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The Artist's Gauntlet: A Singers' Physiological Responses to the Stimuli of Rehearsing and Performing

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THE ARTIST'S GAUNTLET: A SINGERS' PHYSIOLOGICAL RESPONSES TO THE STIMULI OF REHEARSING AND PERFORMING

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ABSTRACT

This study examined the relationship of a subject's heart rate variability, respiration rate and other vital statistics to rehearsing and performing as a singer. Among the events used for data collection were individual lessons of undergraduates and a lecture-recital presented by a graduate student. Findings indicate a general upward trend in HRV and an increase in range of HR%MAX among subjects while singing, along with a general decrease of respiration rate.

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LIST OF ABBREVIATIONS

BPM .... Respiration Rate

HRV .... Heart Rate Variability

HR%MAX .... Heart Rate as Percentage of Theoretical Maximum

PI .... Physiological Intensity

CHAPTER 1

INTRODUCTION

In recent decades, heart rate variability (HRV) has become increasingly used as an indicator of relative conditioning in medical research, athletics training, and even real-time monitoring of public service and military personnel in hazardous situations.[1] Defined in simple terms, heart rate variability measures the distance in time between the onset of complete heart beats.[2] In general, it is desirable to have a variety of HRV values over a time span, as opposed to a stable HRV. It is noteworthy that the main function of HRV monitoring currently is as a detection precursor to a heart-related issue. HRV is not singularly accepted as a be-all, end-all indicator, but it does consistently aid in diagnosing individuals who are in danger of severe health issues but do not yet have a structural heart-related issue. The following study will undertake an examination of various subjects' HRV (as a primary measurement) while in the act of singing. This will be achieved through two separate types of contained studies: a sample of voice students with varying levels of voice study (measured during a subject's lesson) and a self-study

[1] Electrophysiology, Task Force of the European Society of Cardiology the North American Society of Pacing. "Heart Rate Variability Standards of Measurement, Physiological Interpretation, Clinical Use." *Circulation* 93, no. 5 (March 1, 1996): 1043–1065. doi:10.1161/01.CIR.93.5.1043.

[2] Huikuri, Heikki V, Timo Mäkikallio, K.E.Juhani Airaksinen, Raul Mitrani, Agustin Castellanos, and Robert J Myerburg. "Measurement of Heart Rate Variability: a Clinical Tool or a Research Toy?" *Journal of the American College of Cardiology* 34, no. 7 (December 1, 1999): 1878–1883. doi:10.1016/S0735-1097(99)00468-4.

that will involve a variety of conditions, including a voice lesson, a church choir rehearsal, and a recital performance. The goal, for which the data will be collected, is to view the differential in HRV and other vital statistics between singing and not singing, and between singing in varied circumstances. In other words, to see the real-time and direct physiological impact of singing on the performer's body. Many studies have examined the affects of music on non-musicians and generally indicate a positive correlation between musical stimuli and increased HRV (a positive cardiovascular health indicator).[3] However, studies that examined instrumental musicians as they performed found that heart rate and HRV trends were tied to the experience levels of performers and what type of 'performance environment' was in effect (rehearsal vs. performance, performance vs. competition).[4] The advent of certain wireless and mobile technologies now allows study subjects to be untethered while their ECG/EKG data is collected- an enormous advantage in measuring data while a subject moves on stage.

1.2 PURPOSE OF THE STUDY

This study will examine certain parameters in the physiology of a singer in the act of rehearsing and performing repertoire. The technology that will be used gathers a significant number of vital statistics; this study will primarily be focused on HRV and,

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[3] Vickhoff, Bjorn, Helge Malmgren, Rickard Astrom, Gunnar Nyberg, Seth-Reino Ekstrom, Mathias Engwall, Johan Snygg, Michael Nilsson, and Rebecka Jornsten. "Music Structure Determines Heart Rate Variability of Singers." *Frontiers in Psychology* 4 (July 9, 2013). doi:10.3389/fpsyg.2013.00334.

[4] Iñesta, Claudia, Nicolás Terrados, Daniel García, and José A. Pérez. "Heart Rate in Professional Musicians." *Journal of Occupational Medicine and Toxicology* 3, no. 1 (July 25, 2008): 16. doi:10.1186/1745-6673-3-16.

secondarily, the percentage of heart rate maximum (HR%MAX) and rate of breaths per minute (BPM). By focusing mainly on HRV, we hope to demonstrate in real terms the physiological benefits of singing on the singer's body. A recent study stated that HRV increases in singing (perhaps due to performers being required to control and coordinate their individual breaths) and that heart beat rates tended toward synchronicity within the performing group.[5] The purpose here is to look closer at HRV changes in solo singing- at what occurs physiologically while a singer is in the act. A comparison of HRV trends across a variety of non-musical activities will demonstrate that musical activity, and particularly singing, has a remarkably positive effect on the cardiovascular system. It is believed that this singing-acting zone may be as healthy as other forms of moderate exercise. The results will also be perused for the effects of change (tessitura, languages, etc.) and the often-dreaded differential of anxiety experienced in a live performance versus a closed rehearsal.

The parameters that are collected are wirelessly transmitted in real time from the measuring device to a computer. Specialized software then translates the provided data into chart and graph form for analytical purposes. The equipment used will also provide a time-stamp relationship between changes in heart-rate, heart rate variability, and the actual musical demands as they occur in real time. That is, the study will examine what happens on a physiological level while a singer is in the act. There are two primary concerns- what happens in terms of measured physiological parameters (as the performer-subject varies repertoire, languages sung, etc.) and what is the relationship of anxiety to performance, as expressed by the differential between a rehearsal 'average'

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[5] Vickhoff et al.

and the data provided on in a lesson and/or recital. By a large margin, the bulk of the existing studies on performance-anxiety and physiology have used instrumental musicians as subjects, due to the constraints of past technologies. Even so, such studies (particularly Iñesta et al.) suggest that there is a positive correlation between a performer's physiological load and a sensation of anxiety in performance. When solo sections or particularly difficult passages occur, a noticeable increase in HR%MAX has been documented. This study will examine not only this observation in terms of real-time data provided by subjects, but also how anxiety levels affect HRV. Future research might delve deeper into this field in a more finite manner, such as using physiological data to help determine what *Fach* (vocal category), and operatic roles might be best for an individual singer from a purely physical level. It seems possible that how a group rehearses and prepares for a performance, or perhaps how an individual singer prepares an opera role, could be influenced by using such data as biofeedback information. That is, how to aid the singer in being 'healthy' in an overall sense by avoiding 'over-rehearsal', or highlighting anxiety-causing passages. Future use of this technology might also show that some singing-actors react negatively to mitigating the demands of singing over an orchestra, as opposed to the pianos used in rehearsals and coaching. Such real-time data would be able to show the effects of 'oversinging', or 'pushing' the sound, in order to compensate for an expanded acoustic for performance space.

1.3 LIMITATIONS OF THIS STUDY

The first and foremost limitation to mention is one of sample size. Because the combination of wireless devices with electrocardiography monitoring is recent, the expense involved in a study for the necessary equipment that measures more than one live subject at a time would be high.[6] Such applications do exist, however, for use in aerospace and military medical support. On the basis of affordability, the sample group of subjects must be limited to one-at-a-time observation. Secondly, the technologies involved will be limited, and varied, in their respective capabilities. Newer technologies often come with a proprietary component; every manufacturer's equipment will vary slightly. This study will be in part governed by the state of privately-obtainable hardware and software. The data collected might be skewed by some unknown mechanical or technological flaw that is related to its manufacturing process. That being said, no updates or changes to either the hardware or software package will occur during the study. There are additional limitations to the communication standards placed on wireless devices that are commercially available and legal for the public at large. All wireless devices have a limitation on their transmission range. Common wireless devices (i.e. "Bluetooth", Wifi-related) that transmit and receive in the 2.4GHz spectrum compete for signal among many other digital wireless devices. Additionally, many cordless phones, remote controls, and electronic doorbells operate in this same spectrum. Line-of-sight transmission is the way to control most of the potential attenuation and contamination problems. The equipment selected for this study records data and transmits data by default, providing an additional error buffer. Although the sensor array (which in this case is an undershirt-worn band around the mid-chest) cannot be removed during any part of data collection, the freedom of movement allows for longer contact time between

[6] At time of writing, it costs just under $1000 USD to acquire the necessary hardware/software package. At least one manufacturer sells systems designed to test live teams of individuals- ten subjects at a time.

subject and sensor, and also allows the potential for measurements to be taken while the subjects are engaged a broad range of sample activities.

1.4 REVIEW OF LITERATURE

In the sample of studies related to the topics of both electrocardiography and music, the majority deal with issues related to music therapy. That is, the application of musical stimuli for the goal of some level of physiological rehabilitation or relaxation. The overall trend of such studies suggests that musical stimulus has a broad-context effect of relaxation, demonstrated in particular by a decrease in HR and an increase in HRV. As this study touches on a well-scrutinized body organ, we must also be mindful of the vastness of information on cardiovascular studies. An enormous aid in this process are the databases which are maintained by US National Library of Medicine and the National Institutes of Health (USA). Medical knowledge is notoriously fluid; historians suggest that heart rate was not studied until the beginning of the 17th Century (and the invention of a watch that allowed heart beat rate to be calculated)[7]. However, since heart-related issues have become known as a leading cause of mortality in the modern world, parameters of heart function measurement (such as HRV) have increased research focus.

As previously stated, studies that involved performing musicians indicated that HR and HRV are greatly affected by two primary factors: the level of experience and training of the individual performer, and the context of the 'performance' itself [8,9]. The

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[7] Billman, George E. "Heart Rate Variability - a Historical Perspective." *Frontiers in Physiology* 2 (2011): 86. doi:10.3389/fphys.2011.00086.

[8] Yoshie, M., K. Kudo and T. Ohtsuki. "Effects of psychological stress on state anxiety, electromyographic activity, and arpeggio performance in pianists." Medical Problems Of Perfonning Artists 23, no. 3 (September 2008): 120-132. CINAHL Plus with Full Text, EBSCOhost (accessed March 12, 2012).

less-trained musicians involved showed demonstrable increases in anxiety levels experienced during performance. Of great interest to this study is the research that finds the difference in physiological responses (again, primarily through HR and HRV) between rehearsal, performance, and competition performance conditions. The observed trend demonstrates that greater levels of anxiety are experienced in certain performance conditions (especially competition) over traditional live performance.

With the advent of certain technologies, here namely wireless tethering or the use of a device's on-board memory to allow download via serial bus, the physical connection between the sensors placed on the subject and the data-collection apparatus (i.e. computer) need not be constant. It should be noted that untethered studies- studies that used wireless technology, therefore allowing subjects to move and sing normally, are not common. This wireless advantage has not gone unnoticed, even outside of medical research. There are numerous studies on HRV relating to sport training and sports medicine. The diversity of studies does create some difficulty for the field of HRV study at-large; there is no standardization of equipment or of measurement values used. Each study is in effect limited to the technologies chosen.

1.5 METHODOLOGY

As previously mentioned, this study will be two small studies: a survey of a sample of voice students with varying levels of vocal training, and an extended monitoring of a single subject in multiple environments. For the multiple subject study, volunteer voice students will have their vital signs recorded wireless during their normal

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[9]Williamon, Aaron, et al. "Influence of fitness and physical activity on cardiovascular reactivity to musical performance." Work 41, no. 1 (2012): 27-32. CINAHL Plus with Full Text, EBSCOhost (accessed March 12, 2012).

weekly lesson time. A minimum of 30 minutes of data will be collected from each subject. The data is date-time stamped and then uploaded to a computer with specialized software that analyzes the information. The information can be examined in total elapsed time or by real time clock.

We will specifically look at changes to HRV while the subject is singing. Additionally, the study will examine the parameter of heart rate maximum, expressed as a percentage. Once this information is gathered and interpreted, the data can be placed alongside data collected from other studies, thus allowing a comparison of the physiological load placed on a singer actively singing versus other pursuits. To be sure, an individual's level of physical conditioning, mental state-of-mind at time of measurement and other factors will need to be excluded, in favor of the search for a broader trend of HRV and HR%MAX values.

Once the sensor equipment is installed and tested, a baseline reading of the subject's vital signs will be acquired. This will be done while the subject sits in a relaxed position, breathing deeply, until their vital signs reflect a decrease in HR. A marker is placed in the software at the moment the student begins physically singing. Voice lessons are often filled with starts-and-stops, so it should not be assumed that full-voice singing for a full hour will occur in each lesson.

For the second study, a trained singer-subject will have their vital signs measured in a variety of musical activities. Each collection session will be no less than thirty (30) minutes and will reflect data from: 1. individual practice, seated at a piano, 2. two church choir rehearsals and 3. a lecture recital. The physiological data gathered from these activities will be compared to other subjects' results and analyzed for changes in heart-related parameters.

CHAPTER 2

STUDY OF PHYSIOLOGICAL OUTPUT WHILE SINGING

2.1 STUDY OF UNDERGRADUATE SINGERS IN LESSONS

Once the equipment was acquired and tested, the study began by examining eight (8) subjects while in their normally scheduled voice lessons. Each subject was fitted with the sensor strap for the duration of their lesson. We should note here that the strap was too small to correctly fit certain subjects. Where not enough data was collected, the subject's heart rate variability cannot be discussed in depth. The equipment provides feedback on its signal strength via a parameter which the software describes "heart rate confidence". This signal confidence parameter was also recorded; sections where the signal confidence was too low (for accurate data to be collected) are ignored in this study. Overall, five male and three female singers were measured. Each subject had their age, height and weight entered into the data collection software. Subjects were asked about the length of their vocal study in years, and if they had eaten any food prior to the lesson. This last factor is a general consideration; heart rates are normally accelerated around two hours after eating a meal (as body organ use more energy to digest food intake). There was no consideration given to repertoire sung in the lesson or to the demands of Fach.

The data gathered from each subject was recorded to a solid state drive and subsequently loaded into analysis software provided by the sensor manufacturer. The software allows two (2) data streams to be displayed simultaneously on a y-axis.

Additionally, markers were manually added through the software to approximate different events in each lesson (warm-up, repertoire, etc.).

2.2 CHART EXAMINATIONS

Subject A: This chart (Figure 1) presents a general impression of a declining HR%MAX during the lesson. According to the data, the subject underwent a shift from a range of 50-65% down to 35-50% in HR%MAX. Note that as this general trend occurs, there is not as much variation plotted on the chart in HRV. Looking at the parameter of HR Confidence (or, signal strength) reveals that the sections where there is a 'flatline' reading of HRV corresponds to a temporary loss or weakness of signal. The possible reasons for this anomaly are numerous; the most likely cause is that the sensor strap itself was slightly loose on the subject's torso.

Until the identifier 'Marker 1', the subject was in the warm-up section of the lesson. Note how, even without singing repertoire, overall HR began diminishing, with the spikes in HR%MAX generally accounting for temporary spikes in tessitura. At 'Marker 1', the subject began working on the notes to a Handel oratorio aria. The range of heart responses is less than in the warm-up section and HRV stays near 50ms. The section delimitated by markers 3 to 4 corresponds to a Mozart opera aria. There is a rise in HRV here, but the signal from the strap becomes more flatline after this rise. Other subject's charts will further indicate the presence of signal quality issues where HRV appears stagnant.

Marker 5 shows a section where the subject read aloud a text in monologue style. At Marker 6, the same text was sung full voice. In both the sung and spoken version, HR%MAX decreased during the event. However, the sung version has a pronounced spike in HR. It would be errant to make a blanket assumption that singing a text is *always* more work for the body than speaking the same text; one observation does not constitute a trend. However, the coordination of the breath along with the physiological load of singing does at least here have an impact on HR%MAX.

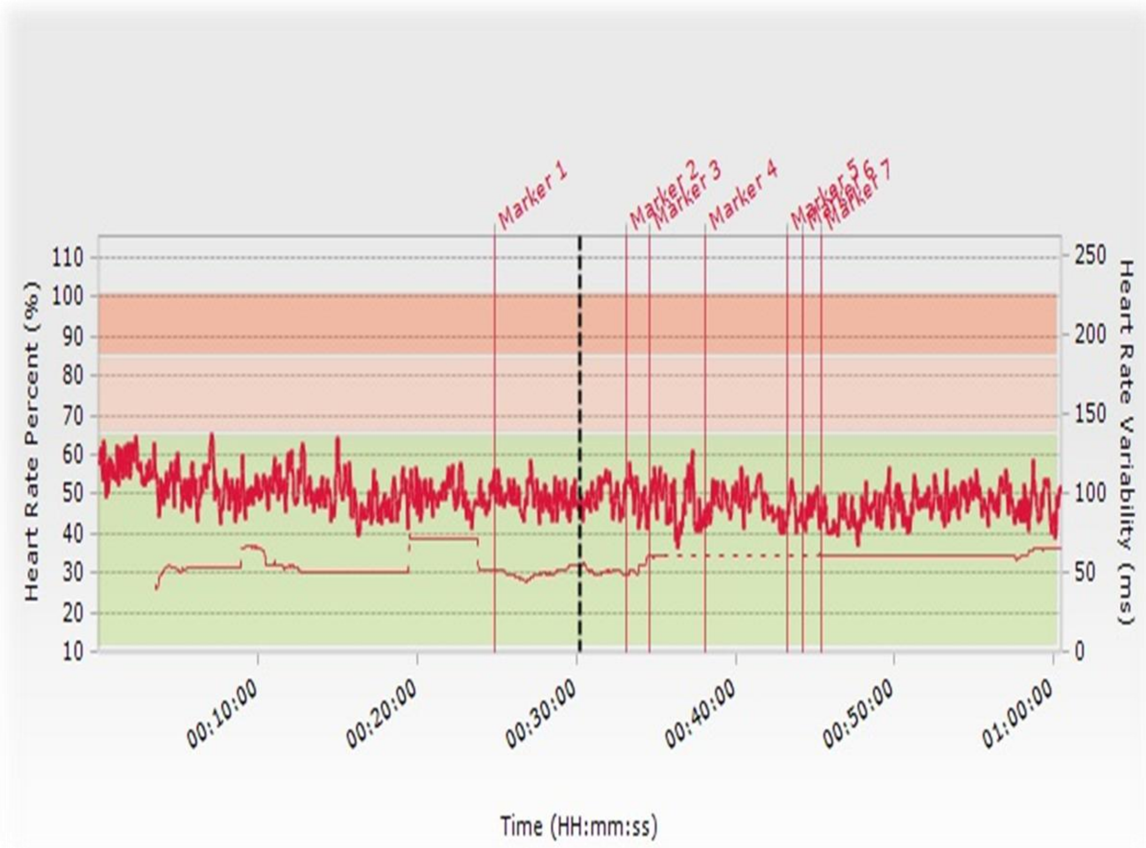

Figure 2.1 Subject A, HR%MAX and HRV

Subject B: Shown here in Figure 2.2 are the measured HRV and breath rate per minute (BPM). These two lines can be seen as opposite indicators- where the subject breathes normally (a higher rate of breath), HRV diminishes; the opposite occurs when coordinating the breath to sing. The spikes in HRV occur in moments of musical phrases.

The breath is in an exhalation mode for an extended period of time. This subject's HRV ranged between 45-104 ms for the measured hour, while breaths per minute ranged from 6 to 22 BPM. Periods of singing demonstrated a decreased rate of breath.

The calculated HR%MAX shows another interesting relationship between singing and the response of the heart. As the range of HR diminishes while singing, HRV often spikes. While sustaining a breath line for a phrase, it is supposed that the body is challenged in breath-gas management. The longer a particular phrase needs to be sustained, the less air enters the lungs over time. The response of the human body to this dilemma is, effectively, to lengthen heart beats. The corresponding chart shows that as the lesson went on in time, a general upward trend in HRV occurs.

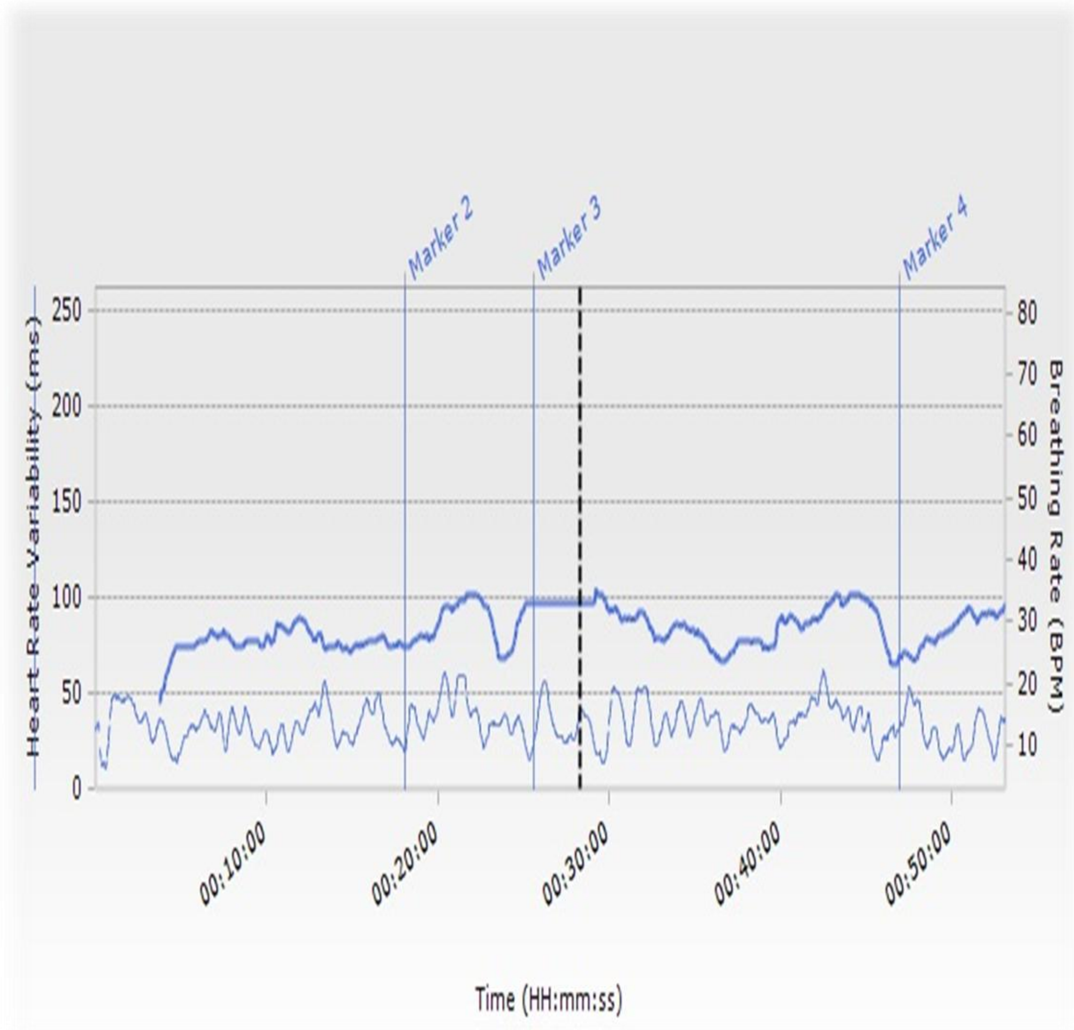

Figure 2.2: Subject B, HRV and Respiration rate

Subject C: The chart (Figure 2.3) for this subject reflects a contrast of demands on the heart. Markers 1-3 are the subject participating in the normal lesson events of warming up, followed by two songs. Note that the subject's HRV decreased during the warm-up phase, but increased while singing the two songs. At Marker 4, the subject sat down to view part of their recent recital which was on video. Even though the subject was seated, HRV changes stayed active. Observed HR%MAX diminished in range while the subject was seated and not singing. It is worth pointing out that the small spike in both recorded parameters near the end of the session was due to a good laugh, indicating the positive correlation between humor and heart already discovered in cardiovascular research. Another observation is that this subject's breath rate is in a less narrow range from Markers 1-4 than after Marker 4 where the video viewing began (see Figure 2.3 below).

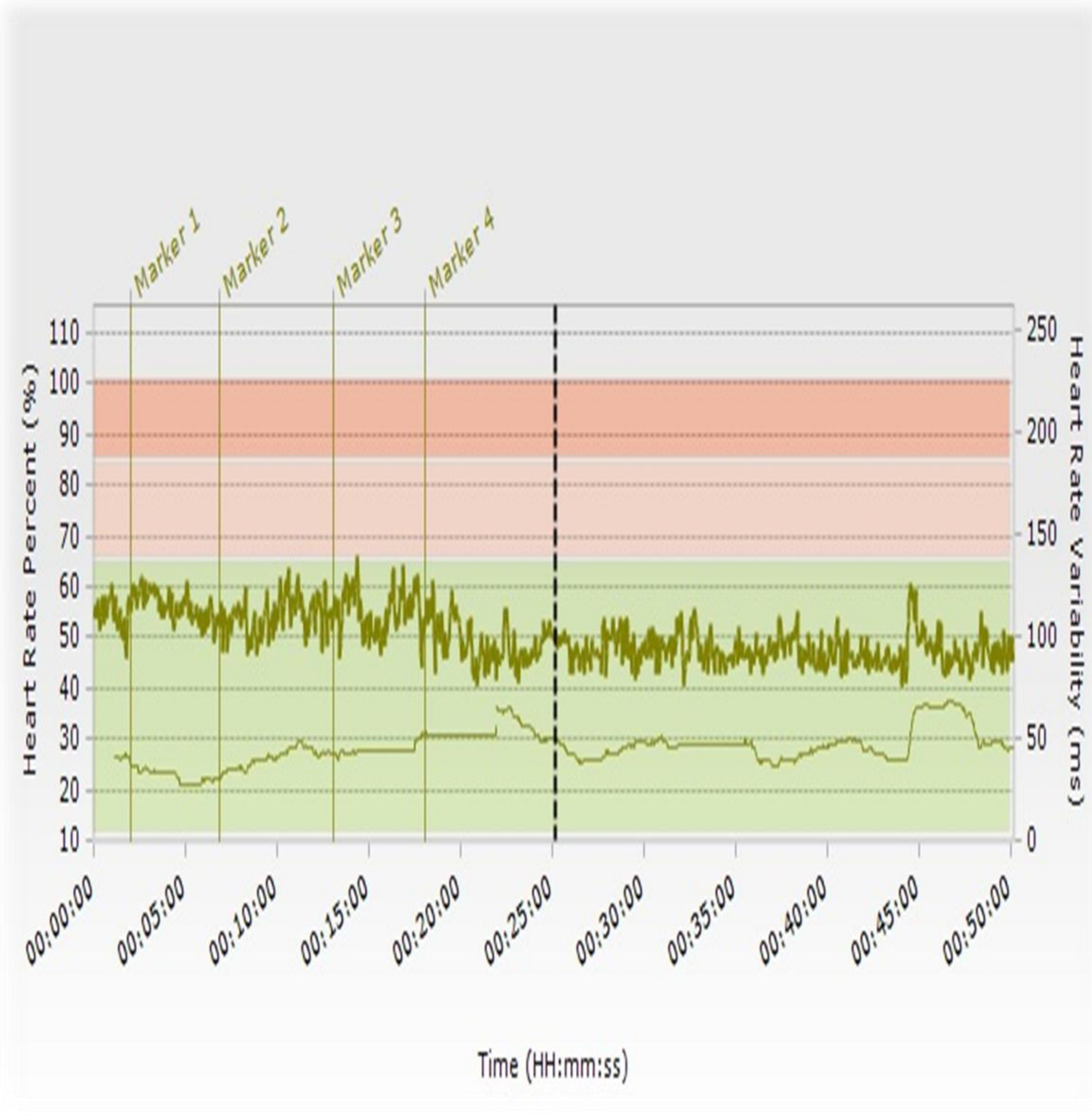

Figure 2.3: Subject C, HRV and BPM

Subject D: The amount of data collected for this subject was limited to a thirty (30) minute lesson time (Figure 2.4). As such, broad trends are not readily visible. However, another mitigating circumstance might be at work. This subject's primary instrument was trumpet. It was not clear during the lesson if the student had yet mastered the technique of sourcing the breath from the lower abdomen; breathing in this manner is not universally accepted as common practice in the study of singing, much less in instrumental breath management instruction. A possible interpretation is that a breath higher in the torso (commonly called 'chest breath') might be the technique the student employed. There is no desire in this study to enter into a comparison of breathing techniques, but rather to point out that Markers 4 and 5 (where the student sang a German and English language song, respectively) do not show the rise in HR%MAX as observed previously in other subjects. Additionally, the data collection process reflected a problem in gathering samples for the HRV parameter. Figure 2.6 shows that when the data was briefly collected with some confidence the subject's HRV slightly increased in coordination with a narrowing of BPM range.

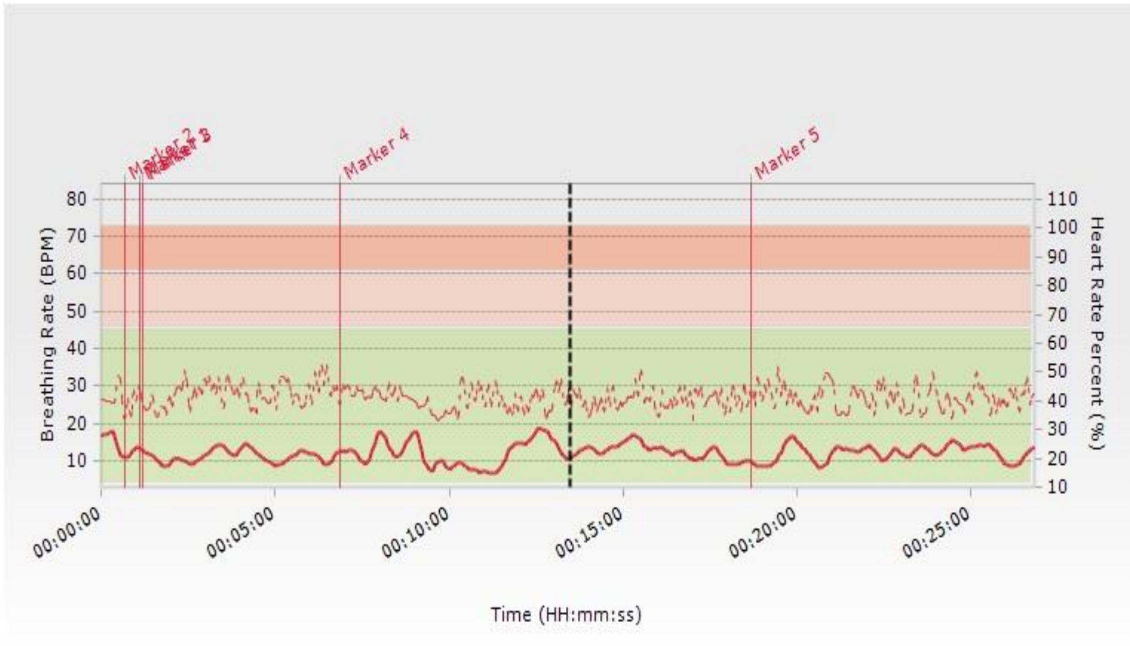

Figure 2.4: Subject D, Respiration rate and HR%MAX

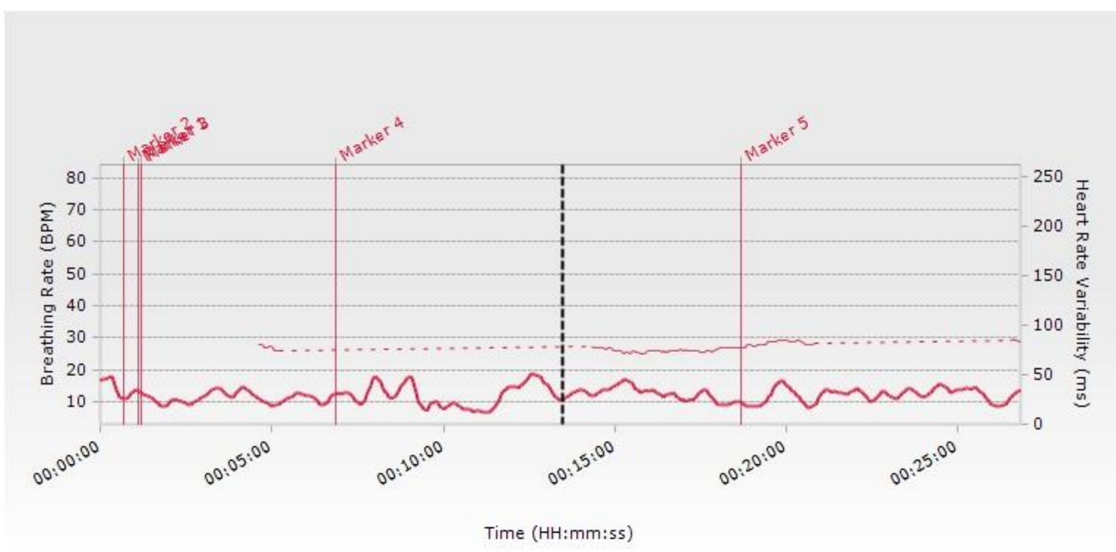

Figure 2.5: Subject D, Respiration rate and HRV

Subject E: This subject was an upper-level performance major, with the most years of voice study among the sample group (over six years of lessons). Marker 1 shows the 'warm-up' area of the hour lesson. During this phase, the subject's HR%MAX increased and HRV decreased as the student worked on vocalizing at and around the second passaggio. Markers 2-3 identify the time span of a Bach cantata aria. Here we see the effects of longer phrases (requiring a single breath to last upwards of ten seconds) as demonstrated in the positive increase in HRV and the decrease of HR%MAX. As the student began to coach two French songs, the shape of spread between HRV and HR%MAX returns to what was observed in the warm-up period.

Marker 5 was placed where the subject sang a Verdi opera aria. The aria had wide range and ended in the low chest voice register. The subject experienced a noteworthy decrease in HR%MAX (from approximately 56% of theoretical maximum down to below 40%). Even more interesting was the spike in HRV, which more than doubled from measurements taken immediately prior to the Verdi aria. The subject's HRV went from 38ms just prior to singing the aria to 100ms at the zenith. Figure 2.8 displays BPM and HRV to show that the time period where the large increase in HRV occurs pairs with BPM in the lower part of the subject's observed range.

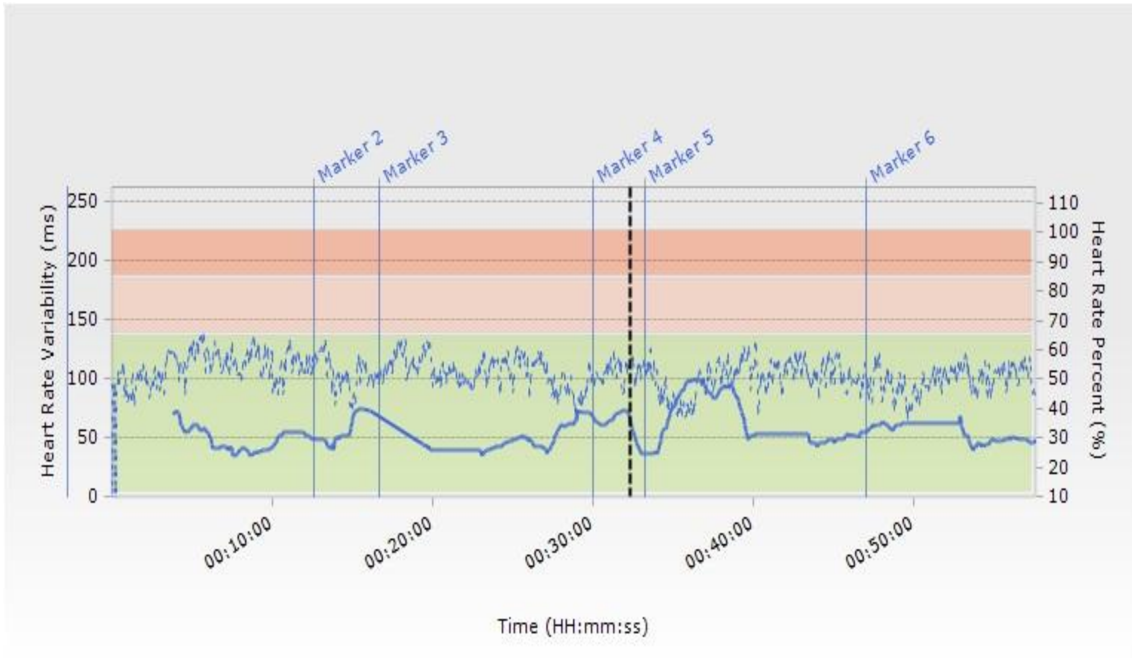

Figure 2.6: Subject E, HRV and HR%MAX

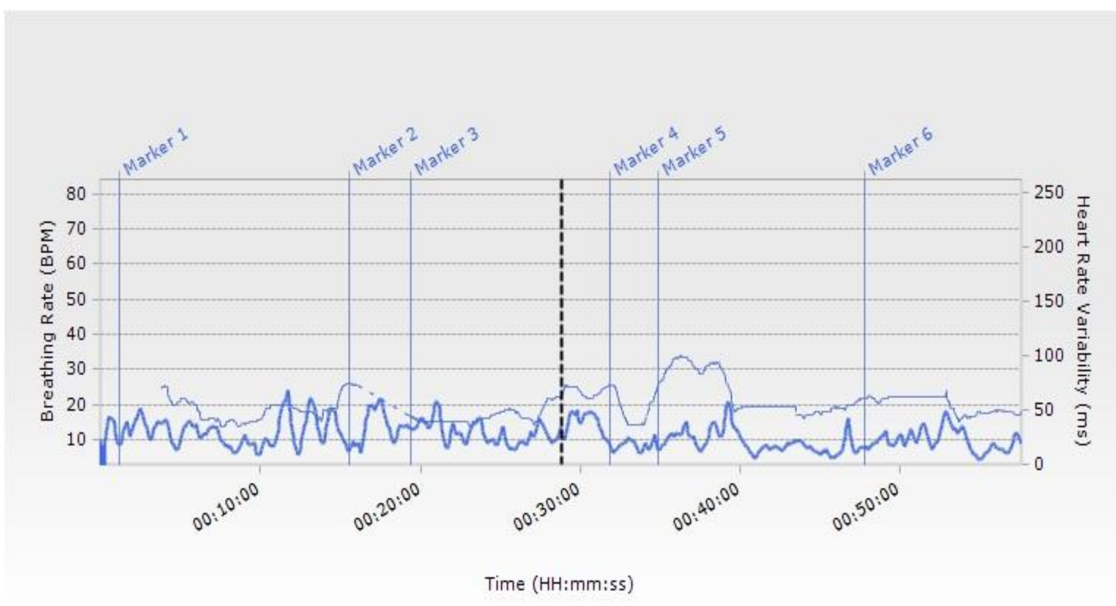

Figure 2.7: Subject E, Respiration rate and HRV

Subject F: This subject's data (as well as the data for Subject G) reflect a problem with data collection during the session. The problem is related to the size of the sensor strap and certain body types (here notably, the most thin of ectomorphic body types). A smaller diameter strap is available from the manufacturer but was not available at the time of measurement. By the point of Marker 1, the problem was repaired and accurate data collection began. At and immediately after Marker 3 was the section where the subject young soprano vocalized up to (and sustained) several ‘high C’s’ (on the piano, C5). Note the spikes in HR%MAX and the decrease in HRV. All voices perhaps will not experience such a dramatic shift, as not all voices would find this exercise as Herculean this particular soprano. Even so, such a pattern in a general sense was observed in subjects.

Another observation during this subject’s lesson occurred just before Marker 4. The teacher asked the student to recall an emotional memory- a memory that subject had personally experienced, and one the subject found to be particularly sad and painful. Note the decrease in HRV immediately after the 30:00 minute elapsed time point as the student focused on that memory. It seems less-than-trivial to mention that many studies link depression and grief in general and negative effects on the condition of the heart.[10] The positive recovery of the subject’s HRV in the following section (beginning at Marker 4) shows the aggregate effects of singing.

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[10] Mostofsky, Elizabeth, Malcolm Maclure, Jane B Sherwood, Geoffrey H Tofler, James E Muller, and Murray A Mittleman. “Risk of Acute Myocardial Infarction after the Death of a Significant Person in One’s Life: The Determinants of Myocardial Infarction Onset Study.” *Circulation* 125, no. 3 (January 24, 2012): 491–496. doi:10.1161/CIRCULATIONAHA.111.061770.

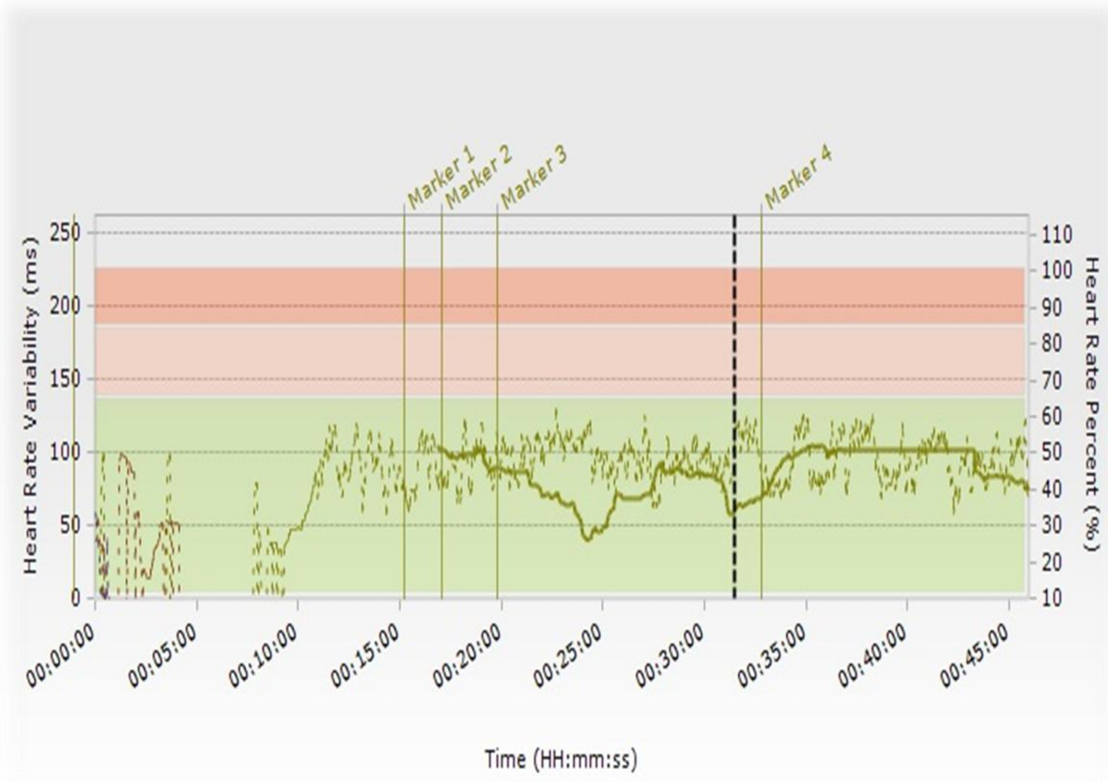

Figure 2.8: Subject F, HRV and HR%MAX (signal error)

Subject G: As with the previous subject, the sensor strap required significant adjustment before an accurate data collection session could begin. The area following Marker 2 developed pronounced collection issues and are excluded from commentary.[11] This particular subject entered the lesson with a heart rate that was above 50% of theoretical maximum. As before, Markers 1-2 denote the warm-up phase; a slight general trend upward in HRV while the HRV%MAX touches 70% was recorded. The range of HRV was smaller than the range observed in other subjects, here demonstrating approximately 50ms of variation, while the subject's HR%MAX varied widely. During the periods

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[11] The sensor strap required significant adjustment following just before the 2:40PM mark; readings after this point, though the lesson had not yet completed, are not considered here.

where the observed subject's HR%MAX increased, a general flat-to-downward trend in HRV is shown.

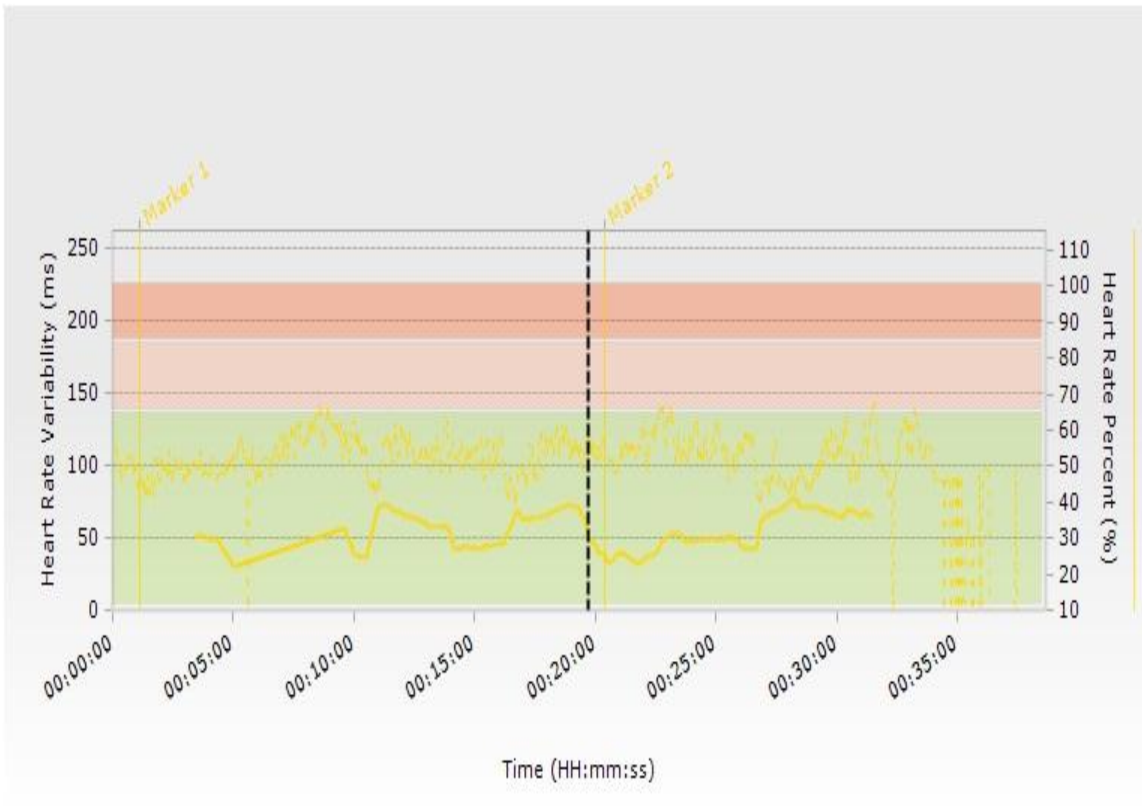

Figure 2.9: Subject G, HRV and HR%MAX (signal error)

2.3 SELF-STUDY OF PHYSIOLOGICAL RESPONCES TO PRACTCING, REHEARSING AND PERFORMING AS A SINGER

The genesis of this self-study comes from the examination of the chart below (Figure 2.10). With the sensor strap attached and data recording, I sat down at a piano to practice reading open orchestral scores. The impacts of this are reflected in the first section of the chart. Note that both HR%MAX and HRV show a range of variation that indicates the activity level is slightly above sedentary. However, Marker 2 indicates where I began singing; a short warm-up followed by art song repertoire.

As indicated below, HRV more than doubles and the range of HR%MAX approaches a 20% range while singing (even though seated) when compared to score study at the piano. This is not to suggest that an accomplished pianist would not experience pronounced physiological load while rehearsing; my piano skill is closer to elementary and years of additional training might elicit a more active response at the piano. However, it is worth mentioning that it was not necessary for me to stand in order to demonstrate a rise in physical activity. Even while seated, the recorded HR%MAX touches in the areas above 60%- the area of heart rate often targeted for cardiovascular training.

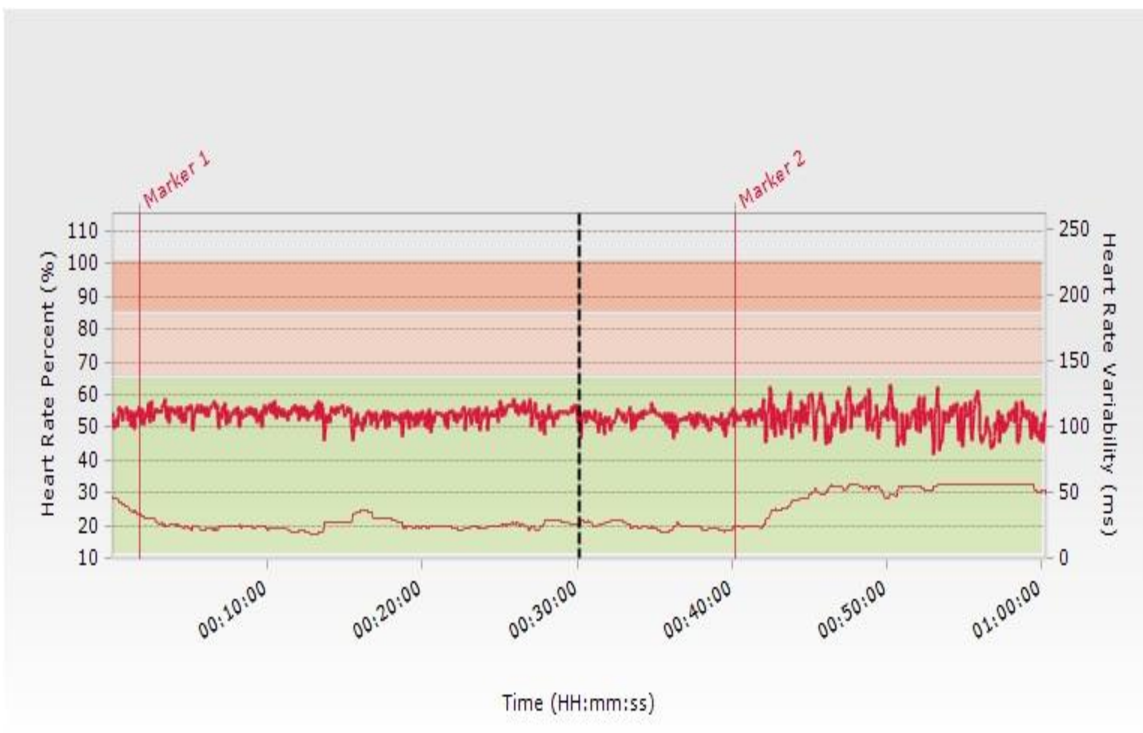

Figure 2.10: Self, Individual Practice

For the next series of observations, the effects of a choir rehearsal were recorded. As with the previous score-study/sing session, a seated posture was maintained during the rehearsal time period. Rehearsed during the session were a series of anthems, unison and in parts. Since I was involved in the rehearsal, there were no data markers placed. However, the analysis software used for this study places a real-time stamp on the data as well.

Note that the range of HR%MAX stays near 60% for much of the rehearsal. It is normal to experience an elevated heart rate during post-meal digestion. When combined with the demands of rehearsal, the overall physiological load remained in well above sedentary. The spike in HR%MAX (near the 19:46 mark)[12] also coordinates with a temporary drop in HRV. The Haydn anthem "The Heavens are Telling" (from *The Creation*) was rehearsed during this phase. There is a brief moment of a sustained A4 in the tenor part. The demands of a temporarily exposed high note are the likely explanation of such an increase in output.

[12] Please note that the software used for this study records real-time session data on a 24-hour, and not 12-hour, clock basis.

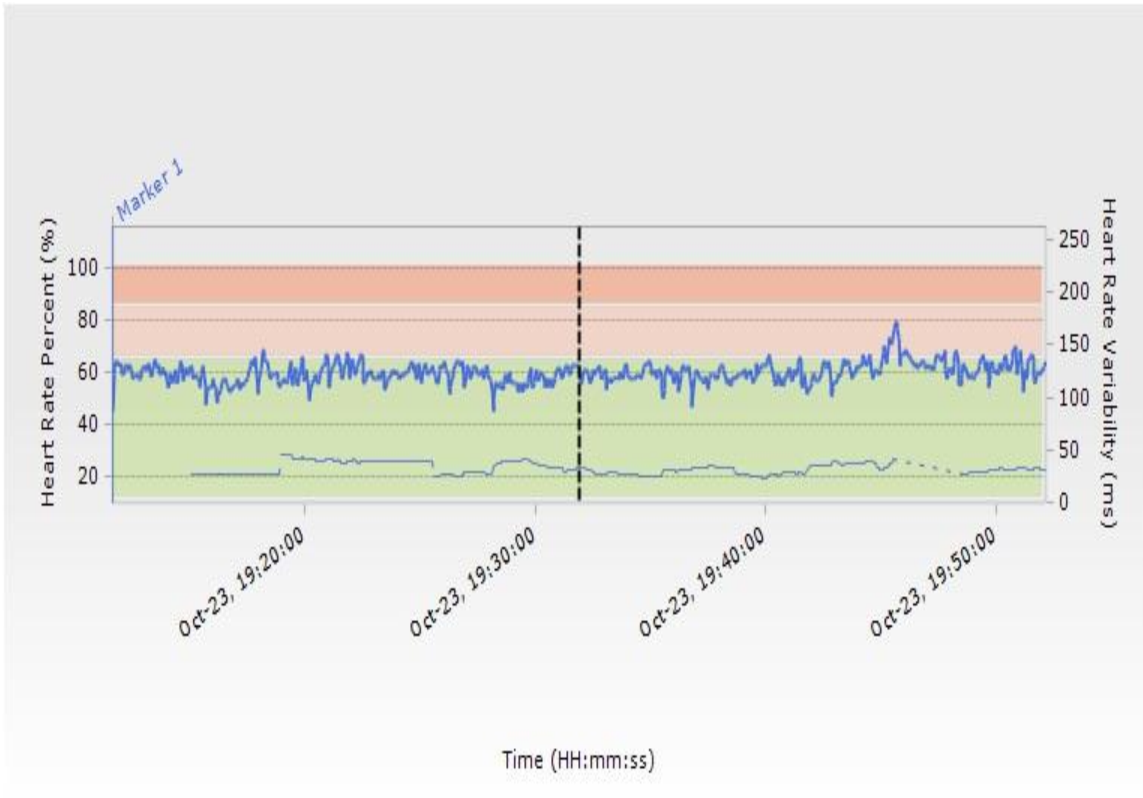

Figure 2.11: Self, Choir rehearsal A

The idea that pitches that lay in high vocal tessitura cause temporary spikes in HR%MAX is supported by the next chart (Figure x) that shows three different spikes- each of which caused by the previously mentioned Haydn anthem. The two spikes before the 20:00 mark and the spike shortly after the 20:30 mark all represent the demands of singing the sustained A4 in the tenor part. In each of these cases, the recorded respiration rate drops just prior to the spike in HR%MAX. In preparation for singing the aforementioned pitch, there was a brief period of deep inhalation. This chart shows that the range of respiration rate (or BPM) stays lower than 20 BPM during most of the rehearsal. This decreased rate of breath seems to aid in the elevation of HRV values. The opening section of the chart (shortly after 19:00) was recorded before the rehearsal got underway, during conversations and the like. As the singing began, note the decrease in respiration rate.

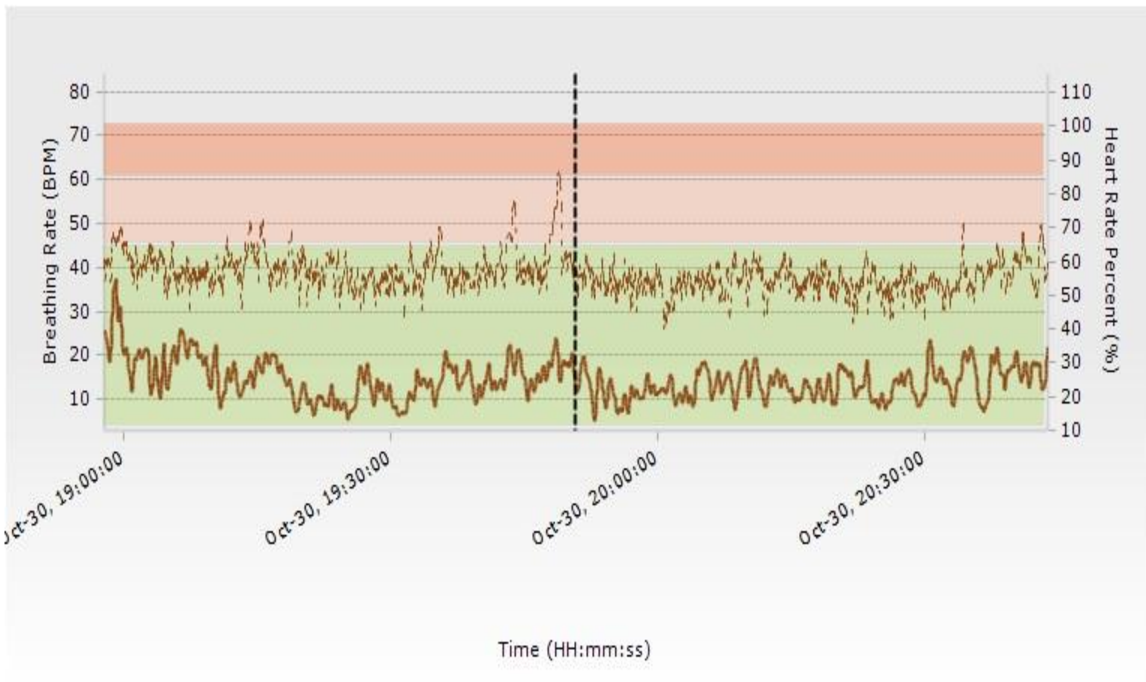

Figure 2.12: Self, Choir rehearsal B

The next chart details the responses to stimuli experienced during a lecture-recital. As this is a real-time chart, we can see the period before the recital began. Even though 17:00 was a half-hour before the recital was to start, the chart displays a range of approximately 20% in HR%MAX during the pre-recital phase. It is not unreasonable to believe that general nervousness was a factor during this time. The significant rise in HR%MAX, followed by a higher sustained range, was recorded during the opening set of music: four *Lieder* selections by Brahms. It is during this phase that we may observe HR%MAX often above 70% and ranging to nearly 90%. The two pieces that were bookends for the set of selections had faster tempi than the interior selections ("Botschaft" and "O liebliche Wangen" were first and last, respectively; "Minnelied" and

“Feldensamkeit” were the interior selections). Whether it was tempo, or the difficulty of the songs themselves that caused the pronounced ‘shoulder’-shaped spike in HR%MAX is not possible to say; multiple factors could easily contribute to such a reading.

Following the opening song selections there was a period of lecturing, followed by another set of musical selections (this time, Faure’s *Poeme d’un jour*). During this second group of songs we find a similar pattern to the first: a rise during and decline after singing. The middle song of this set (“Toujours”) had the fastest tempo of the set; notice how during this particular song there was the zenith of HR%MAX for this set. The observed range of HR%MAX was not the same as in the Brahms, but it did increase as before. In between the two sung portions there was a significant drop in HR%MAX. Note the second interpolated scale on the chart, “Physiological Intensity”. This simple scale (1 through 10) rates the instantaneous output of the body against its potential maximum (for example, a 4/10 indicates that 40% of the body’s potential maximum output is being exerted). We can interpret that lecturing and singing had dramatically differing demands, and subsequently effects, on the body in this instance. According to the chart, a physiological intensity near 7 of 10 was experienced during the performance parts of the lecture-recital, while during the spoken voice sections PI dipped to a nearly sedentary level.

Last sung during this event was a Puccini opera aria (“Recondita armonia” from *Tosca*). I sat down briefly to help demonstrate the difference in HR%MAX between resting and working positions. The aria is less than three minutes in length, but still manages to increase the observed HR%MAX above 80%, likely the point near the fermata 'high' Bb4. As before, once the singing ended, a downward recovery in HR%MAX occurred.

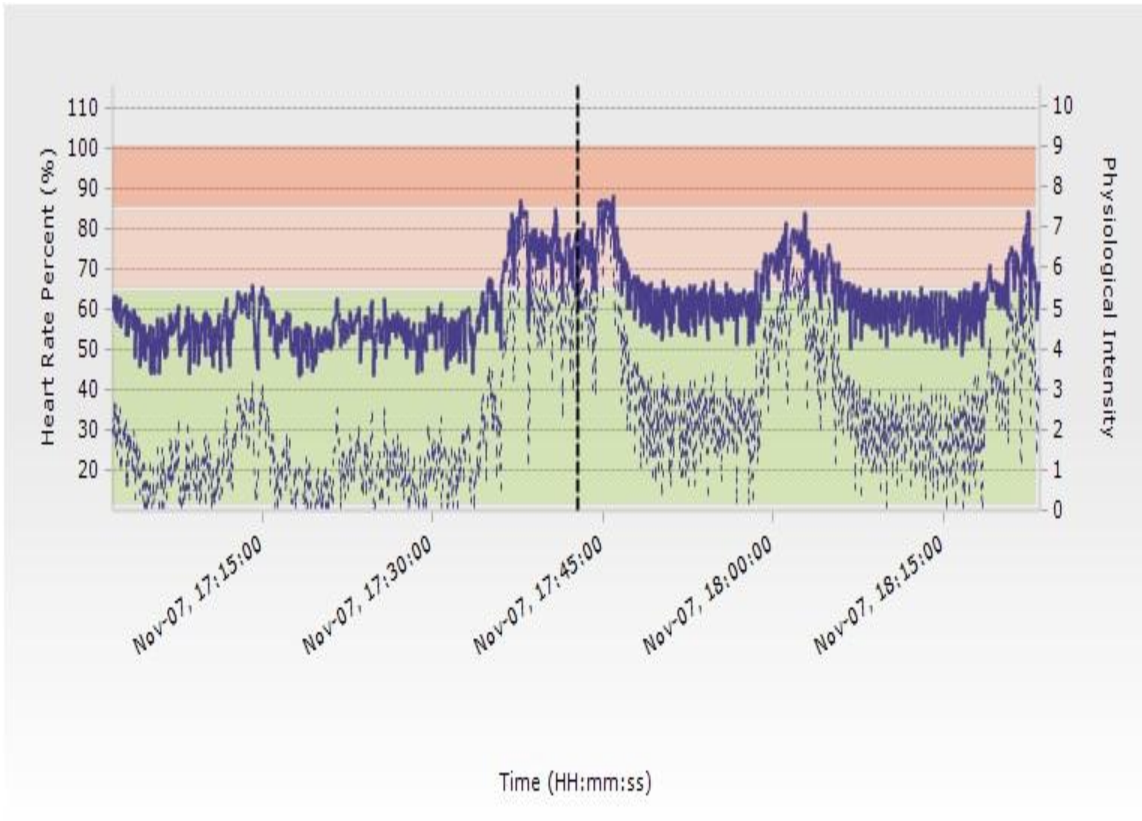

Figure 2.13: HR%MAX and PI

Since the act of singing requires breath management and coordination with musical events, it is important to note the interaction between respiration rate and general physiological output. The following chart beautifully illustrates this. During periods of singing there is a marked increase in instantaneous load in the body in coordination with a decrease in respiration rate. It is this relationship, between reduced breath rate and increased physiological load, that seems to become the stasis for one in the act of singing.

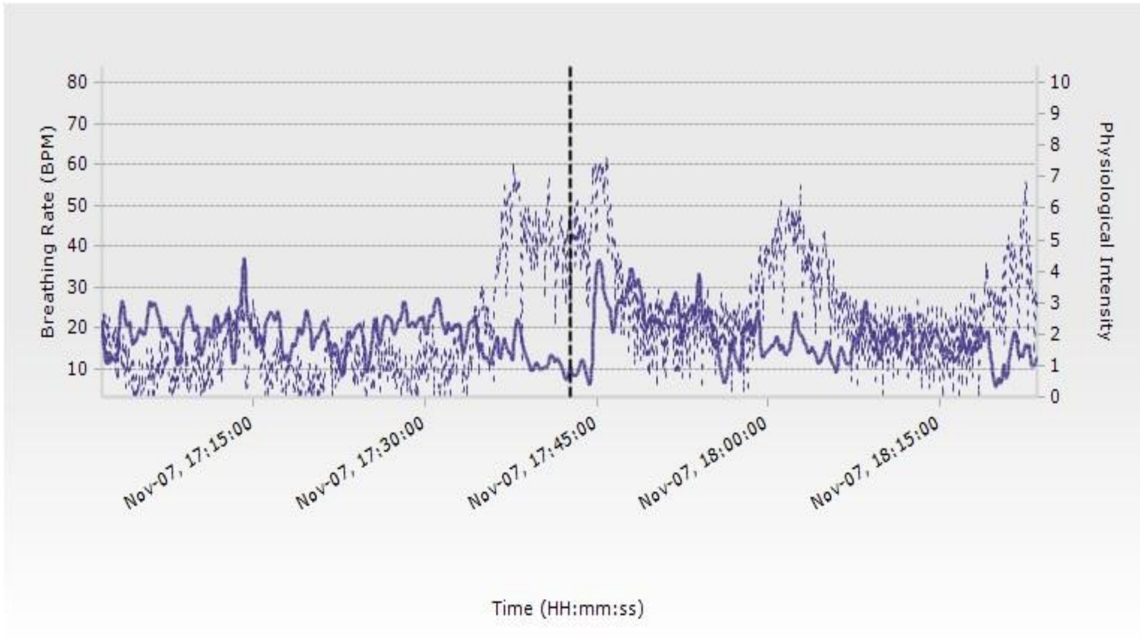

Figure 2.14: Respiration rate and PI

2.4 SUMMARY OF FINDINGS

This study set out to observe changes in vital statistics that occurred during singing events. Primary attention was given to heart rate variability, respiration rate and heart rate as a percentage of theoretical maximum. The technology used for the study also provided additional data, such as posture, skin temperature, and theoretical caloric output.

Observed subjects demonstrated an overall increase in HRV range during periods of singing. The exact amount of increase varied widely, but the trend of a general rise in HRV is common among subjects while singing was noted. Changes that were observed ranged between ten (10) to over 100% in HRV. Amounts of variation in HRV were observed to be more pronounced in students that had received the most amount of vocal instruction.

An additional HRV-related finding was that vocalizing at the upper extreme of an individual singer's vocal range caused a temporary decrease in HRV range. It is logical to deduce that singing at the high end of one's possible vocal range is a somewhat Herculean task. Long, sustained high pitches cause a notable spike in HR%MAX as well. Weight lifting is an exercise that causes similar temporary spikes.

The heart rates of individuals as measured during singing had a larger range in general than heart rate ranges observed in talking. Coupled with the requirement of breath management, the aggregate effect of the physiological demands of singing often puts individual subjects into a moderate workout zone (between 50-70% HR%MAX). This is not dissimilar to the effects of participating in a yoga session, but the key difference is that the length of musical phrases (and subsequently the length of a singer's breath to accommodate the phrase) varies widely. This variability in breath-phrase length is a key factor in the reasons HRV increases in while singing.

2.5 FUTURE STUDIES

The next study to undertake would likely involve a larger sample group. As the technology employed would allow over ten (10) subjects to be measured simultaneously, we would likely have greater statistical relevance than the smaller group of subjects observed here. An ideal venue for the next study would be an opera company. It would be desirable to observe not only the principal singing-actors on stage, but perhaps the orchestra conductor as well. Additionally, pairing the data collected by the sensor strap with a real-time audio recording of the session would better illustrate the relationship of the demands of a sung role to real-time vital statistics. Only with the advent of wireless technology (and relatively unobtrusive sensors) has such a study become possible.

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Appendix A

Description of Equipment

This study used the Assessment Pack from the Zephyr™ Technology Corporation (Annapolis, Maryland). The package includes the sensor strap, module recharging station, wireless gateway and Omnisense™ software (both Omnisense Live and Omnisense Analysis programs). The software was installed on a laptop using Microsoft Windows 7©.

Appendix B

Recitals for Degree

music
University of South Carolina **School of Music**

Presents

JOHN H. PRITCHARD, *tenor*

in

Doctoral Recital

Sharon Rattray, *piano*

Wednesday, October 19, 2011 • 4:30 PM • Recital Hall

Beau soir Nuit d'Étoiles Mandoline	Claude Debussy (1862- 1918)
from *Messa di Requiem* Ingemisco	Giuseppe Verdi (1813- 1901)
Vier ernste Gesänge, Op. 121 Denn es gehet dem Menschen wie dem Vieh Ich wante mich und sahe an alle O Tod, wie bitter bist du Wenn ich mit Menschen	Johannes Brahms (1833- 1897)
from *Eugene Onegin* Lensky's Aria	Pyotr Il'yich Tchaikovsky (1840- 1893)
Three Songs, Op. 10 Rain has fallen Sleep now I hear an army	Samuel Barber (1910- 1981)

Mr. Pritchard is a student of Walter Cuttino.
This recital is given in partial fulfillment of the requirements for the Doctor of Musical Arts degree in Performance.

University of South Carolina
School of Music

JOHN H. PRITCHARD, *tenor*
in
OPERATIC ROLE

Opera at USC

February 25-27, 2011
Drayton Hall

Cendrillon	Jules Massenet
Role of "Prince Charmant"	(1842-1912)

Mr. Pritchard is a student of Walter Cuttino.
This recital is given in partial fulfillment of the requirements for
the Doctor of Musical Arts degree in Performance.

UNIVERSITY OF
SOUTH CAROLINA
School of Music

JOHN H. PRITCHARD, *tenor*
in
DOCTORAL RECITAL

Ruby Wang, *piano*

Monday, September 23, 2013
4:30 PM • Recital Hall

Recitative and aria from *Jeptha* — George Frederick Händel (1685-1759)
Deeper and deeper still
Waft her, angels, through the skies

Dichterliebe, Op. 48 — Robert Schumann (1810-1856)

"O del mio amato ben" — Stephano Doraudy (1879-1925)
"Perduta ho la speranza"
"Freschi luoghi, frati aultenti"

"L'invitation au voyage" — Henri Duparc (1848-1933)
"Soupir"
"Chanson triste"

Aria from *Tosca* — Giacomo Puccini (1958-1924)
E lucevan le stelle

Mr. Pritchard is a student of Walter Cuttino.
This recital is given in partial fulfillment of the requirements for the Doctor of Musical Arts degree in Performance.

University of South Carolina
School of Music

JOHN H. PRITCHARD, *tenor*
in
DOCTORAL LECTURE RECITAL

Sharon Rattrey, *piano*

Thursday, November 7, 2013
4:30 PM • St. John's Episcopal Church (Shandon) Choir Rehearsal Hall

"The Artist's Gauntlet: A Study of a Singer's Physiological Responses to the Stimuli of Rehearsing and Performing"

"Botschaft" "Minnelied" "Feldeinsamkeit" "O liebliche Wangen"	Johannes Brahms (1833-1897)
Poème d'un jour, Op. 21 "Rencontre" "Toujours" "Adieu"	Gabriel Fauré (1845-1924)
Aria from *Tosca* Recondita armonia	Giacomo Puccini (1858-1924)

Mr. Pritchard is a student of Walter Cuttino.
This recital is given in partial fulfillment of the requirements for the Doctor of Musical Arts degree in Performance.