapt the dynamic sound stimuli to the heart rate and to monitor the evolvement of the pulse throughout the different conditions, was a Garmin HRM-Pro breast strap, measuring the heart rate through an electrocardiogram (ECG). The test was conducted on 46 subjects in an age ranging from 20 to 28. 19 men and 27 women who was all told that they participated in a listening experiment with four different soundscape conditions each of five minutes but not the characteristics of these conditions. Prior to each phase, each test subject was exposed to a one-minute long combined physical and psychological stress test, to increase the heart rate and emulate a stressed body state. This involved stepping up and down a step bench in the tempo of a 115 BPM, while performing a *Stroop Color test* [10]. After the one-minute stress test, the subject was without further instructions placed in a comfortable chair wearing headphones and then one of the four stimuli would play for five minutes. The playback level was adjusted to the individual preference. To avoid any unfortunate effects from a fixed stimuli order, the order of the different conditions was randomized. Furthermore, the soundscape composition played through speakers during the introduction of the test for the test subjects to habituate to its characteristics. When all four phases had been conducted the test was wrapped up with a short interview to collect demographic data and to address the perceptual experience of the stress test and the soundscape characteristics.

3.2 Data processing

The method in analyzing the collected data was directed at determining the (quite stable) heart rate reached during the five-minute resting period, and the velocity of how fast this value was reached. The heart rate time series data was modelled using a piecewise linear shape: A slope describing the change of heart rate from high to low, and a flat section describing the stabilized (low) heart rate. In order to find the value of the stabilized heart rate the heart rate dataset was divided into two distributions corresponding to two groups of high and low heart rates, respectively. Using a Gaussian mixture model (GMM) [11] the datasets were split into two clusters with mean and variances as output for each cluster. The lowest mean is the stabilization value. The stabilization time was found as the time it takes the heart rate to reach the lower mean from the maximum value. The stabilization velocity is the slope of the linear regression applied to the heart rate data from $t = 0$ (the starting time of the five-minute intervention after the one-minute stress test) to $t =$ stabilization time. An example of these calculations and the development of the heart rate for one of the test subjects is shown in Figure 1. These values enable us to talk about at what level the heart rate of a test subject can be considered to be stabilized and the velocity of how fast they reach that level. In correlation with the different stimulus conditions, these values are what form the basis of the statistical test.

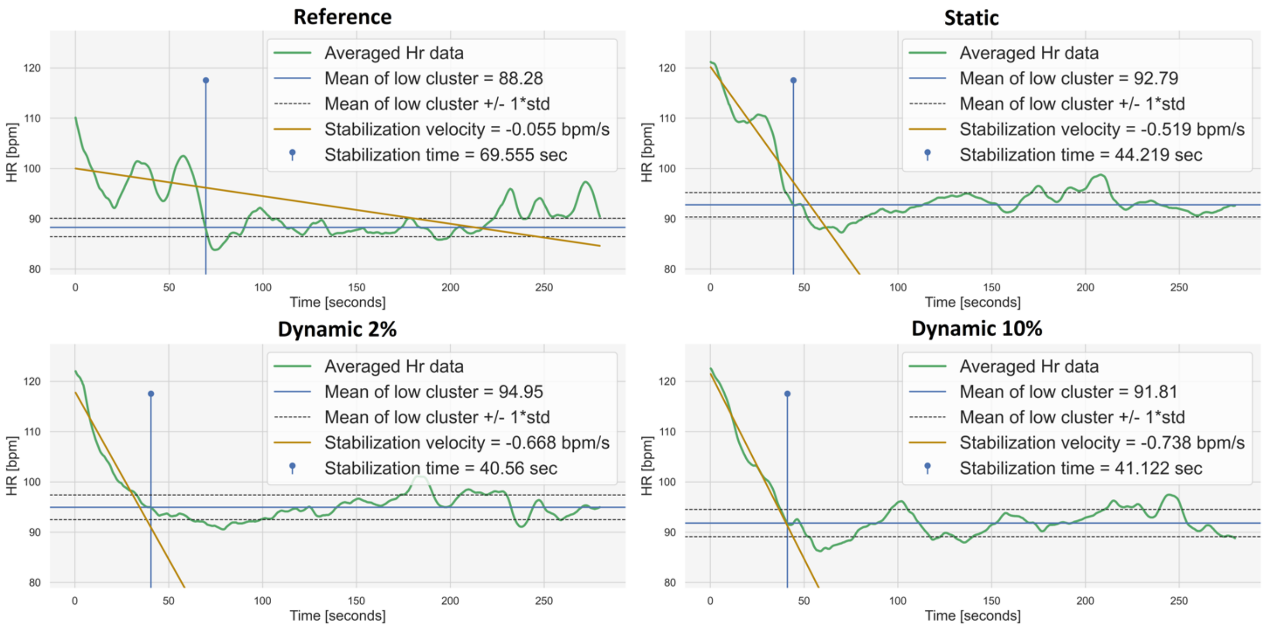

Figure 1: Calculation of heart rate stabilization and velocity of decrement. T = 0 is the starting time of the five-minute intervention after the one-minute stress test.

3.3 Statistical method

To test for an effect on the velocity in the different conditions, a one-way repeated measures ANOVA within subjects was conducted using the *ezANOVA()* function in RStudio with *Condition* being the predictor variable and *Velocity* the outcome variable [12].

3.4 Results

3.4.1 Statistical findings

With the statistical analysis it has been found that the null hypothesis cannot be rejected, since the calculated p-value is 0.8 and thus there is an 80% chance of the result being arbitrary. The study therefore indicated no significant difference between how fast the dynamic and the static soundscape decreases the heart rate. Figure 2 illustrates how the four conditions have a wide distribution of velocity values and a small effect size. With the velocity values distributed on both sites of zero, it indicates that the effect of the conditions sometimes opposed what was assumed. The characteristics of the data distribution corresponds to the lack of statistical significance. Nor does Figure 3 present any convincing results. If we were to extract any indications in favor of the study though, a feeble inclination of the expected tendency, about the dynamic soundscapes being faster in decreasing the heart rate than the static soundscape or no intervention, can be found in the mean values of the measured data. However, with all the mean values being within the overlapping confidence intervals, the final excerpt is still that the results might as well be arbitrary.

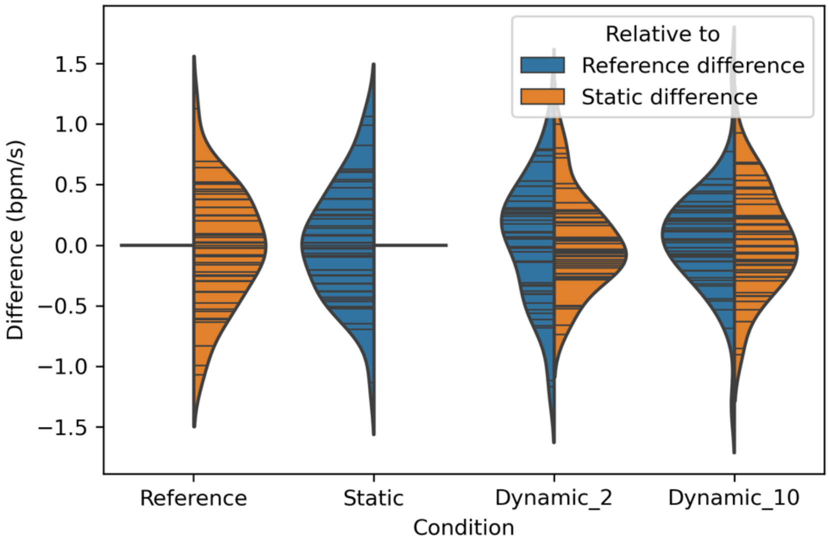

Figure 2: Violin plot illustrating the data distribution and the conditions and their difference in velocity relatively to each other.

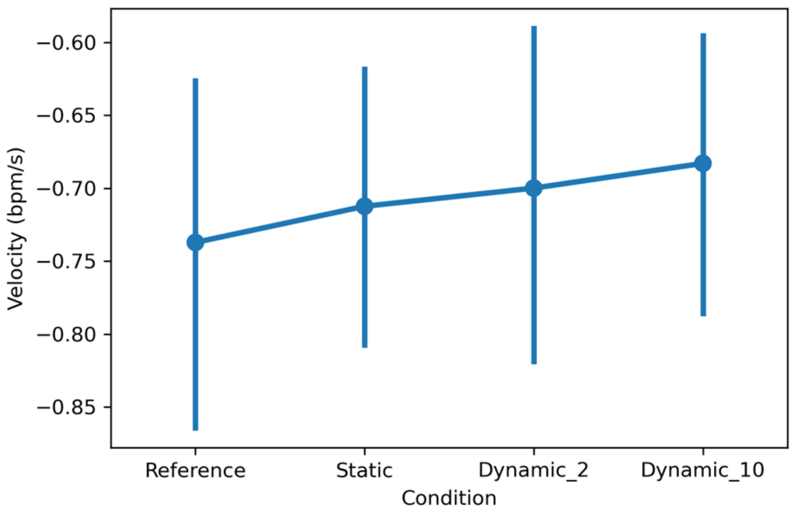

Figure 3: Plot of mean values and confidence intervals.

3.4.2 Demographic data and the perceptual experience

Regarding the collected demographic data, the key study was that the group of test subjects appeared relatively uniform. All test subjects were somehow related to programs at Aarhus University, which reflects the age ranging from 20 to 28. Furthermore, we asked for a self-assessment on physical shape which varied over a scale from one to ten, but with the majority assessing themselves above average. The results and any possible tendencies can therefore only assert itself for this specific demography.

According to how the test subjects perceived the overall characteristics of the soundscape composition, they were asked to what degree they agreed on the soundscape possessing eight predetermined characteristics. Figure 4 presents a broad consensus about the soundscape characteristics being relaxing and comfortable. In contrast, Figure 4 reveals inconsistencies when it comes to the perception of the soundscape being exciting, boring, and vibrant. In more open questions about a comparison between the different stimulus, the majority commented on how they felt that the sound stimulus helped them direct focus towards the soundscape and their breathing. It slowed down their racing thoughts, which instead was dominant in the silent stimuli. Furthermore, the interview did not disclose any prevalent pattern in whether the subjects perceived any difference between the soundscape tempo being static or dynamic. Some perceived the dynamic evolvement of the tempo being a guide in decreasing the pulse and reaching a more relaxed state, while others found the change of tempo less relaxing. Several subjects found it hard to tell the three sound conditions apart.

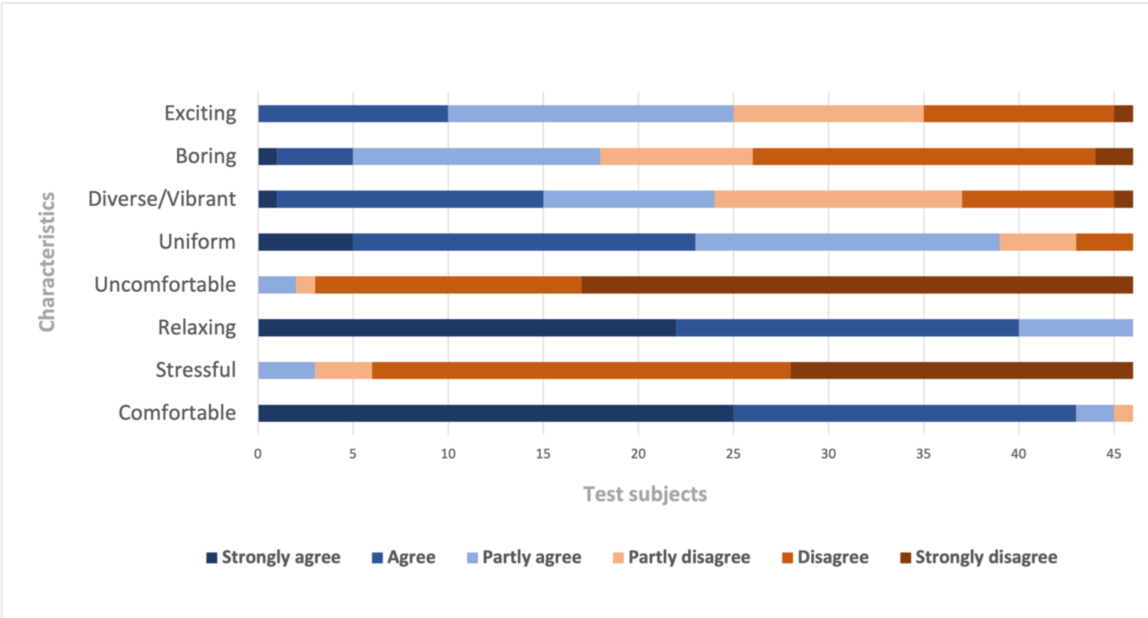

Figure 4: Evaluation on the experience of the soundscape within predetermined characteristics.

4 Discussion

The results from the statistical model do not allow us to reject our null hypothesis, since there is no significant difference between any of the four conditions. This could be due to many factors.

4.1 Data processing methods

In considerations of what could have had an impact on the results not achieving statistical significance, one reason could be in the chosen method for processing the physiological measurements. Perhaps the simple data model consisting of a constant stabilized heart rate in combination with a linear decrease in heart rate was not the ideal method. Other data models which can better accommodate the more complex evolution of heart rate as function of time could be investigated.

4.2 Characteristics of soundscape composition

Regarding the characteristics of the soundscape composition, this too could have an impact on the decrement velocity. Figure 4 indicates an overall agreement on the soundscape characteristics being relaxing and non-stressful, but even more efficient approaches in composing soundscapes for the purpose of relaxation and decreasing the heart rate could exist. Though tempo could seem like the obvious parameter to control the heart rate by, other parameters such as frequencies or amplitude levels could be of relevance to consider. Furthermore, one could ask why the composition consisted of synthetic sounds and not nature sounds, when these are the ones, the composition tries to mimic. An answer to this could be the advantage of flexibility in the synthetic elements and the fact that the dynamic tempo changes could add unwanted and unnatural distorted effects to nature sounds. Though it might be more convenient to use synthetic sounds in a dynamic context, it does not necessarily mean that synthetic sounds are the best choice for every occasion. Exposure to nature sounds has proven to be associated with reduced stress, and the reason why the natural elements are calming to us, is asserted to have linkage to human biology and our survival in the past [13]. It could be essential to investigate a comparison between an actual natural soundscape and a synthetic (dynamic) soundscape simulating the behavior of nature sounds, to see if the relaxation response mainly depends on the acoustic qualities of the sounds or the referentiality in the behavior of a nature soundscape.

To address the more opposing responses in determining the sound characteristics as boring, exciting, or vibrant, this could be due to individual preferences of music. Music-genre preferences depend on both intrinsic properties of the music and external associations. Therefore, the affective reaction to music is not only shaped around musical qualities, but also factors such as psychological dispositions, social interactions, generation, culture, etc. [14]. With the test subjects agreeing on the sound stimuli being relaxing and comfortable, but disagreeing in it being exciting and vibrant, it could suggest that, whether the soundscape succeeds in reaching a perceived level of *Soft Fascination* varies from individual to individual. Another interesting observation was the variation in whether the test subjects perceived any change of tempo in the dynamic soundscape compositions. The fact that many test subjects could not tell the three sound interventions apart, could indicate a positive effect of the three intervals in the drum pattern trying to accommodate a pleasant and non-stressful feel of the soundscape across a wide range of BPM values. Those test subjects who noticed the tempo change in the dynamic conditions varied in whether they found it soothing or not, which is in consistence with the results about the effect of the conditions sometimes opposing what was assumed.

4.3 Related work

As stated, this is not the first research project investigating correlations between a musical tempo and the heart rate, but there are not many with a focus of dynamic sound adaptation to physiological parameters in health care. There is a commercial system though, that works with personalized soundscapes. The company *Endel* has created an app, for mobile devices, based on a technology that adjusts soundscapes in real-time to physiological and environmental parameters such as location, weather, and heart rate [15]. It could be of inspiration to take more than just one factor into account, when deciding how to adapt a soundscape to a specific user. The increment of heart rate is not necessarily equal to an unfortunate mental state since the heart rate also increases due to many other factors and feelings [16]. Stress is a complex phenomenon and cannot be assessed reliably through standard heart rate measures only. The physiological level of stress is for example tightly coupled to the heart rate variability (HRV), indicating which part of the autonomic nervous system is currently active. Moreover, this is just one of many factors suitable to clarify a more precise stress assessment [17]. Therefore, it seems appropriate to take other factors and other sensory inputs into account in an adaptive environment. In this way we may move closer to presenting a soundscape solution as accurately as possible in responding reliably to the actual mental or physiological state of a user or patient.

4.4 Reflections on future work

Future work could revolve around trying to meet the assumptions of the study and obtain statistical evidence. This might be achieved through adjusting the data processing methods, possible improvements on the accuracy in assessing the stress level of a patient, or different approaches to composing soundscapes. Another essential perspective to add to this relatively new area of research could be how the concept of dynamic sound intervention could take shape in an actual health care context. Future investigations could potentially benefit from an expanded interdisciplinary approach involving a technical perspective and a more holistic approach in assessing not only the isolated effect and experience of the soundscape composition in itself, but also the soundscape composition in the context of the hospital environment. Following the International Organization for Standardization (ISO) on acoustics and soundscapes one must apply mixed methods to fully grasp the complexity of an acoustic environment and hence reach a comprehensive understanding of the context in which intervention is made [18]. The interviews might give us some insights on how the different conditions of stimuli and the characteristics of the soundscape composition are experienced, however we have no knowledge on the usage scenarios. How will patients experience interacting passively with a soundscape system while being in a perhaps critical physical or mental state? Could the system in any way be of disturbance to the work of the healthcare staff? How is the soundscape composition experienced in the context of other environmental sounds? Within the tradition of Human Computer Interaction (HCI), designing interactive systems does not only require considerations on the system being usable, but also about who the users are, how the system is going to be used, and what the context of the system is [19]. With an intention of investigating the application of dynamic soundscape intervention in hospitals, one could advocate a more ecological approach to not only consider justified or non-justified outcomes, but also the complexity of the context for intervention [20,21]. This could expand the study in a contextual matter, which might also inspire for solutions on how to improve technical matters.

5 Conclusions

In conclusion, this pilot study, and the investigation on the effect of a heart rate-based dynamic sound intervention, reveals that the null hypothesis cannot be rejected. This is due to the lack of significant difference in the velocity of how fast a static and the dynamic soundscapes decrease the heart rate. Besides justifying an effect of working dynamically with sound intervention, the purpose of this study was also to begin a process of exploring ways to work with dynamic sound content in health care. The study gave rise to some interesting considerations within the field of dynamic sound intervention. The approach presented in this study is not the only way of working adaptively with soundscapes. Heart rate is just one way of applying physiological sensory inputs for dynamic sound intervention, and likewise are physiological inputs just some of many possible aspects to adapt soundscape composition around.

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