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Heart Rate Variability During Choral Singing

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Abstract

Contemporary research implies that choral singing is beneficial to health. Singing various kinds of songs with varied emphasis, emotion, and tempo gives rise to diverse physiological responses. Breathing is assumed to be synchronized during choral singing, and breathing has major influence on heart rate variability (HRV). In this study, we compare HRV responses during choral singing with slow breathing exercises. Thirteen amateur singers' HRV were studied during a rehearsal of 4 songs framed by 2 slow breathing exercises without audience. The heart rate was generally higher and HRV generally lower during singing compared to the slow breathing conditions. During singing, but not during slow breathing, peak HRV frequency showed considerable variation among the participants. This could be due to either a low degree of synchronization of breathing during singing or other factors overruling the effects of breathing on HRV.

Keywords

heart rate variability, choral singing, autonomic control, breathing, health

It has been shown that the emphasis and rhythm of music can be tracked in physiological measures, for example autonomic.[1,2] Heart rate variability (HRV) has been suggested as a "physiologically grounded, theoretically explicated, and empirically supported" measure of autonomic function that also reflects the interplay between the central and the autonomic nervous systems well suited for studying the effects of music.[2] The HRV has also been repeatedly associated with health and well-being.[3-5] A considerable amount of the total HRV, at least in short recordings, originates from breathing where heart rate (HR) accelerates during inhalation, due to vagal withdrawal, and decelerates during exhalation, when the vagus is fully activated.[6] This portion of HRV is called respiratory sinus arrhythmia (RSA). Other sources of HRV include, for example, internal physiological regulation, psychosocial stress, and physical activity.[7]

Routine participation in choral singing could be beneficial for one's health.[8] This was illustrated by a recent study performed in Washington DC[9] of elderly institutionalized individuals who began singing in a choir. They were allocated to one wait-list group and one active group. Singing in choirs then took place once a week for 2 years in the active group while the other group did not sing in a choir. A 2-year follow-up showed that health, measured with standardized questionnaires, was significantly better in the choir group than in the wait-listed control group. Choral singing has also been shown to be beneficial for psychological well-being.[10,11] One important notion when studying physiological effects is that singing necessitates a special kind of breathing that is quite different from breathing during nonsinging. The singing activity itself occurs during exhalation—as an active process. The phrases determine the duration of the exhalation. The inhalation on the other hand is often quick, taking place between the phrases. This makes singing possible. Nonsinging is characterized by active inhalation and passive exhalation when participants are relaxed. During choral singing breathing is not only an "internal" process, but it is also a "social" one since the singers share their expression of ongoing music rehearsal in a live performance. The social aspect of choral singing is not confined to breathing; the emotional effects of the music are both individual and collective, and the collective effects are of interest in their own right.[12,13]

One hypothesis about why singing is beneficial to health is that it reduces tension and arousal. Some preliminary

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Figure 1. One line with the 3 voices (soprano, alto, and bass) sung by the participants from the hymn "Joy" ("All världen nu sig gläder") by Johann Steurlein.

Figure 2. One line with the 3 voices (soprano, alto, and bass) sung by the participants from "Blossoming Beautiful Valleys" ("Under rönn och syrén") by Herman Palm.

findings found no difference in this respect between solo and choral singing.[14] In the present study, we investigate choral singers' HRV and how it is patterned in the choir group. This occurs when they breathe according to instruction particularly when communally singing various songs of variable complexity. If singing should instantly lower arousal, we would expect a higher HRV during singing. However, we know that choral singing involves several aspects that could generate some tension, for example, singing in individual lines, following the conductor, and efforts to perform well. There are many factors expected to differentiate HRV during singing and nonsinging and that may also exist between professional and amateur singers. On a smaller scale, a study by our group[15] has shown that well-trained professional singers show much more HRV than amateur singers when they sing during a singing lesson. This could be interpreted as the coordination between breathing and cardiovascular function (mirrored in RSA) improves during singing when somebody becomes a professional singer. This is likely to be an effect of training. It could also be of benefit for the trained singer in other areas of life function. It is of interest to study the types of songs that have the most pronounced effects on physiological states. Slow/fast tempi, high/low notes, and wordless/worded modes are 3 dimensions that were considered crucial to our musical choices, and hence, songs were selected that represented contrasts from these points of view.

Methods

Participants

Participants were 13 members of a choir of whom 11 were women. The mean age was 54 years (range 17-85 years). All were amateur singers. None of the singers were smokers. The participants gave informed consent.

Procedure

Recordings were performed during a normal rehearsal session without audience on a weekday at 6:30 PM. The singing was accompanied by piano and sung in 3 voices (6 soprano, 5 alto, and 2 bass singers). The songs had Swedish lyrics and were the following: (1) "Joy" (the hymn "All världen nu sig gläder" with music by Johann Steurlein; Figure 1): a piece with bright effect sung in a brisk pace (quarter-note speed approximately 120 beats per minute [bpm]) at a medium pitch with some volume, the most difficult of the 4 songs; (2) "Blossoming Beautiful Valleys" ("Under rönn och siren" with music by Herman Palm; Figure 2): a soft and intimate song sung in a quarter-note speed at about 95 bpm and in average pitch range without much volume; (3) "Friendship" ("Vänskap" with music by Joseph Haydn; Figure 3): an intimate and slow song (quarter-note speed approximately 75 bpm) sung in a low pitch with some volume; (4) "Go Down Moses" (traditional; Figure 4): sung

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Figure 3. One line with the 3 voices (soprano, alto, and bass) sung by the participants from "Friendship" ("Vänskap") by Joseph Haydn.

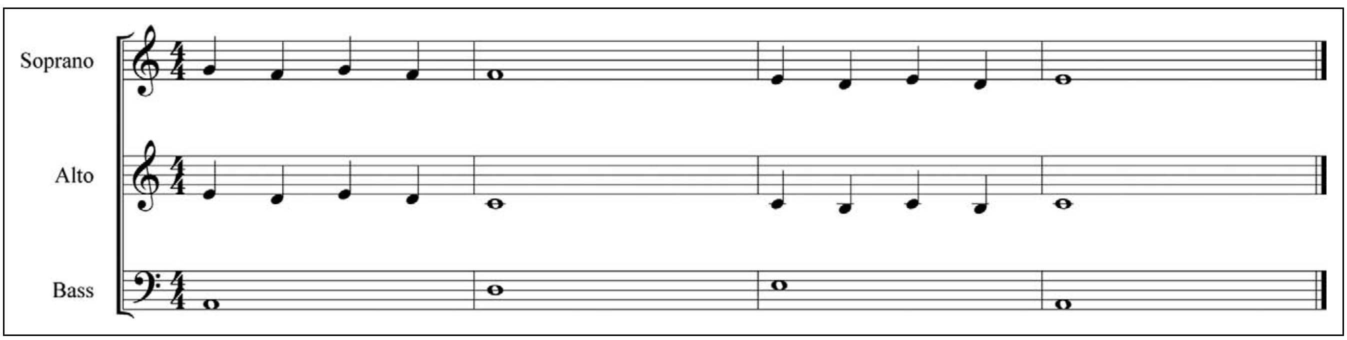

Figure 4. One line with the 3 voices (soprano, alto, and bass) sung by the participants from "Go Down Moses" (traditional).

on "M"-sounds, wordless, and without vowels. The tempo was very slow (quarter note speed approximately 60 bpm), and the pitch quite low without much volume. There was a break of at least 30 seconds after each song. The order in which the songs were usually sung during rehearsals was used in the recording because it was familiar to the participants. Before recording, the participants took part in voice warm-up exercises during which the sensors were in place allowing the participants to get used to them. Recording began with a slow, guided breathing exercise during which the participants were instructed to sound "M" during exhalation for 2 minutes. They were not singing during this exercise, and there were no instructions about pitch or tone. Most participants sounded on a comparably low note. The breathing rate was guided to be approximately 6 breaths per minute. This comparable condition was used instead of a traditional baseline because it is behaviorally more similar to singing but without the musical influence. Thereafter, participants sang the 4 songs mentioned earlier. The recording ended with the same guided breathing exercise as before the 4 songs.

Measurements

The 2-minute recordings of heart rate (HR) from every song were used in the HRV analyses. Throughout the procedure HR was measured continuously using a chest belt connected to a Polar RS800 HR monitor with a sampling rate of 1000 Hz (Polar Electronics, Kempele, Finland). The HRV calculations were made using the cStress software (Stressmedicine AB, Bergvik, Sweden) according to international recommendations.[16] All data were scanned manually for artifacts which were replaced using cubic spline interpolation. The few artifacts found could typically be related to body movements. No participant had more than 5% replaced data in any segment. Fourier analysis was performed on the specified 2-minute segments of detrended data. The HRV measures analyzed were standard deviation of interbeat intervals (SDNN), high frequency power (HF; 0.15-0.4 Hz), and low frequency power (LF; 0.04-0.15 Hz). The LF and HF indices were logarithmically transformed before the analyses because of skewed distributions and to meet the assumptions of parametric statistical analysis. The peak HRV frequency is the frequency, expressed in Hz, of HRV which has the most power according to the Fourier transformation during the time span for a participant.

Statistical Analysis

Results were analyzed using 1-way within-group analysis of variance, where the effect indicates a difference between the conditions. Post hoc analyses were conducted with Tukey honestly significant difference test. The α level was set at $P < .05$, 2-tailed.

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Table 1. *P* Values From Tukey Post Hoc Testing of the Differences Between the 6 Conditions of Which 4 Were Songs and Two Were Slow Breathing ("Breath Pre" and "Breath Post").

	HR	SDNN	LF	HF
Joy vs Breath Pre	<.001	.02	<.001	<.001
Bloss Beaut Vall vs Breath Pre	<.001	.002	<.001	.97
Friendship vs Breath Pre	<.001	.01	.003	.03
Go Down Moses vs Breath Pre	.79	<.001	<.001	.003
Breath Post vs Breath Pre	.91	1	1	.64
Bloss Beaut Vall vs Joy	1	.99	.84	.002
Friendship vs Joy	1	1	.48	.53
Go Down Moses vs Joy	<.001	.82	.63	.96
Breath Post vs Joy	<.001	.02	<.001	.02
Friendship vs Bloss Beaut Vall	1	1	.99	.2
Go Down Moses vs Bloss Beaut Vall	.002	.99	.08	.02
Breath Post vs Bloss Beaut Vall	<.001	.003	.001	.97
Go Down Moses vs Friendship	.008	.86	.02	.95
Breath Post vs Friendship	<.001	.01	.009	.64
Breath Post vs Go Down Moses	.2	<.001	<.001	.16

Abbreviations: HR, heart rate; SDNN, standard deviation of interbeat intervals; LF, low frequency power; HF, high frequency power.

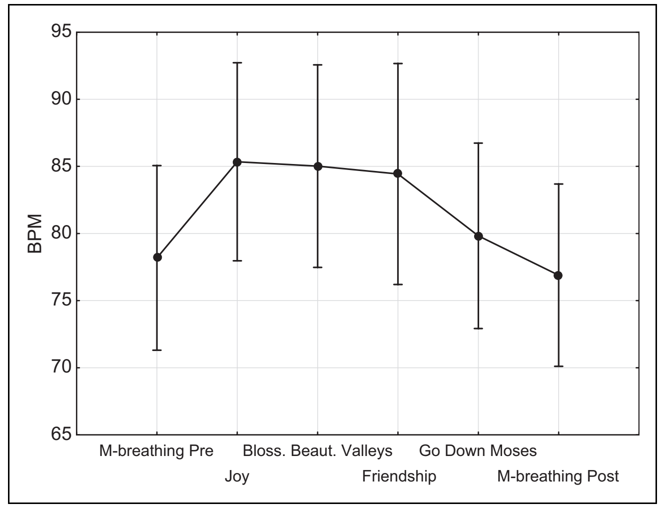

Figure 5. Heart rate (HR) during the 6 conditions. Bars indicate standard errors.

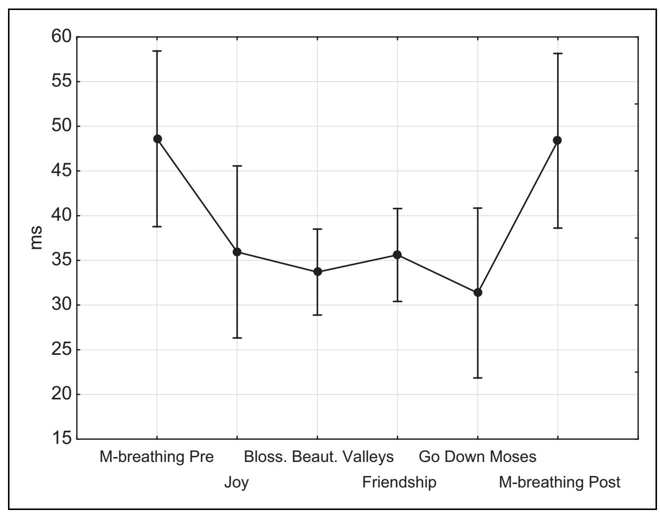

Figure 6. Standard deviation of interbeat intervals (SDNN) during the 6 conditions. Bars indicate standard errors.

Results

There were overall main effects of condition on all HRV measures as well as on HR (all *F*s > 5.1 and all *P*s < .001). When comparing the conditions with post hoc analyses, HR was significantly lower during the 2 breathing exercises and the song "Go Down Moses" than during the other songs (see Table 1 and Figure 5). The SDNN was lower during singing any of the 4 songs than during slow breathing conditions. There were no differences between the songs (see Table 1 and Figure 6). The LF mean was also lower while singing any of the 4 songs than during slow breathing. The LF had its lowest mean during the song "Go Down Moses" during which it was significantly lower than during the song "Friendship" (see table 1 and Figure 7). The HF mean was lower during the song "Joy" compared to both breathing conditions and the song "Blossoming Beautiful Valleys." The same is true for the song "Go Down Moses" with the exception of the last breathing condition from which it was not significantly different. During the song "Friendship," the HF mean was lower than during the first breathing condition (see Table 1 and Figure 8).

There is a wide individual variation both in HR and in HRV, best shown by plotting all individuals' HR during examples of the conditions (see Figures 9–12). During the first breathing exercise, the RSA was salient, and the frequency of the breathing and HR variations, which make up the HRV, seemed to be similar among the participants. This is also shown by analyzing the participants' peak frequency of HRV. During the first breathing exercise, 12 of the 13 participants had their peak HRV frequency within the range 0.04 to 0.08 Hz (see Figures 9 and 13). During the last breathing exercise, all the 13 participants had their peak frequency of HRV in this range (see Figures 12 and 13). This is in variation with the patterns during singing, where the participants' peak HRV frequency showed pronounced variation (see Figures 10, 11, and 13). Visual inspection of the graphs gives no conclusive support for the hypothesis that the difference in variation can be explained by the voice (soprano, alto, or bass) the participants were singing (see Figures 10 and 11). Note that the 2 basses sang long notes during "Go Down Moses" and consequently showed large variability in the LF span (see Figure 11).

Discussion

Heart rate was, with one exception, higher and all indices of HRV were, with one other exception, lower during all the songs compared to the slow breathing conditions. This indicates that choral singing is not immediately relaxing. However, the slow breathing conditions are not to be considered as "baselines." In fact, this kind of breathing usually generates large HRV. It

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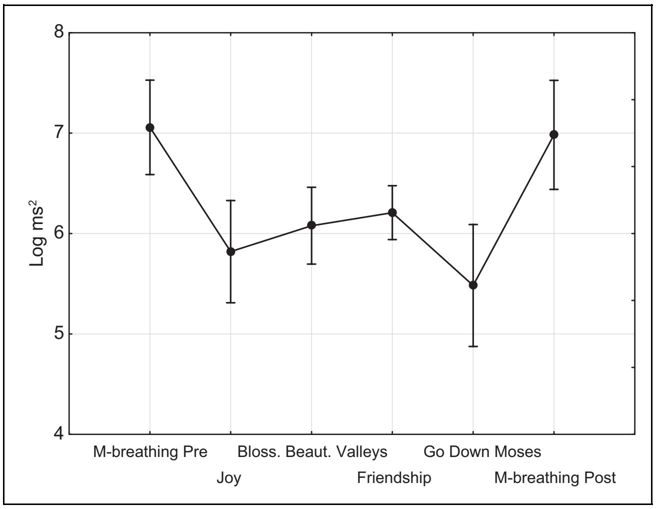

Figure 7. Low frequency power (LF) during the 6 conditions. Bars indicate standard errors.

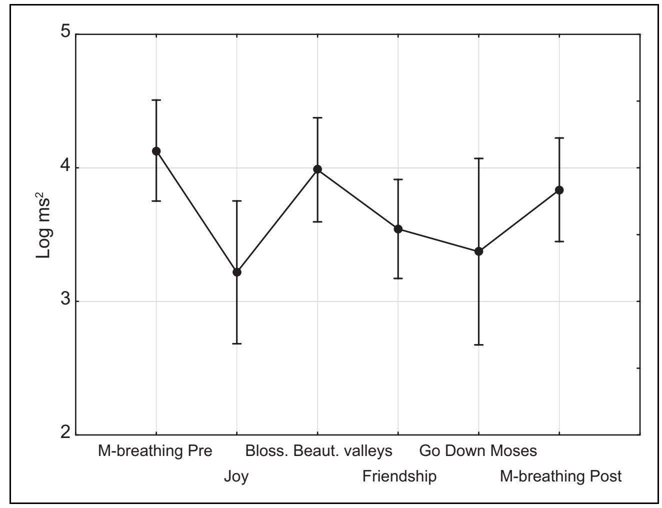

Figure 8. High frequency power (HF) during the 6 conditions. Bars indicate standard errors.

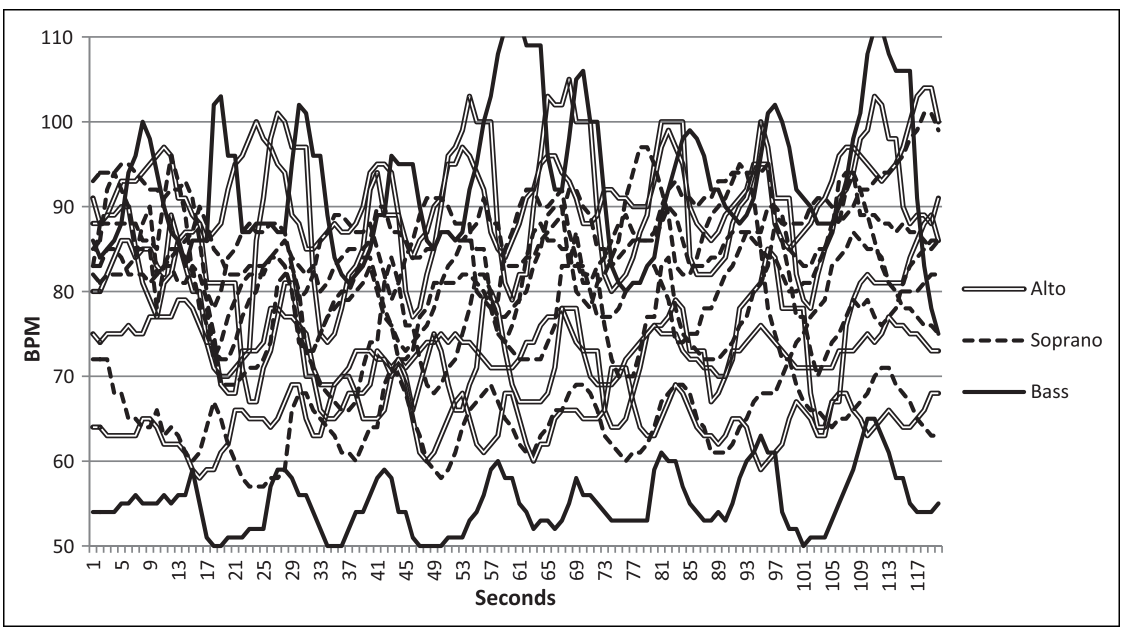

Figure 9. Heart rate during the first breathing exercise for all the participants. The line patterns indicate the participant's voice part when singing. Participants were not singing during this condition.

should also be kept in mind that the immediate effect of an activity on HRV may be different from the long-term consequences. Physical activity, for example, instantly lowers HRV while regular exercise leads to enhanced HRV in the long run.[17]

One song stood out from the others in the physiological analysis, namely, the last song "Go Down Moses," which was arranged without words in chords that required no extraordinary physical effort (no extremely high or low notes) and with phrases with an average length of 5 seconds (corresponding to 0.2 Hz which is in the HF spectrum). It deviated from all the other songs with a significantly lower HR, more resembling of the nonsinging conditions and the lowest HRV in terms of SDNN and LF of the songs. The song "Blossoming Beautiful Valleys" stands out as the song with the most HF variability, significantly different from 2 of the other songs and with HF resembling the nonsinging conditions. "Blossoming Beautiful Valleys" has many words, some of which may be difficult to remember. It also has relatively long phrases and large tone intervals.

As mentioned, "Go Down Moses" lacks the cognitive effort associated with the memorizing of words and requires less physical effort. It is constructed in a "physiological way."[18] This is also mirrored in a low average HR in the participants, more resembling of the nonsinging conditions, which is quite in line with the expectations. In 3 of the 4 songs, HF was

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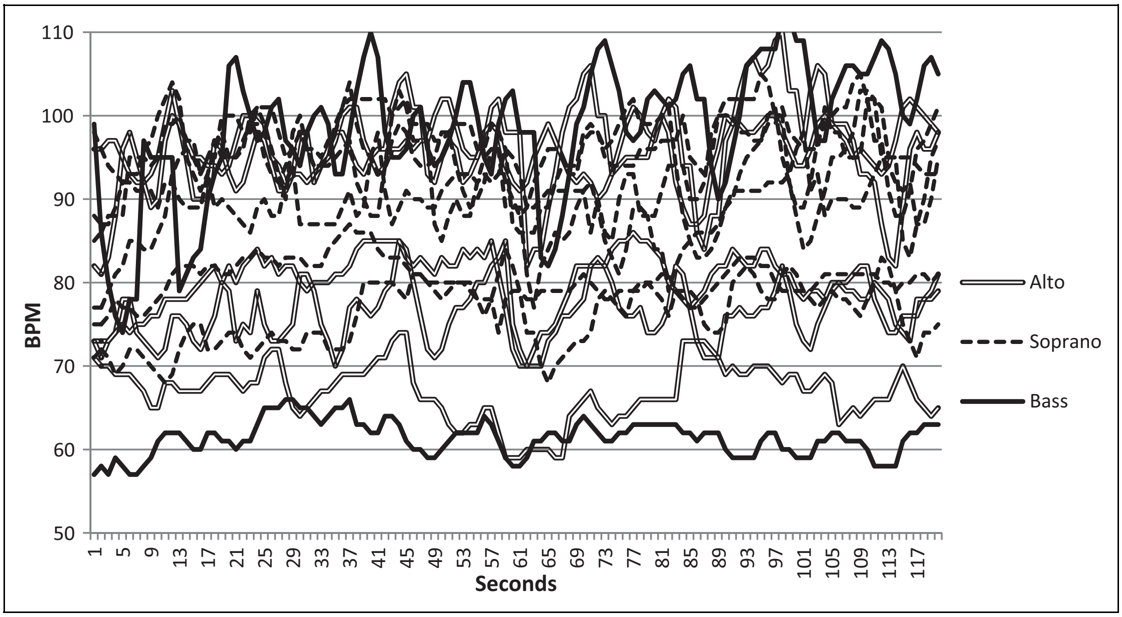

Figure 10. Heart rate during the song "Blossoming Beautiful Valleys" for all the participants. The line patterns indicate the participant's voice part.

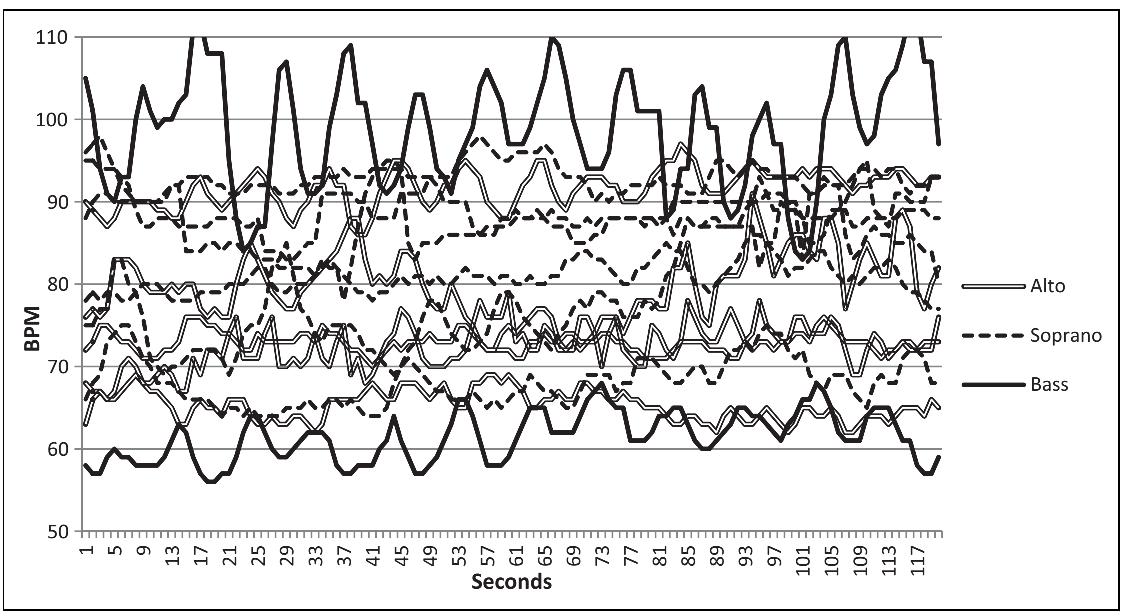

Figure 11. Heart rate during the song "Go Down Moses" for all the participants. The line patterns indicate the participant's voice part.

significantly lower than during the breathing conditions. The HF is assumed to reflect a high parasympathetic activity indicative of a relaxed condition.[19] Conversely, LF is mostly assumed to mirror a mixture of sympathetic and parasympathetic activity and is therefore mostly used—when it is compared with HF—to show more of arousal and lack of relaxation. The observation in the present study that the singers have a relatively low LF during all of the songs is therefore in line with the accepted theory. If choral singing were to be considered a relaxed condition, the observation of a low HF would be more unexpected. When singing, the respiration rate sometimes drops below the HF span and consequently so does RSA. During such circumstances more vagal activity is expected in LF. Low HF may also be due to the fact that singing is not a relaxed condition. Furthermore, the singers have coordinated their phrases with those of the other singers and as long as the breathing is in the HF interval it may have extinguished some of the spontaneous HF.

When the peak frequency of HRV during the conditions is observed, it is noticeable that more participants had their peak in the very low frequency band, below LF, during singing while this was very unusual during the breathing exercises. This indicates sympathetic activation during singing.

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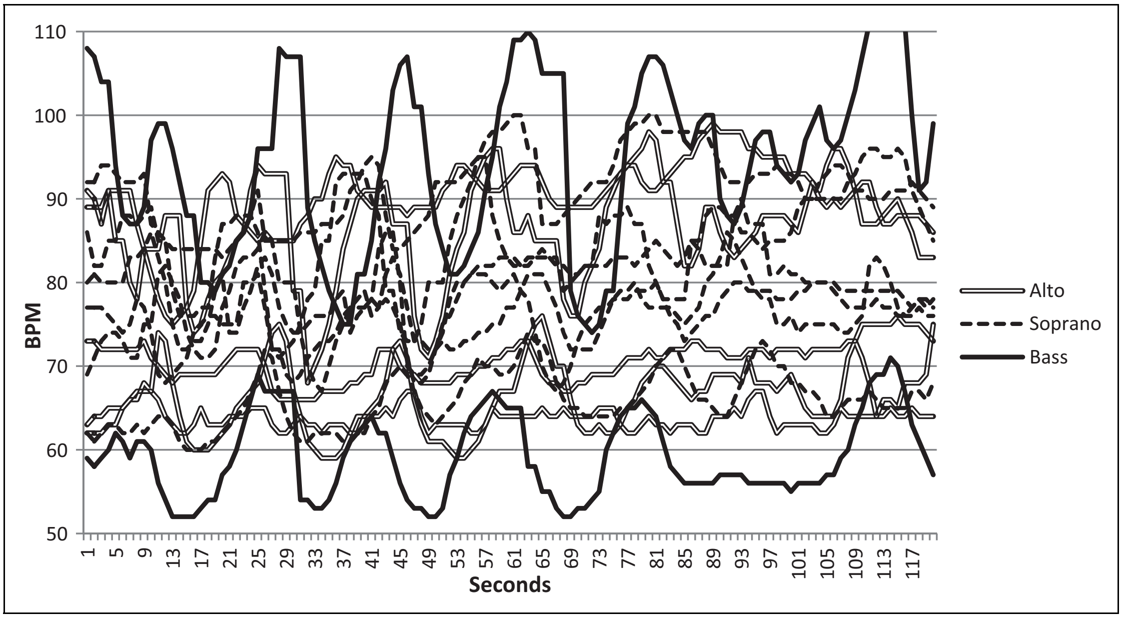

Figure 12. Heart rate during the last breathing exercise for all the participants. The line patterns indicate the participant's voice part when singing. Participants were not singing during this condition.

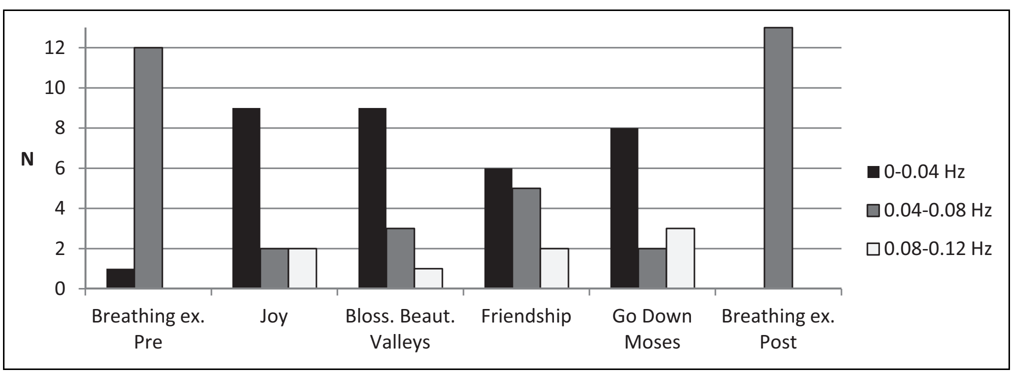

Figure 13. Peak heart rate variability (HRV) frequency for the singers during the 6 conditions. The graph indicates how many of the singers have their peak HRV frequency within certain frequency bands.

During the breathing exercises, the HR pattern was quite synchronized among the participants. This was in variance with the HR pattern during singing, which was expected to be synchronized as well since the participants breathing should be synchronized with the common phrases. The peak frequency of HRV, which reflects the typical frequency of HRV, was almost the same in all the participants during the breathing exercises. During singing it varied considerably. There are 2 possible reasons for this. First, breathing may not have been as synchronized during singing as was expected. The voices had somewhat different phrases, but visual inspection of the data does not support that this explains the variation. The statistical power of this study was not large enough to test whether this was the case. It is also possible that in a choir you might be able to inhale at somewhat different points even during long notes since other members may cover for you. This pattern might differ with professional singers. Second, if breathing was synchronized during singing, the observed unsynchronized HRV must have other sources. The HRV during singing is the result of several processes other than breathing but still related to the music sung, for example, emotional, physical effort. These processes may vary among the participants, which might result in the less synchronized and more chaotic pattern shown here.

Although HRV seems to be lower immediately during singing, we have not measured what happens later. It is indeed very possible that singing exercises the autonomic system and that this may render higher HRV in other situations and better adaptation and possibly health. It is also possible that measuring HRV at some time (eg, 30 minutes) after singing may have yielded different results. A liberal interpretation of the data indicates that participants appear to be better able to do the synchronized breathing exercise after singing than before.

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This study has several limitations. As earlier research has shown, professional singers might have more HRV than amateurs.[15] The sample was small. The age range was large and the distributions in gender and voices were skewed. We did not collect data on, for example, health status and body mass index that possibly could have an effect. However, the design only used within-subject comparisons, with the exception of the exploratory comparison of voices that did not use statistical inference testing.

More research with larger samples, more control variables (eg, health related and physiological), more diverse songs, and more controlled experimental designs is needed to identify the mechanisms between choral singing and health.

Declaration of Conflicting Interests

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