The physiological demands of Singing for Lung Health compared to treadmill walking

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Abstract

Participating in singing is considered to have a range of social and psychological benefits. However, the physiological demands of singing, whether it can be considered exercise, and its intensity as a physical activity are not well understood. We therefore compared cardiorespiratory parameters while completing components of Singing for Lung Health (SLH) sessions, with treadmill walking at differing speeds (2, 4, and 6km/hr). Eight healthy adults were included, none of whom reported regular participation in formal singing activities. Singing induced physiological responses that were consistent with moderate intensity activity (METS: median 4.12, IQR 2.72 - 4.78), with oxygen consumption, heart rate, and volume per breath above those seen walking at 4km/hr. Minute ventilation was higher during singing (median 22.42L/min, IQR 16.83 - 30.54) than at rest (11L/min, 9 - 13), lower than 6km/hr walking (30.35L/min, 26.94 - 41.11), but not statistically different from 2km/hr (18.77L/min, 16.89 - 21.35) or 4km/hr (23.27L/min, 20.09 - 26.37) walking. Our findings suggest the metabolic demands of singing may contribute to the health and wellbeing benefits attributed to participation. However, if physical training benefits result remains uncertain. Further research including different singing styles, singers, and physical performance impacts when used as a training modality is encouraged.

Background

Singing is a ubiquitous cultural practice throughout history and across the world[1], and participation in singing is believed to have a range of health and wellbeing benefits[2,3]. Research to date has predominantly focused on psychosocial, and psychobiological impacts[4–8]. However, the cardiorespiratory demands of singing, and the potential for it to serve as a form of exercise and contribute to daily physical activity are less well examined.

An appreciation of the physiological demands of singing could improve understanding of how best to use singing in a therapeutic capacity. An example of a structured therapeutic singing intervention is Singing for Lung Health (SLH), which has been developed as a strategy to help people with respiratory disease[8–12], particularly those who continue to be limited by breathlessness despite optimal medical care[13–15]. Though high-quality research on the impacts of SLH is limited[16], participants report a range of biopsychosocial impacts[8,17], including physical improvements relating to balance[18] and physical aspects of quality of life[8]. Furthermore, it is known that exercise training is one of the most effective management strategies for people with long term respiratory conditions[19], usually in the form of pulmonary rehabilitation, however many people are unable to access PR[20], hence alternative approaches could be complementary in expanding provision of exercise training opportunities and diversifying delivery modalities, if an evidence base were to be established.

Additionally, identifying existing, enjoyable, and well attended physical activities of sufficient intensity to be considered exercise is useful from a public health and health promotion perspective. Physical activity is important both to maintain health and to mitigate the impact of long term medical conditions[21]. This is particularly relevant during the present COVID-19 pandemic, where physical distancing measures to reduce risk of COVID-19 transmission, combined with the concerns about the virus itself, are having unintended negative impacts including inactivity, social isolation, and anxiety[22,23]. As such, there is an urgent need to provide and support evidence-based strategies, that are deliverable in the current situation and beyond, which could, for example include online singing groups[18,24].

To evaluate this further we undertook a study to compare cardiorespiratory parameters during singing, and various SLH exercises, with i) rest and ii) three different walking speeds.

Methods

Participants

We conducted a non-blinded observational study. A convenience sample of colleagues and staff at the National Heart and Lung Institute (NHLI) were approached face-to-face and invited to participate in the study. The initial intention was to recruit 12 participants, however the implementation of restrictions on aerosol generating procedures due to the COVID-19 pandemic meant we decided to stop at eight. None of the participants sung regularly. Inclusion criteria included: age 18 to 99 years; no significant medical conditions or active musculoskeletal disease impairing exercise; no contraindications to exercise or spirometry as per American Thoracic Society/European Respiratory Society criteria; and capacity to consent to exercise testing.

The study was prospectively registered at clinicaltrial.gov (NCT04121351) on 9th October 2019. Ethical approval was granted by the Imperial College Research Ethics Committee (IREC) (19IC5429). All participants provided informed written consent, and all methods were performed in accordance with the relevant guidelines and regulations.

Physiological parameter assessment

Physiological parameters assessed were VO_2 ml/kg/min, end tidal CO_2 (kPa), heart rate (bpm), minute ventilation (L/min), respiratory rate (breaths/min), mean volume per breath (L/breath). Gas analysis and flow were collected using JLab software package, Breath-by-Breath, and the Jaeger Oxycon Pro and Vyaire Oxycon mobile devices (see photos wearing device in supplementary information). The device was calibrated between participants as per standard protocol. Heart rate was assessed using the Polar heart rate monitor (Polar, Finland). Measures of perceived effort and dyspnoea were recorded at baseline and following each component according to the Borg RPE and Dyspnoea scales. Each stage of the protocol was completed for two minutes with 20 seconds between each section to allow for a verbal reminder of the next stage of the protocol to the participant, equipment check, and change of participant position if necessary. The two-minute duration of protocol components was selected based on a compromise between recommendations regarding exercise testing guidelines[25], being representative of real-world SLH sessions, and pilot work comparing the second minute values with longer protocol durations, which suggested stability of values during the second minute of each component. As such, the mean value from the second minute of assessment was used. Data were recorded continuously as the protocol was completed by each participant.

Spirometry was conducted as per American Thoracic Society/European Respiratory Society Guidelines (ATS/ERS) [26]. Physical activity intensity was considered as light, moderate and vigorous, according to Metabolic Equivalents (METs), derived from the VO_2 ml/kg/min data, with light physical activity if below 3 METS, moderate if between 3–6 METS and vigorous if above 6 METS[27]. METs for each component were calculated by dividing by 3.95 ml/kg/min, which was the median measurement for the group during the resting phase 1.

Singing Protocol

Singing for Lung Health (SLH) is a structured group singing programme for people with chronic respiratory conditions[8] see https://www.blf.org.uk/support-for-you/singing-for-lung-health. The components of a SLH session are similar to those found in most community choirs and singing groups, but in addition, aim improving participants symptoms through song, breathing exercises and relaxation techniques. We selected SLH components as an established method of group-singing for which the session content has been clearly defined and evaluated indicating intervention fidelity[8,11]. Each component was demonstrated by AL to each participant who briefly practiced the content of each component to show understanding, before resting for 30 min during study set up.

The full study protocol is provided in the online supplementary material. However, components in brief were as follows:

1. Baseline assessment at rest
2. Physical warm up (gentle, dance-based, to music)
3. Rhythm exercise, seated singing
4. Pitch exercise, seated singing
5. Vocal fricatives, focusing on consonant vocalisations
6. Song repertoire, standing singing
7. Rest component 2
8. Treadmill walking 2 km/hr
9. Treadmill walking 4 km/hr
10. Treadmill walking 6 km/hr

Walking speeds were selected as being representative of a slow, medium, and fast walk. These speeds also cover the NHS definition of a 'brisk' walk of 3 miles per hour (4.8 km/hr)[28], recommended as moderate intensity exercise which can increase aerobic fitness[29].

Rest component two was included to ensure that the protocol included sufficient time for full recovery between components, and to enable participants physiological parameters to return to baseline before the walking components.

Statistical analysis

Analyses were carried out using Stata 14 (StataCorp, TX). The Friedman test was used to assess for differences in the impact of protocol components on physiological parameters. Post-hoc Wilcoxon-signed rank tests were used for pair wise comparisons between singing, rest, and walking. Statistical significance was set at $p < 0.05$. Readers wanting to adjust for multiple comparisons within each physiological parameter could apply a Bonferroni alpha of 0.013 ($p < 0.05$ divided by 4 tests per parameter). Further adjustment for multiple comparisons across the different physiological parameters was not calculated given our sample size was small and our study exploratory. Data are presented to two significant figures.

Results

Participant characteristics are shown in Table 1. Data comparing physiological parameters during singing with rest and walking at three different speeds is shown in Table 2. Freidman tests demonstrated that the protocol components induced differences in all physiological parameters: VO_2 ml/kg/min ($Q(9) = 65.78$, $P < 0.001$); METs ($Q(9) = 65.78$, $P < 0.001$); end tidal CO_2 ($Q(9) = 45.19$, $P < 0.001$); heart rate ($Q(9) = 58.44$, $P < 0.001$); minute ventilation($Q(9) = 57.30$, $P < 0.001$; respiratory rate ($Q(9) = 48.60$, $P < 0.001$); volume per breath ($Q(9) = 43.31$, $P < 0.001$); Borg breathlessness scale ($Q(9) = 32.91$, $P < 0.001$); Borg perceived exertion scale ($Q(9) = 40.50$, $P < 0.001$).

Data are shown in Fig. 1. The main singing condition (protocol component 6) showed that singing induced statistically significant increases in oxygen consumption, heart rate, and volume per breath compared with rest conditions, walking at 2 km/hr, or walking at 4 km/hr (pairwise comparisons using Wilcoxon-sign rank test). Minute ventilation was higher during the singing component than at rest, and lower than walking at 6 km/hr, but not statistically significantly different from walking at 2 or 4 km/hr. End tidal CO_2 was higher singing than at rest or walking at 2 km/hr, but not statistically different from walking at 4 or 6 km/hr. Borg breathlessness scale ratings suggest singing was associated with an increased sensation of breathlessness compared with rest and all walking speeds. Perceived exertion during singing was greater than during rest and walking at 2 km/hr, but not different from walking at 4 or

6 km/hr. Respiratory rate was lower during singing than rest or walking, however this is likely due to the phrasing of the songs, rather than being a representative of a physiologically driven respiratory rate.

Table 1
Participant Characteristics

Demographic	Mean (SD)
Age (years)	32 (4)
Gender	2 female, 6 male
Height (m)	1.71 (0.07)
Weight (kg)	77.1, (15.6)
Ethnicity	4x White European; 3 x Arabic (2x Saudi, 1x Egyptian)
BMI	26.4 (5.8)
FEV1 (L)	3.81 (1.01)
FEV1% predicted	95.9 (17.2)
FVC (L)	4.86 (1.09)
FVC % predicted	102.5 (14.3)

Table 2
Comparison of singing with rest and walking at three different speeds.

Cardiorespiratory parameter	Singing repertoire (component 6) Median (IQR)	Baseline rest period 1 Median (IQR)	Difference from singing repertoire (p-value*)	Walking at 2 km/hr Median (IQR)	Difference from singing repertoire (p-value*)	Walking at 4 km/hr Median (IQR)	Difference from singing repertoire (p-value*)	Walking at 6 km/hr Median (IQR)	Difference from singing repertoire (p-value*)
VO_2 ml/kg/min	16.27 (10.74–18.86)	3.95 (3.69–4.35)	-12.32 **(0.012)**	8.19 (7.26–9.01)	-8.08 **(0.012)**	10.42 (9.68–11.33)	-5.85 (**0.036)**	15.39 (14.68–16.64)	-0.88 (1.00)
METs	4.12 (2.72–4.78)	1.00 (0.93–1.10)	-3.12 **(0.012)**	2.07 (1.84–2.28)	-2.05 **(0.012)**	2.64 (2.45–2.87)	-1.48 (**0.036)**	3.90 (3.72–4.21)	-0.22 (1.00)
End tidal CO_2 kPa	5.16 (4.91–5.51)	4.24 (3.80–4.52)	-0.92 **(< 0.05)**	4.43 (3.88–4.45)	-0.73 **(< 0.05)**	4.62 (4.08–4.91)	-0.54 (0.069)	4.91 (4.40–5.14)	-0.25 (0.12)
Heart rate (bpm)	108 (97–114)	76 (63–82)	-31 **(0.012)**	86 (81–91)	-22 **(0.012)**	99 (88–107)	-9 (**0.042)**	108 (101–119)	0 (0.62)
Minute ventilation (L/min)	22.42 (16.83–30.54)	11 (9–13)	-10.9 **(0.012)**	18.77 (16.89–21.35)	-3.72 (0.069)	23.27 (20.09–26.37)	+ 0.85 (0.89)	30.35 (26.94–41.11)	+ 7.93 **(0.017)**
Respiratory rate (breaths/min)	10 (7–13)	15 (14–17)	+ 5.35 (**0.017)**	23 (21–29)	+ 12.75 **(0.012)**	23 (20–31)	+ 12.49 (**0.012)**	24 (20–35)	+ 13.32 (**0.012)**
Volume per breath (L/breath)	2.11 (1.92–2.70)	0.69 (0.63–0.77)	-1.42 **(0.0117)**	0.80 (0.68–0.98)	-1.31 **(0.012)**	0.93 (0.86–1.05)	-1.18 (**0.012)**	1.21 (1.09–1.43)	-0.90 (**0.012)**
Borg dyspnoea scale	1.0 (1.0–2.5)	0 (0–0)	-1 (**0.013)**	0.00 (0.00–0.50)	-1 **(0.019)**	0.75 (0.50–1.00)	-0.25 (**0.049)**	1.00 (0.75–1.00)	0 (**0.049)**
Borg rating of perceived exertion scale	8.5 (8.0–9.0)	6 (6–6)	-2.5 (**0.019)**	6.00 (6.00–7.00)	-2.5 **(0.035)**	7.50 (7.00–8.00)	-1 (0.052)	9.00 (8.00–9.00)	+ 0.5 (0.8788)

*Wilcoxon-sign rank test. Data are provided to 2 decimal places, or less when appropriate for degree of accuracy of the specific measurement. VO_2 = Oxygen consumption, METS = Metabolic Equivalents, L/breath = litres per breath, L/min = litres per minute, bpm = beats per minute

Figure 1: Box and whisker plots of physiological parameters during each component of the protocol

For box and whisker plots the line in the centre of the box represents the median, the box includes the first to third quartiles, the whiskers indicate upper and lower values (excluding outliers), the dots represent possible outliers. Freidman tests demonstrated that the protocol components induced differences in all physiological parameters $P < 0.001$.

Discussion

Main finding

We found that the singing produced changes in physiological parameters including oxygen consumption, end tidal CO_2, METs, heart rate, and minute ventilation, comparable to those seen when walking at a moderate to brisk pace, consistent with the changes in these parameters seen during moderate intensity physical activity.

Research regarding the oxygen cost of singing by non-professionals is limited. Sliiden et al (2016) present data from 20 musical theatre performers which suggest similar physiological responses to the current study when singing compared with rest, including heart rate, oxygen consumption, minute ventilation, and breath volume[30]. Another study of nine musical theatre performers compared cardiorespiratory parameters while singing and dancing together, with dancing alone. The study found significantly lower breathing frequency and higher lactate when singing and dancing together, compared with dancing alone, but other parameters including oxygen consumption and heart rate did not differ significantly [31]. However, singing alone (without dancing) was not compared to rest which limits comparisons. Regarding ventilatory volumes, our findings support previous research that suggest increases during singing and speech compared with spontaneous breathing [7,32–36]. However, much of the previous research concerns speech alone, and where singing has been investigated, the studies have largely focused on professional singers, or employed limited protocols that do not fully represent the range of activities engaged in during a community singing group. As such, application of previous research findings to the most common contexts in which people sing is challenging. To our knowledge this is the first study to systematically assess physiological parameters in amateurs, including pulmonary ventilation volumes, during the various singing activities commonly found in amateur community singing groups. As such, our findings build on those of other studies by demonstrating comparable physiological responses related to singing in non-professionals, and by comparing singing to a standardised form of physical activity in the form of treadmill walking.

Of note, the relative increases above baseline in ventilatory parameters may be of importance when considering aerosol transmission of infectious agents, including SARS-CoV-2, from both the perspective of people with the infection, and people who could be infected, in a setting. This is important particularly given that community singing groups have been identified as high risk for transmission[37, 38]. Larger ventilatory volumes are relevant to dispersion of aerosols from infected individuals but may also impact the 'dose' of aerosols inhaled by those at risk of infection. As such, approaches such as remote singing groups delivered via video conferencing applications may mitigate associated risks, with pilot work suggesting potential health and wellbeing benefits from such approaches are still possible[18].

An important consideration when interpreting our findings, is that the extent to which people are moving is also likely to be a major factor in determining the physiological demands of the activity. Though completely static singing is unrealistic, we should consider that different types of singing encourage different levels of body movement, gesture, and dance like movements, in addition to voice production. Comparing the seated components of the protocol to standing singing (component 6), gives some indication of the contribution of posture and body movements to physiological demands.

A further point for consideration is the extent to which changes in the physiological parameters assessed result from physical exertion, or a degree of relative hyperventilation required for vocalisation. For example, one might expect to see larger ventilatory volumes, and possibly heart rate, because of the air flow velocity and volumes requirements for vocalisation. However, the pattern of end tidal CO_2 during singing, compared with walking, suggests that hyperventilation alone does not account for the changes in the other parameters seen during the singing component. Furthermore, while minute ventilation approximately doubles from baseline, VO_2 approximately quadruples, suggestive of an important contribution from higher cardiac output, respiratory muscle extraction, and skeletal muscles involved in movement, however the relative contribution of these factors has not been investigated here.

Methodological considerations

This study has multiple strengths. To our knowledge, this is the first study to compare the physiological demands of singing to walking, using measures of ventilation, oxygen consumption, end tidal CO_2, and perceived effort and dyspnoea simultaneously. The focus on amateur singers makes the findings highly relevant for the vast majority of people who sing.

Certain limitations should be mentioned. Firstly, the use of healthy, relatively young participants may limit the extent to which our findings can be extrapolated to older people, or those with significant medical conditions, such as those with chronic respiratory disease (CRD). However, individuals with CRD are likely to find activities such as singing, more rather than less physiologically demanding, as a proportion of their VO_2 max[39]. Therefore, one might reasonably suspect that the potential for physical benefits related to training effects would also be increased, though in what way, and to what extent, remains unclear. Secondly, the sample size is small; although it was sufficient to meet the aims of the study by comparing the parameters during protocol components, replication of our findings in larger samples is encouraged. Thirdly, although we considered real world applicability when developing the components of the protocol, the total protocol duration was approximately 25 minutes, while most community singing sessions are longer. As such, further studies during real world community singing group sessions would be of interest. Lastly, though this study has demonstrated that singing induces physiological responses that are similar in magnitude to moderate intensity physical activity, this study has not assessed training effects of singing. As such we cannot draw clear conclusions from this study alone regarding impacts on physical fitness.

To build on these findings, future research could include maximal exercise tests for comparison; explore the training effects following a programme of singing; directly compare professional and amateur singers; specifically assess the impact of musical genre, volume, and physical movements; and compare healthy controls with people with certain chronic diseases, in whom singing is being delivered in a therapeutic context.

Conclusion

This study demonstrated that singing when standing induced physiological responses similar in magnitude to moderate intensity physical activity. The study also identified increases in minute ventilation, and breath volumes during singing and during singing related activities, that may be important when considering risk of transmission of respiratory infections including SARS-CoV-2. These findings suggest that health and wellbeing benefits attributed to singing participation, may in part, result from physical mechanisms. Further research including different types of singing, and singers, and training effects would be valuable.

Declarations

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Competing Interests

No conflicts of interest declared.

Authors Contributions

KP and AL had the original idea for the study, and collected the data with assistance of CM. KP analysed the data and wrote the first draft of the manuscript. All authors contributed to the study design, writing, reviewing and editing the manuscript, and approved the final manuscript for submission.

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Data Availability Statement

Data may be made available on reasonable request.

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Figures

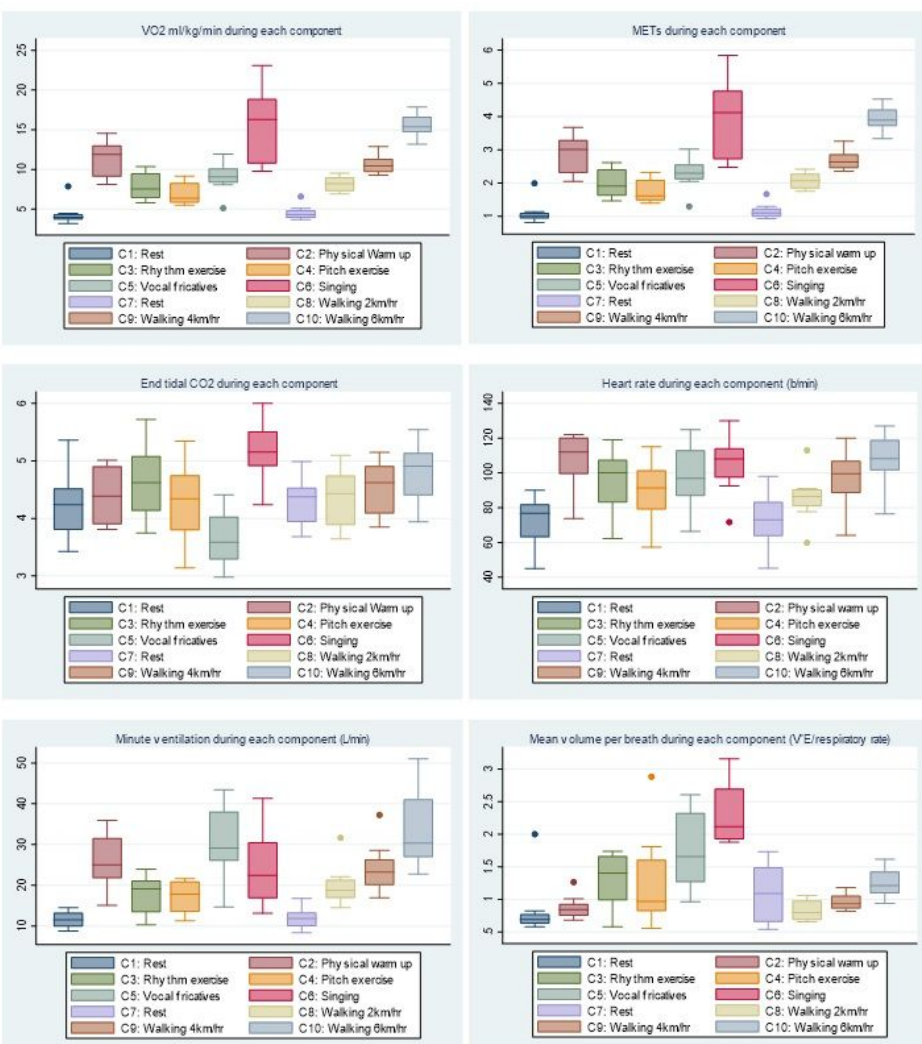

Figure 1

Box and whisker plots of physiological parameters during each component of the protocol. For box and whisker plots the line in the centre of the box represents the median, the box includes the first to third quartiles, the whiskers indicate upper and lower values (excluding outliers), the dots represent possible outliers. Freidman tests demonstrated that the protocol components induced differences in all physiological parameters P <0.001.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SuppPhysiologicaldemandsofsinging28DEC2020.pdf