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The Effect of Physical Effort on Voice Characteristics

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Key Words

Physical activity · Activity level · Voice disorders · Acoustic analysis

Abstract

Background: Individuals using their voice intensively during physical effort are at risk for developing voice problems. This study was aimed at examining the influence of physical activity on voice characteristics. ***Methods:*** Fourteen physical education students (age: 27 ± 4.23 years) were recorded in a resting position, and during mild, moderate, and high exercise intensities (active conditions). Participants were also recorded immediately after each activity, while standing (recovery condition). All recordings were analyzed acoustically. ***Results:*** A significant elevation in the fundamental frequency (F0) was observed with the increase in activity level ($p < 0.05$). For all other acoustic measures, a gradual increase was observed as the activity level was raised. This increase was statistically significant for a specific set of measures (jitter, PPQ5, and shimmer) during the active conditions. In most cases, significant contrasts were found only between the high activity level and the other levels. During the recovery conditions, a similar increase in values was observed. However, these findings failed to reach statistical significance. ***Conclusion:*** Findings imply that high levels of physical effort lead to a significant reduction in vocal stability and to an elevation in F0. These changes result from vocal effort and could therefore lead to voice disorders and pathology.

Introduction

Individuals who are engaged in physical activity are often required to speak or even shout during the activity. Coaches, aerobics instructors and cheerleaders, for example, are required to speak and raise their voices during intensive physical activity. The impact of physical effort on voice characteristics has been studied in a limited number of studies. It has been documented that vigorous physical activity has a significant effect on the respiratory system [1]. During exercise, metabolic rate and oxygen consumption rise with the requisite rate of carbon dioxide emission. Producing speech during physical exercise requires the respiratory system to support these two activities simultaneously and make the appropriate adjust-

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ments [1, 2]. It was suggested that physical activity lowers the risk for developing voice disorders, as it is assumed that this type of activity reduces stress and therefore enables voice production with decreased muscle strain [3].

The relationship between speech and phonation and physical exertion has been examined in a few studies [1, 2, 4]. These studies showed that speaking during physical effort leads to changes in physiological variables related to cardiovascular, aerodynamic and metabolic systems, in comparison with physical effort without speaking. Specifically, a significant decrease in ventilation with a subsequent reduction of 11–15% in oxygen consumption, an increase in systolic blood pressure and a significant increase in blood lactate level were observed [1]. It was concluded that speech during physical activity reduces the effectiveness of the aerobic metabolism and causes an increase in the anaerobic metabolism. In addition, it was shown that voice use during physical activity increases laryngeal effort and closure forces, as manifested by increased values of phonation threshold pressure and changes in upper airway temperature [4]. Furthermore, vocal fold dehydration during physical activity was also shown to increase phonation threshold pressure, thus affecting voice production [5].

Individuals who use their voice intensively (e.g., aerobics instructors, cheerleaders, vocal performers, drill sergeants and teachers) are considered at risk for developing voice disorders [6–11]. Within the group of teachers, physical education teachers are assumed to be at higher risk [7]. Within the performing arts group, singers and actors in musicals or in the opera, who are required to phonate during physical activity, are also considered at higher risk for developing voice problems [7]. However, only a small number of studies have examined voice characteristics of this specific population. Vocal fold behavior or its acoustic output has typically been studied under artificially constrained laboratory conditions. Nonetheless, voice characteristics during less constrained and more natural tasks might be different from those observed during controlled conditions. Therefore, the aim of the present study was to examine changes in values of a basic set of acoustic measures during physical activity at different intensity levels.

Materials and Methods

After approval was obtained from our Institutional Helsinki Committee and written informed consent was received from all participants, 14 physical education students (males, age 27 ± 4.23 years, weight 73 ± 8.51 kg, height 178 ± 6.13 cm) from the Zinman College of Physical Education and Sport Sciences (at the Wingate Institute, Israel) volunteered to participate in the study. Standard calibrated scales and stadiometers were used to determine their height and body weight.

All participants were in good health and at an average fitness level. Prior to the physical effort, participants underwent a laryngeal examination by an otolaryngologist (A.P.-F.) to exclude vocal fold pathologies. Perceptual speech and voice evaluation was performed by an experienced speech and voice pathologist (O.A.) to exclude any voice or speech impediments in the participants. Exclusion criteria included history of general anesthesia in the preceding 5 years, hearing, voice, or speech problems, and any reported medical condition. All participants completed the Hebrew version of the Voice Handicap Index [12]; their mean score was 10.93.

The study was performed in the Exercise Physiology Laboratory at the Zinman College of Physical Education and Sport Sciences. Resting heart rate (HR) was measured using a chest strap HR transmitter system combined with a Polar Beat wristwatch (Polar®, Polar Electro, Kempele, Finland). The resting HR was subtracted from individual maximal HR to calculate the HR reserve. Individual maximal HR was obtained from each participant's fitness and exercise record.

Each participant performed three constant-level running bouts at velocities corresponding to 60, 75, and 90% of each subject's HR reserve. These velocities represented three levels of intensity: mild, moderate and high. Participants ran until reaching the target HR, and then maintained it for 2 min. During these 2 min, within each activity level, participants were requested to evaluate the rate of perceived exertion (RPE), using the modified Borg Scale [13]. To assess the involvement of the anaerobic glycolytic system, fingertip blood samples were taken immediately at the end of each activity level, using a portable lactate analyzer (Accusport, Boehringer Mannheim, Germany). Before each testing session, the lactate system and reagents were calibrated and then used according to manufacturer guidelines. To ensure a clean sample, the finger was first cleaned with an alcohol swab and allowed to dry [14]. Then participants rested for 10–15 min, until HR decreased to around 100–120 beat/min, before starting the next experimental stage.

Voice recordings were performed initially at rest, before starting all physical activities. This recording was termed the 'pre-exercise' condition. Recordings at each activity level were performed as target HR was achieved and maintained for 2 min ('active' condition) while running. Then recordings were performed again, immediately after completing each activity level, while the participant was standing ('recovery' condition). Consequently, each participant was recorded 7 times (pre-exercise, and then during and immediately after each activity level). As described, recording sessions were arranged in an ascending order of activity levels, and not in a random order. This was deemed necessary to allow for a relatively short recovery time between recordings and to reduce possible bias effects, which could be attributed to larger intervals between recording times (e.g., nutrition, sleeping time, general health, motivation).

Digital recordings were performed using a Sennheiser PC20 headset microphone (Sennheiser Communications GmbH, Wedemark, Germany), which was secured to the participant's head with a flexible band to ensure a constant distance of 7 cm between the microphone and the speaker's mouth. The microphone was connected directly to a computer. Audio recordings were performed with Goldwave software version 5.57 (Goldwave Inc., Mount Pearl, Nfld., Canada) on a single channel, with a sampling rate of 48 kHz (16 bits).

Table 1. Means and standard deviation (in parentheses) for all acoustic measures, blood lactate and RPE at the different activity levels

Measure	Activity level						
	pre-exercise	mild		moderate		high	
		active	recovery	active	recovery	active	recovery
F0, Hz	138.02 (13.64)	156.93 (13.27)	146.52 (15.95)	167.58 (10.54)	150.37 (13.65)	193.62 (33.15)	167.21 (23.85)
F0 range, Hz	19.45 (25.64)	37.17 (27.06)	16.81 (7.58)	65.34 (119.38)	21.83 (19.30)	60.89 (49.68)	27.65 (33.78)
Voice breaks	0.01 (0.04)	0.04 (0.07)	0.013 (0.05)	0.31 (1.07)	0.05 (0.18)	0.13 (0.35)	0.06 (0.22)
Jitter, %	0.33 (0.13)	0.81 (0.24)	0.35 (0.11)	0.98 (0.36)	0.38 (0.14)	1.12 (0.29)	0.45 (0.37)
PPQ5, %	0.17 (0.06)	0.38 (1.11)	0.18 (0.06)	0.47 (0.19)	0.19 (0.07)	0.52 (0.2)	0.24 (0.22)
Shimmer, %	2.31 (1.24)	4.60 (1.46)	2.19 (0.81)	5.23 (2.19)	2.47 (1.13)	5.57 (2.53)	3.18 (3.83)
APQ11, %	1.78 (0.83)	5.55 (1.53)	1.89 (0.66)	5.89 (1.77)	2.06 (0.67)	6.00 (1.03)	2.44 (2.09)
NHR	0.010 (0.007)	0.040 (0.019)	0.009 (0.005)	0.067 (0.054)	0.015 (0.025)	0.091 (0.058)	0.024 (0.057)
Lactate, mmol/l	NA	2.0 (0.32)	NA	4.1 (0.71)	NA	7.5 (1.33)	NA
RPE (1–10)	NA	1.0 (0.15)	NA	3.0 (0.35)	NA	5.1 (1.19)	NA

Recording consisted of six repetitions of the vowels /a/ and /i/ in a random order. Each vowel was produced for 3–4 s. A total of 1,176 vowels (6 repetitions of each vowel × 7 tasks × 14 participants) was collected. The present study is based on the analysis of the vowel /a/ alone; thus, 588 vowels were subjected to the acoustic analysis. Computerized acoustic analysis of the voice recordings was performed using Praat software [15], based on the middle second of each recording, excluding onset and offset. A basic set of acoustic measures was obtained. These included: (a) mean fundamental frequency (F0); (b) two frequency perturbation measures: (i) jitter and (ii) period perturbation quotient (PPQ5); (c) two amplitude perturbation measures: (i) shimmer and (ii) amplitude perturbation quotient (APQ11); (d) degree of voice breaks, and (e) noise-to-harmonic ratio. Because frequency perturbation and amplitude perturbation measures are affected by various factors, both basic measures (jitter and shimmer) were included, as well as their smoothing factor equivalents (PPQ5 and APQ11, respectively).

Statistical Methods

Statistical analyses were performed using SPSS 17.0 (IBM, Armonk, N.Y., USA). Analysis of variance with repeated measures was performed for each acoustic measure, in which the different activity levels were defined as the repeated factor and the acoustic measures were defined as the dependent variables. Separate analyses were performed for the active and recovery conditions. The significance level was set at $p < 0.05$. All subsequent contrast analyses were performed using a Bonferroni correction for multiple comparisons between adjacent levels.

Results

Group means for all acoustic measures were obtained by first calculating mean values of the six vowel repetitions within a specific condition, for each participant. Based on these individual values, group means were calculated. Table 1 presents group means and standard deviations for the acoustic and physiological measures for all recording conditions, arranged by activity level.

Initial inspection of data demonstrated large differences between the values obtained in the active and recovery conditions, for most acoustic measures. As shown, values obtained during the active conditions were 2–6 times larger than those obtained during the recovery conditions. Therefore, all statistical comparisons were performed separately for the active and recovery conditions. Results will be summarized for the active conditions first, followed by the recovery conditions.

Active Condition

A significant main effect for activity level, within the active condition, was found for F0 ($F_{2, 26} = 24.99$, $p < 0.001$). Contrast analysis between adjacent activity levels was performed using a Bonferroni correction for multiple comparisons; therefore, significance level was set at $p = 0.025$. Significant differences were found between the mild and moderate levels, as well as between the moderate and high levels. Figure 1 illustrates F0 values for the active and recovery conditions at all activity levels.

A significant main effect for activity levels, within the active condition, was also found for the two frequency perturbation measures: jitter ($F_{2, 26} = 11.27$, $p < 0.001$) and PPQ5 ($F_{2, 26} = 5.59$, $p = 0.01$), as well as for shimmer ($F_{2, 26} = 4.55$, $p = 0.02$). Contrast analysis between adjacent levels revealed a significant difference between the moderate and high level (adjusted $p < 0.025$), but not between the mild and moderate levels, for the two frequency perturbation measures (jitter and PPQ5). Contrast

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analysis for shimmer failed to reveal a significant difference between adjacent levels, but did find a significant difference between the mild and the high levels. All other acoustic measures (F0 range, voice breaks, APQ11, and noise-to-harmonic ratio) did not reveal a significant difference between activity levels ($p > 0.05$).

Significant differences in blood lactate concentration were found between the three activity levels: mild, moderate and high ($p < 0.05$). Significant differences in RPE were found between the mild and the high, and between the moderate and the high activity levels ($p < 0.05$), but not between the mild and moderate activity levels.

Recovery Condition

A significant main effect for activity level, within the recovery condition, was found for F0 ($F_{3, 36} = 14.45$, $p < 0.001$). Contrast analysis was performed using a Bonferroni correction for multiple comparisons, with significance level set at $p = 0.016$. A significant difference was found between the moderate and high activity levels, and a marginally significant difference was found between the pre-exercise and mild activity levels ($p = 0.017$). No significant difference, however, was found between the mild and moderate activity levels. These results are illustrated in figure 1. For all other acoustic measures, a gradual increase was observed as activity level was raised, similar to F0. Nonetheless, this increase in values failed to reach statistical significance. Figure 2 illustrates jitter and shimmer values at the different activity levels, as representing all other results.

Discussion

Individuals who use their voice extensively while performing strenuous physical activity, such as drill sergeants, aerobics instructors, and physical education teachers, are at high risk for developing voice disorders [7, 10]. Therefore, the present study was designed to examine the effect of physical activity at varying levels on voice characteristics. It was previously reported that an increase in laryngeal muscle tension leads to an increase in F0 [16]. The most prominent result of the present study was the elevation in F0, which occurred with the increase in physical activity level. It is conceivable that an increase in overall body tension during strained physical activity would encompass an increase in laryngeal muscle tension. The significant difference in blood lactate concentration between the three activity levels in the present study demonstrates the differences in the physiological

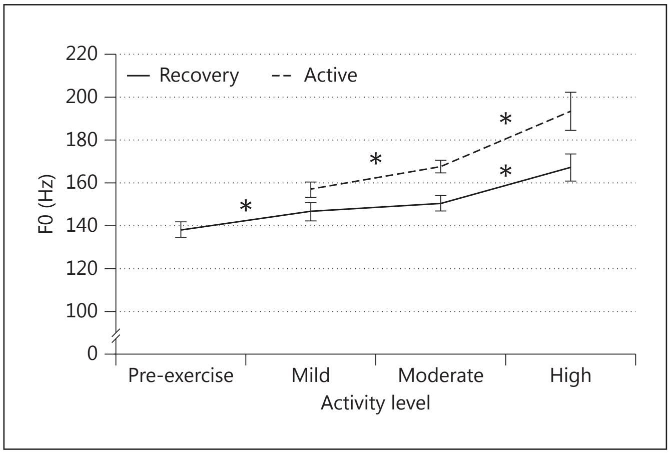

Fig. 1. Mean F0 and ±1 SE bars in active and recovery conditions for the different activity levels (an asterisk indicates a significant contrast).

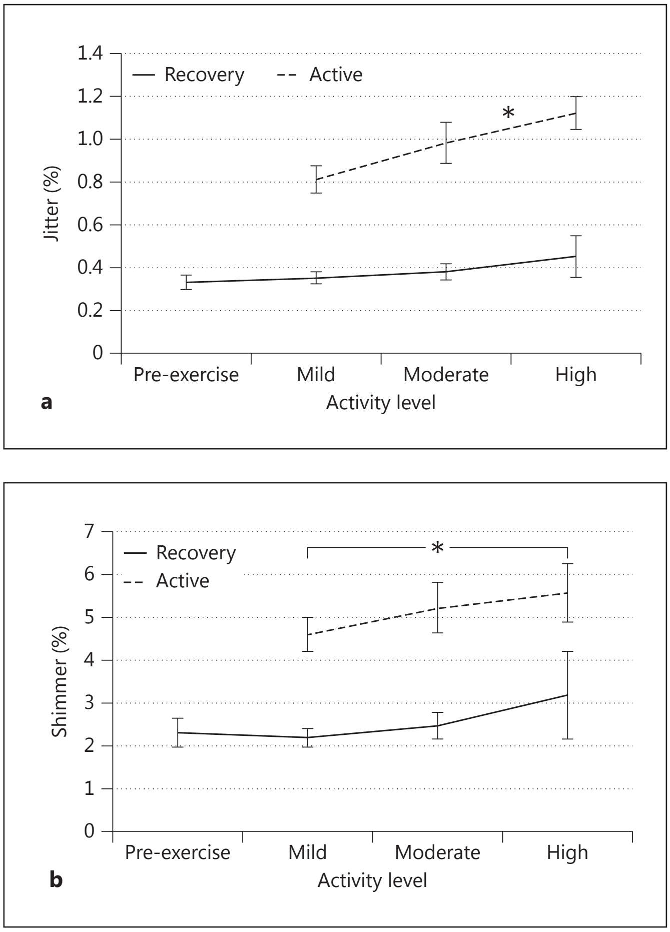

Fig. 2. Mean jitter (**a**) and shimmer (**b**) values and ±1 SE bars for the different activity levels in both active and recovery conditions (an asterisk indicates a significant contrast).

demands and muscle strain required by the participants for each stage.

Two additional explanations for the increase in F0 with the increase in activity level can be suggested. First, during physical activity, airflow in exhalation is increased, due to the relative shortening of exhalation time compared to inhalation. Increased airflow during phonation raises intensity and elevates F0 [17]. Second, phonation necessitates precise neuromuscular control over the laryngeal mechanism for achieving vocal fold adduction, as well as synchronization between breathing and laryngeal activity. On the other hand, extensive physical effort obligates *abducted* vocal folds for obtaining maximal airflow [1]. Forcing phonation during extensive physical effort requires the vocal folds to overcome the intense aerodynamic forces of breathing. This creates vigorous adduction and increased tension of the vocal folds, which leads to an elevation in F0.

The second major finding of the present study was the increase in values of the perturbation measures as activity level was raised. Specifically, an increase was found for both frequency perturbation measures (jitter and PPQ5) and for shimmer. This was observed in both active and recovery conditions of all intensity levels. However, it reached statistical significance in the active condition but failed to reach statistical significance in the recovery condition. These acoustic measures provide quantifiable insight into the stability of the vibratory mechanism of the vocal folds. In general, relatively low perturbation values are typical of a normally functioning larynx, and high values are related to various pathological conditions or to hyperfunctional conditions [18]. In the present study, participants exhibited perturbation values that are comparable to expected normal values [19] at most activity levels. However, although all participants had healthy larynges and no vocal pathologies, acoustic measurements from the high activity level (i.e., recording made while running at 90% of maximum pulse rate) exceeded normal values.

This finding suggests that as activity level is raised, appropriate adjustments are made in the vocal mechanism to maintain a steady phonation. As long as activity level is either mild or moderate, vocal properties remain within the expected normal boundaries. However, when the activity level is raised beyond that, the vocal and breathing mechanisms can no longer maintain a steady neuromuscular condition, and voice quality is compromised.

It should be noted that in our study, the two basic perturbation measures (jitter and shimmer) were included because they are commonly used in voice analysis and have documented normative values in clinical and research settings. However, these two measures are highly sensitive to various instabilities affecting the vocal mechanism. Therefore, two additional perturbation measures (PPQ5 and APQ11) were also included for better representation of frequency perturbation and amplitude perturbation in unstable conditions. Additionally, it should be noted that recordings in this study were performed in suboptimal conditions (e.g., treadmill noise, footsteps). Also, the acoustic measures used in this study are sensitive to the subjects' movement during the recording. Thus, the increased perturbation values during the activity levels could be partially attributed to this overall unstable condition. Future research should address these limitations and include alternative acoustic measures that are less affected by these factors.

One clinical implication of our study is that people who phonate during strenuous physical activity should be advised to refrain from exceeding moderate activity level. Phonating during high levels of physical effort could increase laryngeal activity forces and impact, reduce voice quality, lead to functional voice disorders, and eventually cause vocal fold trauma. This conclusion is in agreement with previous reports on the prevalence of voice problems among athletes who are required to speak during their physical activity [7].

Conclusion

Use of the voice during physical activity reduces vocal quality and elevates F0. These changes are most prominent at a high effort condition. Therefore, voice production should be avoided during high levels of effort to reduce high vocal fold collision forces and prevent phonotrauma (i.e., vocal abuse). Future studies should examine the relationship between the breathing and vocal mechanisms and include vocal intensity measures and specific aerodynamic measures. Moreover, because perturbation measures can be affected by a wide range of factors, future studies should examine acoustic measures which might be less affected by physical activity or recording conditions. Finally, it should be noted that this study examined only participants with relatively high physical fitness. Replicating the current results with a more diverse population could improve generalizability.

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