A Review of the Physiological Effects and Mechanisms of Singing

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Summary: Daily experience suggests that singing can energize us and even provide a physical workout. A growing amount of evidence has been presented to support anecdotal claims of the benefits of singing on health and well-being. Singing has been shown to be related to numerous physiological changes. The cardiorespiratory system is utilized during persistent singing training, resulting in enhanced respiratory muscles and an optimized breathing mode. In addition, singing can also cause changes in neurotransmitters and hormones, including the upregulation of oxytocin, immunoglobulin A, and endorphins, which improves immune function and increases feelings of happiness. This review is organized by respiratory, circulatory, and hormonal changes that are collectively a part of singing in a healthy population. The various studies are discussed with the intention of helping researchers and clinicians realize the potential benefit of singing and provide a clinical option as an adjunct therapy for a given situation. Better understanding of physiological mechanisms will lay a solid theoretical foundation for singing activities and will present important implications for further study. Evaluations of existing research and recommendations for future research are given to promote the scale and duration to better demonstrate the effectiveness of singing before it can be recommended in clinical guidelines and satisfy criteria for funding by commissioners of health and social care.

Key Words: Singing–Health–Mechanism–Physiological effects–Hormones.

INTRODUCTION

Singing is the act of producing musical sounds with the voice, an activity whose origins are lost in antiquity.[1] In modern times, singing is a universal activity, pervading the daily lives of individuals from diverse cultural, demographic, and political backgrounds. There are diverse forms of singing, such as everyday singing, group singing, karaoke singing, solo singing, and singing education. There is also a large variety of singing styles such as rock, gospel, country, musical theater, and close-knit a cappella.[2] Group singing can be found in a wide range of settings including hospitals, workplaces, local communities, homeless shelters, and prisons as well as more traditional venues such as churches and concert halls.[3,4] In addition, karaoke singing is one of the most popular extracurricular activities among Asian youth, especially in China and Japan.[5]

Although singing is generally considered to be a form of entertainment rather than exercise, it has also been related to numerous health and well-being outcomes. As early as 1930, Rollrath found that many famous singers had lived to be 80 or even more than 100 years old, which suggested that singing could increase longevity.[6] Recent years have witnessed an incremental recognition of the value of singing activities in improving mental and physical health in both nonclinical and clinical settings.[7] Singing, the active music intervention, has been found to bring about better outcomes than the receptive music intervention (eg, listening or music games) as an adjunctive treatment option.[8] Studies have realized the effects of singing on lung diseases, especially chronic obstructive pulmonary disease[9] and asthma,[10] as well as other chronic medical conditions, including Parkinson's disease[11] and quadriplegia,[12] due to increased lung vital capacity (LVC) and enhanced respiratory muscles. Furthermore, singing has also demonstrated positive impacts on emotional states and neural network reconfiguration, so that the symptoms of mood disorders,[13] dementia,[14–16] and aphasia[17] improve after singing intervention. On the other hand, less research has been conducted on the healthy population or the neuroendocrine system as a potential underlying mechanism.[18–20]

Given the growing popularity of singing, more value should be placed on scientific research highlighting its benefits and mechanisms. Therapeutic benefits of singing may be better understood with a greater knowledge of the mechanisms underlying the relationship between singing and health in humans.[21] Nowadays, many studies related to singing focus on the feasibility and practicality of singing as an adjunct therapy to patients rather than as a rewarding exercise with regard to general well-being. To our knowledge, no review has been done that summarizes the data collected on the biological and neurochemical benefits of singing. The purpose of this manuscript is twofold: We discuss changes in respiratory, circulatory, and endocrine systems during all singing tasks and characterize these relationships by determining the extent to which neurochemistry results in these changes. The second part of this manuscript is concerned with singing therapy and related factors, indicating some implications and limitations of existing research.

RESPIRATORY CHANGES

Respiratory changes are one of the most obvious and perceptible changes associated with singing. The air that is exhaled from the lungs is the source of power for articulation and singing. Continuously stable air pressure vibrates the vocal cords, while resonance apparatuses and articulators adjust the structures to produce different timbres.[22] In the process of singing, repeated utilization of the corresponding organs and the surrounding

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structures can not only coordinate the subsystems but also exercise the respiratory muscles, leading to improved lung function.[23] Professional singers with correct and proper singing patterns can be seen to have an improved "breathing reserve"; that is, they adjust their breathing mode in order to transfer kinetic energy into sound energy more efficiently. This creates a better tolerance to the effects of vocal pathologies.[24]

Gould and Okamura[25] found no significant difference in total lung capacity (TLC) between professional singers, vocal music students, and untrained persons, while the ratio of the residual lung volume to total lung capacity (RV/TLC) of professional singers was significantly lower than that of the other two groups, and the RV/TLC values of the vocal music students were also lower than those of the untrained group. The results suggest that singing can help healthy people take full advantage of the same amount of lung function, indicating better breathing efficiency, which increased with the singing training time. Carroll et al[26] compared the forced expiratory volume in 1 second (FEV1), forced vital capacity (FVC), and forced expiratory flow of 40 professional singers with the standard values of a healthy population. The average results of professional singers were greater than standard values. Irzaldy et al[27] conducted lung measurements in 10 chorus members and 10 ordinary students. Significant differences were found in LVC and FVC ($P = 0.02$, $P = 0.01$, respectively), while no significant difference was found in inspiratory volume, suggesting that the promotion of the relevant indicators was closely related to the expiratory phase. Ksinopoulou et al[28] conducted a randomized controlled trial, in which 58 professional singers and 22 wind-instrument players were enrolled in the experimental group (45 males and 35 females) and 80 healthy subjects were recruited as control groups. There were significant differences in FVC, FEV1, and peak expiratory flow rate (PEFR) between the two groups ($P < 0.01$, $P < 0.01$, $P = 0.001$, respectively), while a significant difference in the FEV1/FVC ratio was only found among the female participants ($P = 0.001$). Nevertheless, Schorr-Lesnick et al[29] compared 34 singers and 48 wind-instrument players with a control group of 31 string or percussion performers. There was no significant difference between the two groups in FVC, mean forced expiratory flow, FEV1/FVC value, maximum expiratory pressure, or maximum inspiratory pressure. This remained true when tested independently and when corrected for age, gender, weight, height, and smoking.

CIRCULATORY CHANGES

Along with the respiratory changes, the circulatory system may change depending on respiratory sinus arrhythmia (RSA). RSA is a special physiological phenomenon where exhalation can increase the vagus nerve (parasympathetic nerve) tension, which results in the extended sinus P-P cycle and vice versa.[30,31] RSA can effectively accelerate lung gas exchange by matching alveolar ventilation and capillary perfusion, and save the energy of the cardiorespiratory system by suppressing unnecessary heartbeat and ineffective ventilation during exhalation.[32,33] Grape et al[34] considered that singing can repeatedly train synergies between the respiratory system and the circulatory system to achieve the best match and show a better breathing cycle vigor. Thus, RSA may be the reason why singing further induces heart rate variability (HRV), the variability between the R-R intervals in successive heartbeats.[35] A reduced HRV is not only an independent risk factor for sudden cardiac death and arrhythmia events but is also related to psychiatric disorders such as depression and anxiety.[36,37] The HRV of 15 students was measured after the performances of different types of singing (humming, mantras, hymns).[38] The results suggest that singing increases HRV, and when the music structure is regular, HRV profiles tend to conform in terms of frequency and phase. Grape et al[34] found that professional singers experienced more significant HRV changes than amateurs during singing.

On the other hand, Niu et al[39] reported the case of a 76-year-old woman with chronic stable hypertension who experienced severely elevated blood pressure prior to total knee replacement surgery and was unresponsive to antihypertensive drugs (systolic blood pressure continued to fluctuate around 200 mmHg). In this case, her blood pressure was found to have dramatically dropped below 180 mmHg systolic after she sang several religious songs. Blood pressure measurements were conducted in 91 instrumentalists and 51 professional singers by Eller et al.[40] It was found that the average blood pressure of the professional singers was significantly lower than that of the instrument players. Valentine and Evans[41] presented that decreased blood systolic pressure and increased diastolic blood pressure were found after respective group activities in all singing groups (10 music majors and 13 amateur choirs), and changes in the two singing conditions were not significantly different from each other. Two groups of singers (n = 12, 13) and a group of nonsingers (n = 12) each produced the national anthem by speaking, by singing the words, and by humming the melody in a study by Formby et al.[42] No significant difference was found in the cerebral blood flow between these groups during speaking or singing.

CHANGES IN NEUROPEPTIDES AND HORMONES

In addition to changes in the cardiovascular system, singing has been shown to help people ease anxiety, bring euphoria, and create a sense of belonging. For example, a study of 210 adults was conducted over an 18-month period, in which 108 members were recruited into the singing group to participate in community singing rehearsals, while the remaining members were recruited as the control group.[43] Results revealed a significant reduction in the proportion of adults in the singing group classified as depressed and a concomitant significant increase in resilience levels, quality of life, sense of connectedness, and social support among this group. There were no significant changes for these variables in the comparison group. Many scholars have noticed this phenomenon and have tried to explore the mechanism behind the neural chemistry, but some studies have had opposite variation tendencies in these neuropeptides and hormones.

Adrenocorticotropic hormones (ACTHs) and glucocorticoids are both important components of the hypothalamic–pituitary–adrenal axis (HPA axis), and are essential hormones to keeping an individual excited and aroused. Increased HPA activity in response to stressful situations is part of the natural fight-or-flight response and leads to an inhibited immune response, narrowed arteries, and increased epinephrine, resulting in raised blood pressure.[44] Fancourt et al[45] examined the impact of singing in a low-stress performance situation (rehearsal without an

audience) and a high-stress live concert (performance in front of 610 audience members) on levels of glucocorticoids (cortisol and cortisone) in 15 professional singers. The results showed a significant decrease in both cortisol and cortisone across the low-stress condition, suggesting that singing in itself was a stress-reducing (and possibly health-promoting) activity, while there were significant increases across the high-stress condition. A study by Beck et al had a similar consequence.[46] Four jazz singers were sampled to sing together in two separate performances, from printed sheet music and improvised, in the research done by Keeler et al.[47] Even though ACTH concentrations decreased in both conditions, only the precomposed group had a significant statistical difference that may have contributed to the social flow experience. A study by Grape et al[34] explored the possible beneficial effects of singing on well-being, which included eight amateurs and eight professionals during a singing lesson. The results showed that cortisol increased after the singing lesson, with the serum concentration of tumor necrosis factor α (TNF-α) increasing in professionals after the singing lesson. Kreutz et al compared the effects of choir music on cortisol in 31 amateur choirs between two conditions, namely singing versus listening to choral music.[48] Listening to music led to a significant reduction in cortisol ($P < 0.001$), and participants reported increased negative mood in the same condition, which indicated music listeners might feel inactive or even bored. In addition, cortisol concentration remained stable during singing. No significant statistical differences for cortisol were found between the singing group (n = 24) and the chatting group (n = 25) in another study by Kreutz.[49] Fancourt et al carried out a multicenter single-arm preliminary study to assess the impact of group singing on stress and immune response in three populations affected by cancer—carers (n = 72), bereaved carers (n = 66), and patients (n = 55)—showing decreases in cortisol ($P < 0.001$) alongside significant increases in cytokine and receptor activity (GM-CSF, IL17, IL2, IL4, sIL-2rα, TNF-α, $P < 0.01$) after five choral activities across all five centers and all the groups.[19] The author believed that the reduction in cortisol following singing reduced glucocorticoid suppression of the immune system, leading to general activation of the cytokine network and immune activity. Several variables, including numerous types of interventions, participants, and genres, influence the consequences of different research, which may be part of the reason why these studies failed to reach a consensus.

Research has repeatedly implicated the neuropeptide oxytocin (OT) as one of the key hormones involved in a range of social and affiliative behaviors.[50] OT was found to increase trust,[51] reduce negative behavior,[52,53] decrease amygdala activation to fearful faces,[54,55] and increase theory of mind skills,[56] indicating a potential direct OT involvement in processes of social bonding and interpersonal closeness. Results of the study by Keeler et al showed OT concentration in four singers increased after improvised singing, suggesting that better social ties lead to growth in OT. In contrast, no changes in OT concentration were found during a precomposed performance.[47] OT concentrations increased significantly in both amateur and professional singers after the singing lesson in Grape et al's study.[34] Kreutz et al[48] found a remarkable upward trend in a singing group compared with a chatting group with a significant difference ($P < 0.01$), indicating that singing enhances individual psychological well-being as well as induces a sociobiological bonding response. However, OT dropped after 1 hour of group singing in all the participants in Fancourt et al's study ($P < 0.001$).[19]

Secretory Immunoglobulin A (S-IgA), one kind of first-line antibody to protect from bacterial and viral infection in the upper airway, is regarded as a clinical indicator of individual immune capacity.[57] It has been found that people tend to stay positive and relaxed with the upregulation of S-IgA while feeling stressful and nervous with the downregulation.[58] Kreutz et al found that S-IgA increased after the singing training and listening class, with only a significant difference in the singing training ($P < 0.005$).[48] Kuhn assigned 33 participants (28 women and 5 men) randomly to one of three groups: a singing and instrument-playing group, a listening group, and a control (rest or sit quietly) group.[59] Secretory Immunoglobulin A (S-IgA) levels of the singing and instrument-playing group showed a significantly greater increase than the others, suggesting that active participation in musical activity produces a greater effect on the immune system than passive participation. Beck et al examined the S-IgA concentration during an early rehearsal (n = 31), a late rehearsal (n = 34), and a public performance (n = 32).[46] As measures of immune system response, mean levels of S-IgA increased significantly, 150% during rehearsals and 240% during the performance. Beck et al collected saliva samples of 10 members of a choral group after a 10-week singing session and conducted the laboratory tests of S-IgA. The concentration of S-IgA increased in both rehearsal and performance conditions, but only significant upward changes were found after a formal performance ($P = 0.012$).[60]

Beta-endorphin is an opioid peptide that is produced by the cleavage of pro-opiomelanocortin, along with ACTHs and other derivatives. It is best known for its analgesic, euphoric, and sedative effects, involving many forms of behavior/symptoms such as anxiety,[61] anger control[62] and aggression,[63] depression,[64] and addictions.[65] Weinstein et al recruited individuals from a community choir that met in both small (n = 20–80) and large (n = 232) group contexts.[66] Results showed that measures of endorphin release increased across singing rehearsals in both groups with a significant difference ($P < 0.001$). However, it seems likely that the decrease in beta-endorphins found in Fancourt's study ($P < 0.001$) was part of a generalized downregulation of stress response.[6] Dunbar et al measured the pain tolerance duration of pressure from a 260-mmHg hematomanometer in 13 choral members and 9 prayer members during respective group activities.[67] The results demonstrated that singing triggered endorphin release (indexed by an increase in postactivity pain tolerance) in contexts where merely other activities do not ($P < 0.001$).

SINGING THERAPY AND RELATED FACTORS

Singing therapy pattern

A standard therapy pattern is urgently needed in related research. To discuss the comparability and effectiveness of singing therapy among different studies, several variables should be evaluated, including intervention strategies, intervention duration, and the demographics of participants.

Most existing studies included explicit breathing instructions as part of the singing intervention. Several different

techniques were used during breathing training, including pursed-lip breathing (breathing out slowly with the lips in a whistling position), diaphragmatic breathing (deep breathing focusing on the abdomen), pranayama yoga breathing (timed breathing with a focus on exhalation), and changing the breathing pattern using computerized feedback to slow down the respiratory rate and increase exhalation time, or combinations of these techniques.[68] The variability of training method leads to the indeterminacy of comparison between different studies, so for this reason, the relationship of breathing training and singing is hard to define. Most scholars believe that even without a separate breathing training, singing itself can also have a positive impact on the respiratory system.[69] Gunji et al suggested that even for healthy people without any breathing guidance, singing can also improve their control of the diaphragm and abdominal muscles.[70] Engen thought that the benefits of breathing exercises alone are limited and that participants have difficulty appreciating the connection between breathing and sounds, resulting in participants quitting their repetitive boring breathing exercises.[71] Singing and breathing should be considered as a whole because singing itself is a procedure of inspiration and expiration. It is unscientific to sort them out physiologically and operationally. Such respiratory and vocal exercises are important steps for a singer to improve his or her respiratory coordination. As a consequence, they are an essential part of the learning process of singing itself. Therefore, singing not only improves social bonding and enjoyment during practice but, because breathing exercise is also an irreplaceable part of singing, it also enhances physical achievement.[72] The value of singing as an adjuvant treatment, then, may be that afflicted individuals can avoid the use of repetitive, boring exercises during therapeutic trials. This, in turn, will serve to keep participants from early withdrawal from treatment.

The duration of singing intervention is one of the most important variables associated with better therapeutic results. McNaughton et al claimed that there is a dose–response relationship between singing and physiological indicators. In other words, no physiological changes will occur until singing training or therapy is performed for a certain amount of time.[73] Goodridge et al presented that participants in singing training, after 3 months, had reached the platform phase of physical function, where even if the duration/dose of intervention increased, there would be a minimal increase in benefits. It may be part of the reason why no significant physical changes can be found after singing intervention in professional singers.[74]

The social status and vocation of the participants can also lead to different results of experiments. Bailey and Davidson compared the psychological changes in eight untrained homeless men and eight professional choir singers after choral activities.[4] The results showed that regardless of the social status of the participants themselves or whether they could make beautiful sounds, no significant differences were found in pleasure and satisfaction. However, professional singers had a stronger awareness of the interpersonal relationship and collective activities. Additionally, the vocation of the participants would greatly impact the goals and intentions during singing tasks, such as pure enjoyment or a high standard of musical and performance excellence. It may be the reason why the change in ACTH varied throughout the several studies in different groups of participants, as we mentioned before. Grape et al conducted a measurement of the changes of the relevant indicators in eight professional singers and eight amateur people over a singing training.[75] Amateurs reported increasing joy and elatedness, whereas professionals did not. Additionally, HRV and TNF-α were higher in professional singers than amateurs. It revealed that professional singers paid more attention to singing skills and physical condition in singing training, while amateur people were taking singing as a way of self-expression.

Social bonds and singing

In the past few years, some studies claimed that social bonding played a key role in health benefits associated with group singing, indicating that some of the benefits were driven by heightened social cohesion. Pearce et al recruited seven newly formed community-based adult education classes (four singing, N = 84, and three comparison classes studying creative writing or crafts, N = 51) to respective activities over 7 months.[76] Although physical health, mental health, and life satisfaction improved overall, singers did not show a significantly greater increase than nonsingers. Moreover, greater changes in collective bonding were significantly associated with increased flourishing, improved physical health, and reduced anxiety independently of the corresponding baseline levels. The authors considered that it is the extent to which individuals felt integrated into their class group rather than singing that directly resulted in an improvement in health and well-being, regardless of the activity in which they participated. Valentine and Evans measured emotional changes in 10 solo singers and 13 chorus singers after singing activities and found that the chorus singers' sense of excitement and pleasure were higher than solo singers.[41] Stewart and Lonsdale collected questionnaire data from 375 participants and found that choral singers and team sport players reported significantly higher psychological well-being than solo singers.[77] Choral singers also reported that they considered their choirs to be a more coherent or "meaningful" social group than team sport players considered their teams. Choral activities seemed to enhance the sense of belonging of the participants, coordinated with the singing itself to further improve the well-being and quality of life.[76]

CONCLUSIONS

Studies that are of adequate scale and duration are urgently needed to demonstrate the effectiveness of singing intervention before it can be recommended in clinical guidelines and satisfy criteria for funding by commissioners of health and social care. Furthermore, the research in regard to the mechanism of singing therapy has not formed a complete theoretical system. Some limitations, including lack of control group and necessary statistics analysis, restricted the credibility of numerous studies.

However, the therapeutic application of singing does seem to be effective in reducing the problematic behavioral and psychological symptoms. Singing training actively utilizes the respiratory muscles to ensure adequate pressure to initiate and maintain vocal cord vibration according to the rhythmic coordination with breathing. Enhanced respiratory muscle strength and control as well as coordinated breathing mode can effectively

improve the efficiency of respiratory and circulatory response and coordinate cardiopulmonary function, resulting in increase in vital capacity, FVC, FEV1, PEFR, and HRV. Also, singing effectively improves the vitality of neurological networks, including OT, S-IgA, and endorphins, either from social bonds or singing itself, which enhance the sense of social belonging, the body immune function, personal happiness, and euphoria. Singing is not only the exercise of the body function but also a way of self-expression, which brings about a positive personal and social impact. Because of this, singing is not just the privilege of professional singers but should be universal to the general public. The rise of the community chorus and school choirs is bound to guide more people to participate in singing, pervading the joy and happiness of singing.

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