Effects of Expiratory Muscle Strength Training with the Healthy Elderly on Speech

Jaeock Kim · Christine M. Sapienza
(Dept. of Communication Sciences and Disorders, University of Florida)

Age-related loss of muscle strength in expiratory muscles with reductions in elastic recoil of the lungs and chest wall compliance may compromise necessary lung pressure for a variety of speech tasks. This study examined the effects of a 4-week expiratory muscle strength training (EMST) program in 18 healthy elderly adults as measured by maximum expiratory pressure (MEP) as well as intraoral pressure (PO) for speech. MEP as well as PO at the softest possible intensity level, phonation threshold pressure (Pth), and the loudest possible intensity level (PL) were measured. The results indicated significant improvements in MEP and PO at the loudest possible intensity level. This study supported that EMST may be an effective way to change or compensate for age-related neuromuscular deterioration in expiratory muscles, which can be utilized to increase vocal intensity.

Key Words: expiratory muscle strength training (EMST), maximum expiratory pressure (MEP), intraoral pressure (PO)

I. Introduction

Respiratory system demonstrates significant changes in anatomy and physiology as a function of age (Berry et al., 1996; Chen & Kuo, 1989; Janssens, Pache & Nicod, 1999). Respiration is a function that is critical for sustaining life but also significantly important for generating the pressure needed to speak (Brooks & Faulkner, 1995; Campbell, 2001; Mizuno, 1991). The main functional changes in the respiratory system with aging are associated with a decrease of lung elastic recoil (Campbell, 2001; Mahler, 1983; Turner, Mead & Wohl, 1968), an increase of chest wall stiffness (Janssens, Pache & Nicod, 1999; Mahler, 1983; Turner, Mead & Wohl, 1968) and a decrease of respiratory muscle function (Berry et al., 1996; Brooks & Faulkner, 1995; Chen & Kuo, 1989). The most common change in respiratory muscles as a function of age is muscle fiber atrophy. Respiratory muscle atrophy (i.e., a reduction in muscle mass and in the number and size of muscle
fibers) causes a reduction in respiratory muscle strength and power, which is referred to as sarcopenia (Greenlund & Nair, 2003; Roubenoff, 2000). Sarcopenia is highly prevalent in the elderly population. Chen and Kuo (1989) indicated that respiratory muscle strength and endurance decreases by approximately 20% by the age of 70. Among respiratory muscle groups, sarcopenia is predominantly observed in expiratory muscles. Mizuno (1991) reported that the mean fiber cross-sectional area of expiratory internal intercostal muscles decreases by approximately 7% to 20% at about 50 years of age. However, these changes are not observed in the diaphragm (Mizuno, 1991). Other studies observing changes in the respiratory muscles demonstrated no or less change in muscle mass and no change in muscle fiber types in diaphragmatic muscle and inspiratory external intercostal muscles with aging (Caskey et al., 1989; Tolep et al., 1995).

The strength of the overall expiratory muscles is measured by testing the function of respiratory muscles using indexes such as maximum expiratory pressures (MEPs) (Black & Hyatt, 1969; Chen & Kuo, 1989; Enright et al., 1994; Ringqvist, 1966). These measures provide an indirect way of examining maximum strength of the expiratory muscles. After Ringqvist (1966)’s study measuring the ventilatory capacity and respiratory forces in healthy individuals aged 18 to 83 years, Black & Hyatt (1969) measured respiratory muscle strength in participants from 20 to 86 years of age. They observed that expiratory muscle strength declines at a rate between 1.14 to 2.33 cm H2O a year for MEP in both men and women, respectively. Enright et al. (1994) also found similar age-related decrements in MEP with a rate of 2 to 3 cm H2O a year for those between 65 to 85 years of age.

Age-related loss of muscle strength in expiratory muscles may hinder one’s ability to generate adequate expiratory driving force for a variety of speech tasks. It is well known that the contraction of expiratory muscles is necessary for certain types of speech tasks such as conversational speech, sustained phonation, loud speech, or singing, since it controls the outflow of air in order to provide the necessary lung pressure when elastic recoil forces are not great enough to vibrate the vocal folds (Hixon, 1973; Hoit et al., 1988). Inadequate lung pressure for speech or singing results in severely decreased vocal intensity (Titze, 1994). In addition, chest wall rigidity associated with aging results in compromised lung volumes available for speech (Titze, 1994). Specifically, normal inspiratory volumes cannot be produced by the elderly, thus limiting the available passive recoil pressure for speech and high-effort tasks. Furthermore, the laryngeal system in the elderly is not an efficient mechanism to increase vocal loudness secondary to insufficient vocal fold closure resulting from senescent changes in the laryngeal musculature, joints, and nervous innervation (Honjo & Isshiki, 1980). Previous studies demonstrated that both elderly males and females produce more than 6 dB lower sound pressure level (SPL) in maximum vowel intensities (sound pressure drops by half) than younger counterparts (Morris & Brown, 1994; Ptacek
& Sander, 1966). Hodge, Colton & Kelley (2001) also noted that mean lung pressures of 10.82 cm H₂O in the control young group and of 7.96 cm H₂O in the elderly group were significant different. This result suggests that lung pressure is significantly decreased in the elderly group as compared with the young group. Changes in lung pressure are closely associated with changes in SPL. The SPL increases at a rate of 8 to 9 dB when lung pressure is doubled (Hodge, Colton & Kelley, 2001). Thus, reduced sound pressure level for loud phonation in the elderly compared to the young represents a reduction in lung pressure which may be accompanied with weakness of the expiratory muscles. Therefore, it was suggested that the changes in lung pressure may be necessary to overcome an age-related changes in laryngeal structure and mechanism to control airflow and air pressure for speech in the elderly (Baker et al., 2001).

Given the age-related declines in expiratory muscle strength, a mechanism for training the muscles might be beneficial and actually aid and/or prevent a certain degree of muscle atrophy (Powers, Coombes & Demirel, 1997). Progressive resistance training of skeletal muscles has resulted in significant improvements in limb muscle strength in the young, elderly, and even in the frail elderly (Charette et al., 1991; Hakkinen et al., 1998a). Particularly, the resistance training program targeting expiratory muscles, known as EMST, has a great impact on increasing expiratory muscle strength resulting in augmenting expiratory driving pressure and positively affect speech characteristics in healthy and clinical populations (Cerny, Panzarella & Stathopoulos, 1997; Gosselink et al., 2000; Hoffman–Ruddy, 2001; Saleem, 2005). <Table - 1> demonstrates the MEP levels increased by a significant amount in healthy young adult participants and clinical populations regardless of the training program, duration of training, and training load. Therefore, it was expected that strengthening expiratory muscles by EMST would enhance the ability of the elderly to generate more expiratory force and compress the chest wall to a smaller volume as a compensatory mechanism, which would increase MEP and intraoral pressure (PO) for speech in the healthy elderly. However, no available outcome data are available on EMST in the healthy elderly, which may be beneficial for prevention or treatment of normal age-related expiratory muscular weakness (Tople & Kelsen, 1993).

The purpose of this study was to investigate the physiological effects of EMST on expiratory muscle strength in the healthy elderly as measured by the primary dependent variable of MEP. Additionally, this study examined the potential effects of EMST on PO for speech affected by the aging process.
<Table - 1> Summary of expiratory muscle strength training (EMST) studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>N</th>
<th>Training program</th>
<th>Training (wks)</th>
<th>Training Load</th>
<th>MEP gain (%)</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>O’Kroy &amp; Coast (1993)</td>
<td>Healthy adults</td>
<td>6</td>
<td>RT</td>
<td>4</td>
<td>32% of MEP</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Suzuki et al. (1995)</td>
<td>Healthy adults</td>
<td>6</td>
<td>PT</td>
<td>4</td>
<td>30% of MEP</td>
<td>25</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Cerny et al. (1997)</td>
<td>Hypotonic children</td>
<td>9</td>
<td>RT</td>
<td>6</td>
<td>2.5~7.5 cm H2O</td>
<td>69</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Smeltzer et al. (1996)</td>
<td>Multiple Sclerosis</td>
<td>10</td>
<td>PT</td>
<td>12</td>
<td>Not reported</td>
<td>37</td>
<td>No testing completed</td>
</tr>
<tr>
<td>Gosselink et al. (2000)</td>
<td>Multiple Sclerosis</td>
<td>9</td>
<td>PT</td>
<td>12</td>
<td>60% of MEP</td>
<td>35</td>
<td>NS</td>
</tr>
<tr>
<td>Hoffman-Ruddy (2001)</td>
<td>High risk performers</td>
<td>8</td>
<td>PT</td>
<td>4</td>
<td>75% of MEP</td>
<td>84</td>
<td>No testing completed</td>
</tr>
<tr>
<td>Sapienza, Davenport &amp; Martin (2002)</td>
<td>Healthy school band students</td>
<td>26</td>
<td>PT</td>
<td>2</td>
<td>75% of MEP</td>
<td>47</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Baker, Davenport &amp; Sapienza (2005)</td>
<td>Healthy young adults</td>
<td>32</td>
<td>PT</td>
<td>4~8</td>
<td>75% of MEP</td>
<td>29~50</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>Chiara (2003)</td>
<td>Multiple Sclerosis</td>
<td>17</td>
<td>PT</td>
<td>8</td>
<td>40~80% of MEP</td>
<td>40</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>Wingate et al. (in press)</td>
<td>Professional voice users</td>
<td>18</td>
<td>PT</td>
<td>5</td>
<td>75% of MEP</td>
<td>77</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Saleem (2005)</td>
<td>Parkinson’s Disease</td>
<td>10</td>
<td>PT</td>
<td>4</td>
<td>75% of MEP</td>
<td>22~37</td>
<td>p &lt; 0.001</td>
</tr>
</tbody>
</table>

Note. MEP = maximum expiratory pressure, N = number of subjects who were trained with EMST program, PT = pressure-threshold training, RT = resistance training, NS = not significant

II. Method

1. Participants

With an approval for the study obtained from the University of Florida Health Science Center Institutional Review Board prior to recruiting participants, a total of 18 healthy elderly individuals over 65 years were recruited in this study (4 males and 14 females; M = 78.25 years, SD = 7.80). Participants
were recruited from local community members (via residential facilities, social and professional organizations, churches, and retirement communities) in the Gainesville area, Florida, USA. All participants had no history of following medical conditions: chronic and acute cardiac disease, pulmonary disease, neuromuscular disease, immune system disease, and/or smoking or tobacco use within the last 5 years as well as upper respiratory infection at the time of the baseline measurements. Additionally, all participants had pulmonary function test values over 70% of the predicted normative value (American Thoracic Society, 1987). Only those participants who were able to maintain their current level of physical activity during participation were included. All participants were asked to report to the investigator any significant changes in their level of physical activity during their participation in the study with regards to intensity and frequency of exercise during the entire training. If participants had significant change in activity level, they were discontinued in the study.

2. MEP

MEPs were measured using a disposable mouthpiece connected to a Smart 350 series pressure manometer (Meriam Process Technologies, Cleveland, Ohio, USA) by 50 cm of 6 mm inner diameter tubing with a 20-gauge (2 mm) needle air-leak at the mouth to prevent the participant from sustaining pressure with a glottal closure (Berry et al., 1996; Enright et al., 1994; Karvonen, Saarelainen & Nieminen, 1994; O’Kroy & Coast, 1993). During the completion of the MEP tasks, each participant stood with his/her nose occluded with a nose clip. After inhaling to total lung capacity, the participant placed his/her lips around a mouthpiece and blew out as forcefully as possible. Repeated measures were taken with a 1 to 2 minute rest between trials for the MEP measures until three measurements were obtained within 5% of each other and no further improvement was obtained. The average of these three values was used for analysis. Approximately 5 to 10 trials were necessary per participant to obtain the 3 trials within 5% of each other.

3. PO

Intraoral pressure (PO) were measured to estimate subglottal pressure (PS) (Hodge, Colton & Kelley 2001; Rothenberg, 1982; Smitherean & Hixon, 1981). PO was defined as the pressure within the oral cavity during the production of the voiceless stop segment /p/ produced in the syllable train /pa/ at both the softest and the loudest possible intensity levels. Participants were asked to repeat syllables while a small disposable plastic pitot tube (2 mm diameter) was placed into the oral cavity between the lips and behind the front teeth. The tube was connected to a pressure transducer.
(PTL-1, Glottal Enterprises, Syracuse, NY, USA) low pass–filtered at 30 Hz which recorded the air pressure signal. The pressure transducer was calibrated with 5 cm H2O prior to data collection (MCU-4, Glottal Enterprises, Syracuse, NY, USA). All pressure measures were recorded using Power Lab/8SP data acquisition system with Chart 4.2.3 for Windows software. The sampling rate was set at 10,000 samples per second for all pressure measures. Air pressure measures were obtained by three tasks. The first task was the repetition of a syllable train /pa/ seven times in one breath at the softest vocal intensity level. Measurement of PO at the softest possible level was utilized for estimating the phonation threshold pressure (Pth). Pth was defined as the minimum pressure required for initiating vocal fold vibration (Titze, 1994). The second task was the repetition of a syllable train /pa/ seven times in one breath at the maximum effort level. This measured PO at the loudest possible level, called as PL. These two tasks were completed randomly. The pressure peaks of PO values from the middle five of seven repeated /pa/ at both the softest and loudest possible intensity levels were measured and averaged to estimate Pth and PL values. The relative change in pressure was calculated in cm H2O. During these tasks, participants were instructed to produce each consonant in the syllable with approximately equal stress and to maintain a syllable rate of about 1.5 syllables per second. In repeating a syllable train at the softest possible intensity level, participants were instructed to initiate voice at the lowest possible intensity level without whispering. Five trials of this task in each individual were recorded on Chart 4.2.3 for Windows and were analyzed on Chart 5. The recordings for air pressure were completed in a quiet room.

4. Training Protocol

After completion of the pre-training baseline session, each participant was provided with the expiratory pressure threshold trainer. The expiratory pressure threshold trainer used to complete the EMST program was a cylindrical plexiglass tube that consisted of a mouthpiece and an adjustable one–way spring–loaded valve <Figure - 1>.

The valve blocked expiratory airflow until a sufficient threshold pressure was reached to overcome the spring force. Participants had to overcome a threshold load by generating an expiratory pressure sufficient to open the expiratory spring–loaded valve. The training protocol for each participant lasted 4 weeks and consisted of five sets of five breaths, 5 days per week with the pressure threshold set at 75% of the participants’ MEP at the time of measurement. The device was readjusted by the investigator according to the newly measured average MEP value each week of training. To insure participants’ compliance with the training protocol, they were provided with written and verbal instructions for the use of their devices and the EMST protocol as well as a training log sheet.
5. Statistical Analyses

Mean, standard deviation, and percent change were calculated from the database in the dependent variable from pre- to post-training. One-way repeated measures univariate analysis of variances (ANOVAs) were conducted to evaluate the effects of EMST on MEP and PO. Within-subject factor included war the training (pre- and post-training). A significance level of \( p = .05 \) was used for all statistical testing. All analyses were carried out using SPSS software version 12.0.

III. Results

1. MEP

The result of ANOVAs to determine the specifics of the training effect indicated that MEP was significantly greater in post-training, \( F (1, 17) = 40.98, p < .001 \). MEP increased from pre-training \((M = 77.14 \text{ cm H}_2\text{O}, \text{SD} = 20.20)\) to post-training \((M = 110.83 \text{ cm H}_2\text{O}, \text{SD} = 26.10)\) <Figure - 2>. 
The results of ANOVA showed that Pth was not significantly different between pre-training and post-training, $F(1, 17) = 0.52, p = .48$. Further, PL significantly increased with training, $F(1, 17) = 21.96, p < .001$. Also PL increased from pre-training (M = 16.36 cm H2O, SD = 6.05) to post-training (M = 22.85 cm H2O, SD = 6.77).

**IV. Discussion**

This study investigated the physiological effects of EMST with the healthy elderly using a
pressure–threshold training device over a 4–week time frame in order to assess the effects on MEP and PO in the softest and loudest possible intensity levels.

1. MEP

The results indicated significant improvements in both MEP following the 4–week EMST program. MEPs significantly increased by an average of 44% (range of 8% to 158%) from pre– to post–training. Increases in MEP represent improved expiratory muscle strength. The MEP gains in the current study are comparable to previous studies completed in healthy young adults as well as clinical populations that used the same pressure–threshold training device (Baker, Davenport & Sapienza, 2005; Chiara, 2003; Hoffman–Ruddy, 2001; Saleem, 2005; Sapienza, Davenport & Martin, 2002; Wingate et al., in press; Suzuki, Sato & Okubo, 1995). The change in MEP following a 4–week EMST program in healthy young adults ranged from 25% to 47%. Suzuki, Sato & Okubo (1995) reported an increase in MEP from 165 ± 71 cm H2O pre–training to 202 ± 77 cm H2O post–training, a 25% increase for six healthy men using a threshold pressure breathing device (Threshold Inspiratory Muscle Trainer, Healthscan Products, Cedar Grove, New Jersey, USA). Sapienza, Davenport & Martin (2002) reported that MEP increased from 99.7 ± 25.2 cm H2O pre–training to 147.0 ± 31.9 cm H2O post–training, which is a 47% increase, in 22 healthy men and women. Baker, Davenport & Sapienza (2005) reported MEPs pre– to post–training from 99.1 ± 34.7 cm H2O to 127.5 ± 41.1 cm H2O, respectively, with an increase by 29% in 32 healthy participants. Together, these results suggest that an EMST program is applicable to both young and old healthy individuals to enhance the strength of the expiratory muscles.

Strength gains in respiratory muscles result from a combination of both neural adaptation and muscle mass adaptation. Neural adaptations commonly occur in the early stage (4 to 6 weeks) of training in both young and elderly individuals with a rapid improvement of muscle strength without hypertrophy. This rapid improvement relates to neural adaptations, including increases in the number of motor neurons and recruitment of motor units to agonist muscles, an increased discharge rate of motor units to agonist muscles, and decreases in antagonist coactivation (Hakkinen et al., 1998b; Powers & Howley, 2001). After 4 to 6 weeks of training, strength gains in young people are predominately related to muscle hypertrophy, while in elderly people strength gains are mainly due to neural adaptation, even after 6 weeks of training (Moritani & deVries, 1980). The findings from the current study suggest that a continual EMST program in the healthy elderly could be helpful in preventing the alterations in muscle architecture in the expiratory muscles.

Hence, it is reasonable to conclude that EMST is an effective program for increasing overall
expiratory muscle strength in the healthy elderly. Older expiratory muscles preserve a high degree of adaptability in response to strength training similar to other limb muscles (Narici et al., 2004). Thus, strength training specifically targeting expiratory muscles may compensate for the age-related changes in function and morphology of the aging human expiratory muscle. This implies that if elderly individuals are involved in a formal exercise program targeting respiratory muscle strength training, the deleterious repercussions of sarcopenia may be reduced.

2. PO

In the current study, Pth was not changed by EMST. The Pth was 3.11 ± 1.17 cm H2O in pre-training and 2.94 ± 0.77 cm H2O in post-training. These values are congruent with previous findings which reported average Pth values ranging from 3 to 4 cm H2O (Baken & Orlikoff, 1998; Hodge, Colton & Kelley, 2001; Titze, 1994). In contrast to Pth, PL significantly increased from pre-training by 45% (range of -2% to 141%). This indicates that by increasing expiratory muscle strength following EMST, chest wall rigidity in the healthy elderly may be compensated for by development of the more adequate positive pressures, leading to increases in SPL (Hixon, 1973). Furthermore, an increase in lung pressure following EMST may play a role in compensating for age-related decreases in the ability of the laryngeal system to control vocal loudness (Baker et al., 2001). It is known that both the respiratory system and laryngeal mechanisms play an important role in controlling vocal loudness (Hodge, Colton & Kelley, 2001; Holmberg, Hillman, & Perkell, 1988; Stathopoulos & Sapienza, 1993). Along with decreased respiratory system, reduced vocal fold closure (Honjo & Isshiki, 1980), histologic and neuromuscular changes in laryngeal muscles (Rodeno, Sanchez-Fernandez & Rivera-Pomar, 1993) and decreased laryngeal muscle activity with age (Baker et al., 2001; Luschei et al., 1999) are commonly observed. Baker et al. (2001) suggested that higher expiratory efforts may be needed to compensate for the age-related stiffness of the vocal folds that causes a reduction in laryngeal adductory mechanism. Accordingly, EMST would theoretically be conducive in overcoming the inefficient laryngeal adductory mechanism in elderly individuals, thereby improving the control of vocal loudness by augmenting the expiratory driving force.

V. Limitations

Admittedly, there were some limitations to this study. EMST involves production of high
expiratory efforts which are associated with health risks, particularly for individuals with high blood pressure or hernia. Therefore, EMST is not applicable for the elderly who have heart or vascular problems or those with untreated hypertension since EMST needs high pressure to overcome the pressure threshold set in the training device. Thus, clinicians or researchers should use with caution when examining the health status of the elderly before implementing the EMST program.

The present study explored the effect of only 4 weeks of EMST. A recent study in a patient with early idiopathic Parkinson’s disease reported that a longer duration of the EMST program leads to more improvement in expiratory muscle strength (Saleem, 2005). This result is a very important finding especially for the elderly population. Since aging is a continuous process, continuing the EMST program in the elderly may help to prevent or compensate for age-related other aspects of physiological deteriorations. However, the present study does not have direct evidence to support this explanation.

VI. Summary

With age, physical functions decline that can influence respiratory performance. Reductions in expiratory muscle strength, elastic recoil of the lungs, and chest wall compliance change the lung pressures necessary for ventilatory and non-ventilatory functions such as speech, in the elderly. This study was designed to investigate the physiological effects of a 4-week EMST program on MEP and PO in the healthy elderly. The program was easy for the healthy elderly to learn and to utilize. The EMST program employed a user-friendly small device that was adjustable to each individual’s capabilities and which change or compensate for age-related neuromuscular deterioration in expiratory muscles, which can be utilized to increase the ability of a certain type of speech tasks over a short period of time. The results of this study also suggest that sarcopenia might be reversible, and that continued EMST may prevent sarcopenia and the subsequent impact on speech function. This may lead to improvement in the quality of life of elderly individuals. EMST seems to be a viable treatment tool for overcoming functional decline resulting from sarcopenia in the elderly.
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초 록

호기근 강화훈련이 건강한 노인의 말에 미치는 효과

김재옥 · 크리스틴 사피엔자  
(플로리다주립대학교 언어병리학과)

고령이 될수록 폐의 탄력성과 흉곽의 유연성이 감소하고 호기근의 근력이 손실되어 말을 할 때 필요한 퍼압이 감소하게 된다. 본 연구는 18명의 건강한 노인들에게 호기근 강화훈련(expiratory muscle strength training, EMST)을 4주간 실시한 후 최대호기압력(maximal expiratory pressure)과 최저 음성강도와 최대 음성강도의 구강내압(intraoral pressure)을 측정하였다. 실험결과로, 최대호기압력과 최저 음성강도의 구강내압이 유의한 수준에서 향상되었다. 본 연구를 통해 호기근 강화훈련이 노 후화에 따른 근신경계의 변화로 유발되는 호기근을 강화시켜 최저 음성강도 발성시 음성강도를 증가시킬 수 있음을 밝혔다.

핵심어: 호기근 강화훈련, 최대호기압력, 구강내압