Turk J Phys Med Rehab 2023;69(1):40-45
DOI: 10.5606/tftrd.2023.10944
Available online at www.turkishjournalpmr.com

Original Article

The correlation between six-minute walking distance and maximum phonation time in healthy adults

Febrian Mulya Santausa[1], Nury Nusdwinuringtyas[1], Tresia Fransiska Ulianna Tambunan[1], Dewi Friska[2]

[1]Department of Medical Rehabilitation, Faculty of Medicine, Universitas Indonesia, Central Jakarta, Indonesia
[2]Department of Community Medicine, Faculty of Medicine, Universitas Indonesia, Central Jakarta, Indonesia

Received: April 12, 2022 **Accepted:** August 08, 2022 **Published online:** February 05, 2023

ABSTRACT

Objectives: This study aimed to determine the association between six-minute walking distance (6MWD) and maximum phonation time (MPT) in healthy adults.

Patients and methods: The cross-sectional study was conducted with 50 sedentary nonsingers (32 females, 18 males; mean age: 33.5±8.3 years; range, 18 to 50 years) between February 2021 and April 2021. Subjects with a history of smoking, respiratory symptoms in the last two weeks, and heart, lung, musculoskeletal, and balance problems were excluded. The measurements of MPT and 6MWD were carried out by two different assessors blinded to each other.

Results: The mean MPT was higher in male subjects (27.4±7.4 sec *vs.* 20.6±5.1 sec, p<0.001). In the bivariate analysis, there was a significant correlation between MPT and 6MWD (r=0.621, p<0.001), as well as body height (r=0.421, p=0.002) and the mean fundamental frequency (r=-0.429, p=0.002); however, no association was found with age, body weight, and the mean sound pressure level. After multiple regression, 6MWD was the only factor associated with MPT (p=0.002).

Conclusion: There is a significant association between 6MWD and MPT in healthy adults, and the results suggest that aerobic capacity might have a role in improving the ability to sustain phonation.

Keywords: Fundamental frequency, maximum phonation time, six-minute walking distance; six-minute walking test; sound pressure level.

Studies regarding voice production are still scarce to date, particularly in the field of physical medicine and rehabilitation. Speech consists of the process of respiration, phonation, resonance, and articulation. Several commonly used parameters, such as voice fundamental frequency (F_0) and intensity or sound pressure level (SPL),[1,2] describe the characteristics of a voice at a certain time but do not describe how long the sound can be maintained.

Maximum phonation time (MPT) is the longest duration during which a person can hold a sound, typically /a/, after maximum inspiration.[3] The longer the MPT, the longer the person will be able to sustain voice uninterruptedly, which will affect overall vocal performance. In clinical practice, MPT is an important parameter, particularly in professions at risk of voice disorder, such as salespersons, factory workers, clerical workers, teachers, counselors, and singers.[4] It is feasible to perform in many health facilities as it will only require a stopwatch and a sound recorder.[3,5]

The value of MPT is largely determined by the phonation volume, the volume of air used for phonation. The phonation volume is in line with vital capacity (VC) of the lungs but not exactly similar.[2] Previous

Corresponding author: Febrian Mulya Santausa, MD. Department of Medical Rehabilitation, Faculty of Medicine, Universitas Indonesia, 10430 Central Jakarta, Indonesia.
E-mail: febrianmulyasantausa@gmail.com

Cite this article as:
Santausa FM, Nusdwinuringtyas N, Ulianna Tambunan TF, Friska D. The correlation between 6-minute walking distance and maximum phonation time in healthy adults. Turk J Phys Med Rehab 2023;69(1):40-45. doi: 10.5606/tftrd.2023.10944

studies have found conflicting results regarding the association between lung volume and MPT. Some studies found a moderate correlation between MPT and VC, whether it is forced VC (FVC) or slow VC (SVC).[6,7] Meanwhile, no significant association between MPT and VC was found in studies conducted in pediatric and elderly patients,[8,9] suggesting that certain age groups might influence MPT as well.

Some studies did not find any association between MPT and maximum inspiratory pressure (MIP) or maximum expiratory pressure (MEP);[10,11] however, an interventional study found that respiratory muscle training significantly improves MPT along with MIP and MEP.[12,13] These conflicting findings suggest that there might be other factors improved by respiratory muscle training that affects the ability to sustain phonation other than MIP/MEP.

Aerobic capacity is the other factor that has not been rigorously studied as a factor affecting MPT. The difference between aerobic capacity and MIP/MEP is that it represents multiple functions at the same time, including the cardiovascular, respiratory, and musculoskeletal systems.[14] Furthermore, instead of measuring maximum strength, it measures endurance function as a whole, which might be more relevant to sustaining phonation, since the test itself only requires the patient to hold the sound at their normal speaking volume.[3,5,6] Thus, it is hypothesized that aerobic capacity would be clinically associated with MPT.

The gold standard test to evaluate aerobic capacity is the cardiopulmonary exercise test (CPET); however, not all health centers provide this clinical test. The six-minute walking test (6MWT) is an alternative to the submaximal exercise test recommended by the American Thoracic Society (ATS) and is used to evaluate aerobic capacity.[15] This test is more commonly performed in many rehabilitation centers, particularly in developing countries. It is a simple exercise test as it only requires the patient to walk on a 15-m track, which has been validated.[16]

This is a preliminary study regarding voice production with an approach from the field of cardiorespiratory rehabilitation. The results of this study were expected to provide an understanding of how important it is to examine cardiorespiratory endurance in the evaluation of phonation time. Therefore, the aim of this study was to determine the association between six-minute walking distance (6MWD) and MPT in healthy adults.

PATIENTS AND METHODS

This cross-sectional study was conducted with 50 sedentary nonsingers (32 females, 18 males; mean age: 33.5±8.3 years; range, 18 to 50 years) at the Faculty of Medicine, Universitas Indonesia, Department of Medical Rehabilitation and Community Medicine between February 2021 and April 2021. Singers were not included in this study due to the possibility that formal vocal training might affect the ability to sustain phonation. Sedentary subjects were determined using the short-form International Physical Activity Questionnaire (IPAQ-SF). The exclusion criteria were: *(i)* smoking, *(ii)* respiratory symptoms in the last two weeks, *(iii)* heart disease, *(iv)* lung disease, *(v)* musculoskeletal disorders, and *(vi)* balance disorders.

Sample size estimation

Subjects were recruited through consecutive sampling. Minimum sample size estimation is calculated using the following formula for the correlation study:

$$n=\left[\frac{(Z\alpha+Z\beta)}{0.5\ \ln\left\{\frac{1+r}{1-r}\right\}}\right]^2+3$$

$Z\alpha$ 95%=1.96

$Z\beta$ 20%=0.842

r=0.5

Therefore, the estimated minimum sample size is 29 subjects.

Subjects were instructed to sit upright with both hands on the thigh to test MPT. In this study, a microphone (BM-8000; Taffware, PT Jakarta Digital Nusantara, Jakarta, Indonesia) was used to record the voice to measure the mean F_0 and SPL along with the MPT. In clinical settings, it will only require a stopwatch and a recorder to measure MPT without mean F_0 and SPL. The microphone was positioned at the same level as the subject's mouth at a 30 cm distance. It was then connected to a laptop with Praat, a software program for acoustic analysis (Paul Boersma and David Weenink, Institute for Phonetic Sciences, University of Amsterdam, The Netherlands).

Subjects were instructed to inhale maximally and hold the vowel /a/ as long as they possibly could at their normal speaking pitch and volume. They were instructed to hold the sound, even if their voice started to sound strained, until they could no longer sustain it. The test was conducted three times with 1 min rest in between. The longest duration was taken as the MPT for each subject. The MPT was measured before the 6MWT to avoid fatigue after the exercise test.

There were two assessors involved in the 6MWT. The first one measured the MPT, and the other one measured the 6MWD. To avoid observer bias, the assessor of the 6MWT did not know the results of the MPT test and vice versa. This study used a modified 6MWT protocol with a 15 m track, which has been validated in the Indonesian population.[16] To ensure each subject achieved submaximal heart rate, determined as 60 to 80% of maximum heart rate, each subject also wore a heart rate monitor (Polar® H10; Polar Electro Oy, Kempele, Finland) during the test.

Vital signs, including blood pressure, heart rate, respiratory rate, and oxygen saturation (SpO_2), were measured before the test. Subjects were instructed to walk back and forth along the track at their own pace as far as possible in 6 min. Subjects were permitted to stop if dyspnea, chest pain, dizziness, nausea, fatigue, diaphoresis, or claudication were present during the test. However, subjects were asked to resume the test as soon as they could with the timer still running during the rest. After the test, the same vital signs were measured once more. Other instructions were in line with the 6MWT protocol released by the ATS.[15]

All the tests in this study were carried out adhering to the health protocol to prevent the transmission of coronavirus disease 2019 as follows: *(i)* the subject and examiner were required to wear a surgical mask; *(ii)* the subject and examiner were at least 1 m apart during the examination; *(iii)* the subject and examiner used hand sanitizer before and after the examination; *(iv)* for the MPT test, disposable microphone cover was replaced every time each subject was examined.

Statistical analysis

All data were processed using the IBM SPSS version 20.0 (IBM Corp., Armonk, NY, USA).[17] The Shapiro-Wilk test was performed to separately assess the data distribution for male and female subjects. The mean difference in MPT and 6MWD between male and female subjects was analyzed using the independent samples t-test. Pearson's test was performed to assess the correlation between 6MWD and MPT due to normal data distribution, followed by multiple regression. Confounding factors were chosen if bivariate analysis produced a *p* value <0.25. A *p* value <0.05 was considered statistically significant for the remaining variables.

RESULTS

The age ranged from 18 to 45 years in male subjects and 23 to 50 years in female subjects. Both MPT and 6MWD were statistically different between male and female subjects (p<0.001). The baseline characteristics of the subjects can be seen in Table 1.

For the MPT, 12 (24%) subjects had the MPT on the first trial, 13 (26%) on the second trial, and 25 (50%) on the third trial. For the 6MWT, all subjects achieved the highest heart rate inside the range of submaximal heart rate (60 to 80% of maximum heart rate). None of the subjects asked to stop or rest in the middle of the test. For both MPT and 6MWT, no adverse events were encountered during the test.

TABLE 1
Baseline characteristics

	Male (n=18)	Female (n=32)
Variables	Mean±SD	Mean±SD
Age (year)	29.2±7.4	36.0±7.9
Body height (cm)	171.1±6.8	156.8±4.8
Body weight (kg)	68.1±10.8	58.1±8.5
Mean F_0 (Hz)	123.0±16.6	217.3±29.7
Mean SPL (dB)	54.7±5.2	55.1±6.0
MPT (sec)	27.4±7.4	20.6±5.1
6MWD (m)	574.8±47.0	492.3±45.9

SD: Standard deviation; F_0: Fundamental frequency; SPL: Sound pressure level; MPT: Maximum phonation time); 6MWD: Six-minute walking distance.

TABLE 2
Association between age, body height, body weight, mean F_0, mean SPL, and 6MWD with MPT

Variables	Correlation coefficient (r)	*p*
Age	-0.252	0.078*
Body height	0.421	0.002*
Body weight	0.195	0.175*
Mean F_0	-0.429	0.002*
Mean SPL	0.114	0.431**
6MWD	0.621	<0.001*

F_0: Fundamental frequency; SPL: Sound pressure level; 6MWD: Six-minute walking distance; MPT: Maximum phonation time; * Pearson's test; p<0.25; variable will be included in multiple regression; ** Pearson's test; p>0.25; variable will not be included in multiple regression.

TABLE 3
Multiple regression

Variables	β	SE	95% CI	*p*
Sex	2.343	4.173	10.758 to -6.072	0.577
Age	-0.013	0.111	-0.211 to -0.237	0.909
Body height	0.052	0.155	0.365 to -0.260	0.737
Body weight	-0.016	0.093	0.172 to -0.205	0.861
Mean F0	0.012	0.032	0.076 to -0.053	0.713
6MWD	0.059	0.018	0.095 to 0.024	0.002*

β: Beta coefficient; SE: Standard error; CI: Confidence interval; F_0: Fundamental frequency; 6MWD: Six-minute walking distance; * Multiple regression; $p<0.05$.

The association between age, body height, body weight, mean F_0, mean SPL, and 6WMD and MPT can be seen in Table 2. For the multiple regression, the mean SPL was not included due to the insignificant result from the bivariate analysis ($p>0.25$). The 6MWD was found to be the only independent factor associated with MPT (Table 3).

DISCUSSION

The 6MWD was the only factor independently associated with MPT after multiple regression. Although the MPT of males was previously known to be longer than females,[18] it was found that sex was not independently associated with MPT. This indicates that the difference in MPT between sexes might be due to the difference in aerobic capacity,[19] represented by the 6MWD in this study. The difference in lung volume[6] and MIP[20] might also contribute to this result. This finding is in accordance with the rationale of this study where cardiorespiratory endurance, including the work of the heart and skeletal muscles (including respiratory muscles), lung volume, oxygen supply in the blood, and cellular metabolism,[14] affect MPT as a whole system.

The significance of this finding lies in the potential of aerobic exercise as a way to improve phonation time, which will affect vocal performance as a whole, particularly in professions requiring high vocal endurance, such as singers, salespersons, teachers, or motivational speakers. Further interventional studies are recommended to evaluate how far aerobic exercise will affect MPT.

There are some studies on the association of MPT and aerobic capacity.[21-23] However, maximum oxygen uptake (VO_{2max}) was mainly used as the parameter of aerobic capacity, measured by CPET, which might not be available in all centers. A study in the Indonesian population by Hardiwuri et al.[21] found a strong correlation ($r=0.89$, $p<0.001$) between MPT and VO_{2max} using the CPET. The stronger correlation strength compared to the results of our study might be caused by the different subjects' criteria, namely males aged 25 to 35 years with a normal body mass index.

Izawa et al.[22] also found a moderate correlation between MPT and VO_{2max} ($r=0.558$, $p<0.001$) in heart failure patients. The same author[23] later found that, after cardiac rehabilitation, the increase in VO_{2max} was in line with that of MPT ($r=0.45$, $p=0.006$). This indicates a longitudinal relationship between VO_{2max} and MPT, where an increase in VO_{2max} will be followed by an increase in MPT as well.

The main strength of this study compared to the other studies with similar issues lies in the use of 6MWT. Although the findings were similar to previous studies, through this study, we can infer that 6MWT can be used as an alternative to measuring aerobic capacity as a factor affecting MPT. Moreover, a 15 m track can be used instead of a 30 m track, which was used in the original protocol by the ATS. This finding might also suggest that walking itself can be used as an exercise method to improve MPT, although further studies are needed to prove this hypothesis.

The limitation of this study is that the subjects are limited to nonsingers; therefore, further studies on singers or other populations at risk of a voice disorder are recommended before implementing the results of this study in particular professions. In addition, this study only focused on MPT, an aspect of the voice that represents phonation endurance. Further studies might be needed to assess whether walking distance is also related to other parameters of the voice, such as peak SPL and range of fundamental frequency, instead of only measuring the mean SPL and F_0 during the MPT test.

Another issue of the MPT test is the lack of standardization of pitch and volume. Most protocols did not instruct the patients to hold the sound in a specific range of pitch and volume.[3,5,6,8,24] Some patients might not be aware of their normal speaking pitch and volume, potentially producing a more effortful voice during the MPT test. However, standardization of pitch and volume also has its issue, particularly the variability of pitch and volume itself in each patient. The MPT test is meant to be a simple screening test feasible to perform in most clinical settings.[3] Standardization of pitch and volume might make this test difficult to perform since it will require an acoustic analysis program and more detailed instructions. Moreover, both mean F_0 and SPL during the test were not independently associated with MPT in this study.

Some might also question whether the use of a surgical mask will alter the results of the MPT test since this study was carried out during the pandemic era. Based on a study by Fiorella et al.[25] conducted on healthy subjects, MPT with and without a surgical mask was not significantly different in both male (25.29±5.52 *vs.* 25.58±5.79 sec, p=0.859) and female subjects (19.86±4.17 *vs.* 20.63±3.97 sec, p=0.420). Nguyen et al.[26] and Cavallaro et al.[27] also did not find any significant difference in F0 and SPL with and without a surgical mask, even when compared to subjects wearing a KN95 mask.

A similar issue was also found in the 6MWT since the airflow resistance by using the surgical mask is suspected to decrease the patient's aerobic capacity. However, a study by Person et al.[28] found that in subjects with and without a surgical mask, there was no difference in 6MWD (708.1±62.3 *vs.* 708.2±68.2 m, p=0.990), SpO_2 at rest (98.3±1.1 *vs.* 98.3±1.0%, p=0.893), and SpO_2 changes after the 6MWT (–2.1±4.0 *vs.* 2.0±3.0%, p=0.795). So far, the available evidence did not show any significant effect of wearing a surgical mask on the results of both the 6MWT and the MPT test.

In conclusion, aerobic capacity represented by the 6MWD is independently associated with MPT in healthy adults. The results of this study also suggest that there is no need for standardization of pitch and volume during the MPT test, as both mean F_0 and SPL were not independently associated with MPT. Further studies are recommended to evaluate whether aerobic exercise, particularly walking, will improve patient's ability to sustain phonation in professions requiring high vocal endurance.

Ethics Committee Approval: The study protocol was approved by the Faculty of Medicine, Universitas Indonesia Ethics Committee (date: 18.01.2021, no: ND-051/UN2.F1/ETIK/PPM.00.02/2021). Clinical trial number: NCT04525742, August 25, 2020. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Contributed all parts of the study: F.M.S.; Contributed all parts of the study except for resources, materials, data collection and/or processing, and literature search: N.N.; Tresia Fransiska Ulianna Tambunan: D.F.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

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