Effects of a respiratory muscle training program on respiratory function and musical parameters in saxophone players

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Abstract

Introduction

A review of current literature reveals a vast amount of studies indicating that the respiratory muscle strength of wind instrumentalists is superior to those of non wind-instrument players[1] . Even if no significant difference with other groups of test subjects is found, there is a general consent that wind instrumentalists have a greater respiratory awareness. Wind instrument playing might be considered as a continuous form of respiratory muscle training due to the respiratory maneuvers necessary for sound generation.. All physical, psychological and environmental factors influencing wind instrument performance (ref) explain a large diversity in playing technique such as breathing technique [2, 3, 8] and technical instructions describing how to play a musical instrument (ref). The performer develops all technique, including breathing, through continuous exercise and evaluates efficacy through influence on the sounding result and playing comfort. Consequently it is impossible and inutile to quantify the influence of an exercise on every segment of the playing mechanism. An alternative approach suggested is to focus on the resultant, which is the produced sound.

As indicated by Bouhuys, players are physically limited according to how much flow or pressure they are able to generate. Each wind instrument requires an input of air by a performer. The uniqueness of each instrument results in different flow requirements ([9]) that can be altered through selecting a different mouthpiece, reed and ligature in correspondence with the physical limitations of the player and his musical taste. This large variation in material and ability of a performer might account for the lacking descriptions of musical parameters in previous respiratory muscle training students with wind instrumentalists [4]. Due to the large variability's in performance technique and the extremely complex correlations between all segments of the playing apparatus we also question the musical relevance of these studies, focusing on one aspect of wind instrument playing.

Arnold Jacobs (ref) advises his students to deal with technical problems away from a musical context, focusing on the specificity of an exercise rather than on a final musical result. In his embodied music cognition paradigm, Leman describes that a player's and listener's actions correlate strongly with their musical intentions. The body and musical instrument serve as a mediator for communicating about musical experiences. Additionally, Leman describes a haptic connection between a performer and his instrument. These findings support our belief that we might be able to alter musical performance through a set of non-musical exercises, provoking a change in a performer's physical capabilities and broadening his action repertoire.

Respiratory muscle training

Respiratory Muscle Training (RMT) can be defined as a technique that aims to improve strength and functioning of respiratory muscles through exercise. RMT was originally intended to improve respiratory function in patients with respiratory disease. However, respiratory muscle training is also shown to increase respiratory muscle strength in

healthy individuals and increases endurance and exercise performance (17). Literature suggests that a combined inspiratory and expiratory muscle training program might be superior to either inspiratory or expiratory muscle training (17). Respiratory muscles react similar to resistive load training as skeletal muscles. Dependent on the chosen resistive load of the respiratory muscle training device, one can target pressure development, flow development or a combination of both. Previous studies show that a combination of flow- and pressure development induces the greatest increase in respiratory muscle strength. (11) As previously stated, wind musicians have a better respiratory awareness than non-wind instrumentalists (1). This experience should counteract the danger that respiratory muscle training using a threshold device misses the desired effect due to bad breathing technique, focusing on the muscles of the rib cage rather than on diaphragmatic respiration (5). The latter is the most favored respiration technique amongst wind instrument players (ref).
There are few studies conducted on the effects of respiratory muscle training on wind instrumentalists. We found one study indicating expiratory muscle training program induced an increase in expiratory muscle pressure with high school band students.(4) However, these results were not related to playing comfort and the quality of sound produced on their instrument. To the best of our knowledge there are no previous studies that directly related the effects of a respiratory muscle training program to musical parameters. We hypothesize that a respiratory muscle training program using a threshold loaded device could be a universal solution for breath development and training in saxophone players. An increase in respiratory muscle strength and a strong focus on breathing technique through this non-musical exercise should allow a player to broaden and improve his action repertoire resulting in a more efficient playing technique, different sound possibilities and increased playing comfort.

Methods and materials

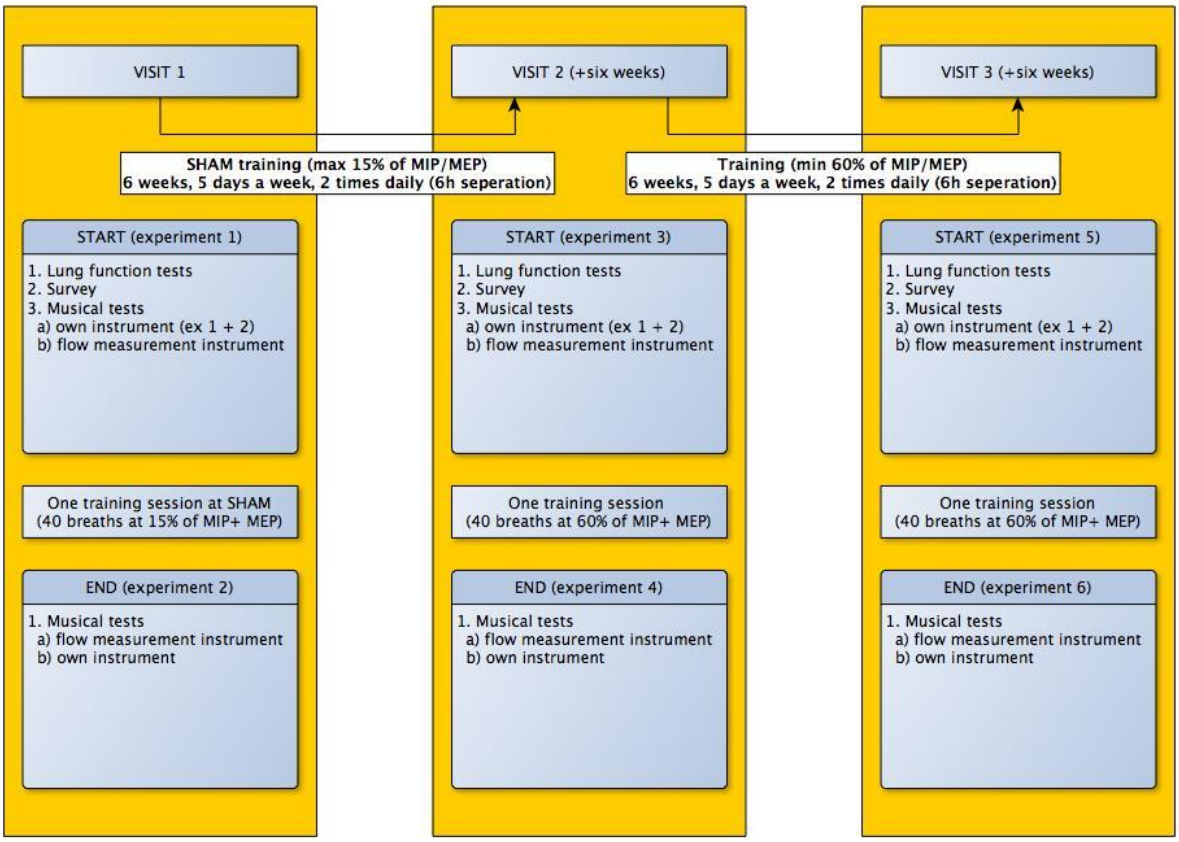
Experiment design

The aim of this study was to investigate if artistic performance can be improved with semi- professional and professional saxophone players if a respiratory muscle training protocol is imposed. This protocol aims at the enforcement of respiratory muscles and should result in the players better controlling their instruments. We recruited 18 participants, all saxophone players with at least 4 years of playing experience, aged between 16 and 45 years. Exclusion criteria were respiratory disease and/or active smoking. Sixteen participants were withheld, two dropouts, one was unintentional un-blinded and one lost to follow-up (see table 1)

	Participants
Male	N= 8 (avg age = 19yrs, avg experience = 25yrs)
Female	N=8 (avg age = 28yrs, avg experience = 13yrs)
Total	**N= 16 (avg age = 24yrs, avg experience = 19 yrs)**

Table 1. Participants

We used a validated 6 week training program with a pressure threshold breathing device (the yellow BreatheAir® Powerlung®), designed for a combination of inspiratory and expiratory muscle training. This device is a small handheld device, which exerts a pressure against the breathing flow during in- and expiration.
The SHAM training (6 weeks) consisted of a training routine, breathing in the device with resistance levels set at 15% of maximum inspiratory and expiratory pressures (MIPS/MEPS) measured at baseline. The following training sheme was imposed: five days a week a set of 40 breaths (4 times 10 breaths in and out), two times daily, followed by two days of non-activity. Adherence, time spend and exertion was monitored with a written diary. This was followed immediately (no washout period) by a "real" training program (6 weeks) consisting of the same training routine, with resistance set at 60% of MIPS/MEPS measured at the visit after SHAM training. It was not randomized nor a crossover protocol, because we could not predict the duration of influence of the "real" training program. None of the participants was aware of the fact that a SHAMtest was preceded a training program, nor the exact aim of the study.



We conducted three visits: baseline, after SHAM training and after real training. During each visit we performed a series of tests to assess influences of training on pulmonary function, airflow in the neck of a saxophone during performance, sound and playing comfort. After these tests, participants were asked to do a single training session. During the first visit, resistance setting of the handheld device was at SHAM level (15%MIPS/MEPS). During the second and third visit resistance of the handheld device was set at training level (60% MIPS/MEPS). Immediately after a training session sound and flow measurements in the saxophone were repeated to determine acute effects of respiratory muscle training intervention (see fig 1).

Questionnaire and diary

Before start of each visit participants were asked to complete a questionnaire including a standardized asthma control test and information about the participants' instrument, practice habits, fatigue sensations. At visit's 2 and 3 we also included questions about adherence of the training program. During the two training periods, participants were asked to track their progress in a diary and documented length of each training session, number of breaths completed and an effort sensation (1-5) on a visual analog scale.

Lung function

Lung function was assessed at start of each visit as a direct way of measuring influences of a training program on pulmonary function. It is also an indirect way of measuring players' ability to meet flow and pressure requirements of his instrument. We used spirometry, lung volumes and maximal in- and expiratory pressure statics (MIPS MEPS) to determine respiratory parameters and muscle forces before any event of the study protocol. Not only to exclude participants with abnormal respiratory values during screening visit, but also as follow-up to investigate influences of training sessions.
During spirometry, peak in- and expiratory flow is measured, representing the highest flow created by a combination of all respiratory muscles during forced in- and exhalation respectively, diameter of airways and the retraction force of the lung (end expiration). MIPS/MEPS is the cmH_2O pressure, measured at the mouth with an open glottis, during maximal forced respiration against a closed valve, representing respiratory muscles force, during in- and expiration respectively. Both measurements are good indicators for respiratory muscle forces and eventual changes. Lung volume measurements were done in a body plethysmography. Total lung capacity (TLC), the total volume (liters) of air in the lungs after a complete slow inhalation, and functional residual volume capacity (FRC), the volume (liters) of air, remaining in the lungs at the end of a normal quite expiration, were withheld at baseline visit and during each consecutive visit. These lung volumes were used to confirm no changes in volume levels during quite normal breathing. A change in the normal breathing volume level, implicated a different position of the diaphragm, resulting in changes of muscle forces.

Musical tests

These tests were conducted to assess the influence of the training on the timbre of each participant. Participants played a series of isolated notes using their own mouthpiece and ligature on a Selmer Superaction(TM) alto saxophone with a modified neck. This neck has built-in pressure sensors (see below) to allow flow measurements during saxophone playing. Participants were asked to perform on a Légère synthetic reed, matched to their preferred reed strength, to exclude variability in quality and strength of regular cane reeds. Series of notes was performed three times to exclude variance in performance quality. The same series of isolated notes was also performed on participant's own instrument, complemented by a musical exercise composed by the researcher. All exercises needed to be performed at a tempo of 60 beats per minute in mezzo forte (medium loud playing). All performance technique, articulation and phrasing were left on every participant's individual decisions.

Flow measurements

To measure airflow in the saxophone, we made use of a customized neck, equipped with a flow sensor based in the Pitot effect. In the neck, two holes of 1.5mm diameter were drilled. In one hole, a tube was soldered with its opening parallel to the air flow direction. In the other hole, a curved tube was soldered with its opening in the center of the neck and at right angles to the flow direction. In this way, the airflow is high at the level of the one opening, and is zero at the level of the other opening, creating a pressure difference between the two. The velocity v of the airstream is then given by:

$$v = \sqrt{\frac{2p}{\rho}}$$

where p is the measured pressure difference between the two tubes and ρ is the density of the air. It is important to notice that there is no airstream in either of the tubes so there is no acoustic leakage introduced in the saxophone neck. The presence of the small tube in the center of the neck had no noticeable effect on sound quality

The pressure difference between the two tubes was measured using a very sensitive pressure transduced (GEMS sensors series 5266, 100 Pa range) equipped with custom built electronics for amplification. The pressure signal was the digitized and recorded simultaneously with the sound signals.

The pressure transducer does not only measure the pressure changes due to changes in air stream velocity, but is also picks up the sinusoidal pressures generated by the sound in the saxophone. As both tube openings are close together, the sound pressure level and sound phase is nearly the same ate each opening, so the sound signal delivers only very small pressure differences at the level of the pressure transduced. Nevertheless, some of the sound pressure signal is picked up, and this is removed by low-pass filtering the pressure signal in post-processing. Finally, the e average flow per note was calculated using the sustain part of the sound.

Sound measurements

Sound measurements were conducted using a Shadow SH-4001 contact microphone attached to the saxophones neck, close to the cork. This recording technique was used to supress environmental sounds and room acoustics. All audio files were normalized and analyzed using the mirToolbox(ref). MirToolbox is a standard matlab framework used for the analysis of musical data. Additionally, we calculated a number of perceptual audio features based on a publication of IRCAM. For these features (1 and 2) we used a bark band-pass filter of the mirToolbox, because it is known to closely simulate human hearing.

1. ***Perceived loudness*** is the sum of the rms power value associated with each bark band.
2. ***Perceived sharpness*** is equivalent to the spectral centroid or the center of mass of the spectrum. To simplify we explain it here as the weighted mean of the bark frequency bands, with their RMS power values as the weight. For the higher bark bands (>14) values are adjusted (Zwicker, 1977).

3. ***Activity and fullness*** as proposed by Alluri (ref) and in the manual of mirToolBox. Perceptual timbre descriptors related to fluctuations in the lower bands (50 – 200 hz) and higher bands (1600 – 6400 hz).
4. ***Spectral flux*** is the distance between the spectra of two successive frames. This paper uses the mean spectral flux of a file.
5. ***Roughness*** is the amount of sensory dissonance when two pairs of sinoids are closed in frequency.
6. ***Regularity*** is the degree of variation of successive peaks of the spectrum.
7. ***Inharmonicity*** represents the amount of energy outside the ideal harmonic series.
8. ***Roloff*** is the frequency where 95% of the energy is situated below.
9. ***Autocorrelation*** is used to compare a signal with a time-delayed version of itself. It is a model for the periodicity of a signal and is also used in human hearing, where non-periodic sounds closely approaching periodicity are "heard" or interpreted as being periodic. We use the **mean value**.
10. ***MFCC's (Mel-frequency cepstrum coefficients)*** are 13 coefficients that represent the power spectrum of a sound.

Fourier transform → **Abs** → **Log** → **Mel Scale** → **Discrete cosine transform**

11. ***Brightness*** is the amount of energy above cutoff frequency of 1000hz.
12. ***Centroid, spread, skewness, kurtosis, flatness, zerocross and entropy*** are statistical moments describing the spectral distribution of the sound.

Questionnaire and diary

All participants were asked to complete a questionnaire at the start of each visit. These questionnaires included a standardized asthma control test and informed about the participants' instrument, practice habits, fatigue sensations. Visits 2 and 3 also included questions about the training program. During the two training periods, participants were asked to track their progress in a diary. This diary documents the length of each training session, the number of breaths completed and an effort sensation (1-5) on a visual analog scale.

Statistics

For interpretation of lung function results and flow measurements we use paired samples t-tests as we compare the same group at two different moments. The difference between the mean values of the population accounts for the change in respiratory muscle strength or flow use. The audio analysis is more complicated due to the large set of audio features. First we made sure each sample existed in all 6 experiments so we have a balanced data set. Next we standardized the dataset using Z-scores. The samples were classified using a K-means clustering algorithm with 10-fold cross validation. This classification was to test our set of predictors for their ability to represent either a player's unique timbre (player classification) or a recording session (experiment classification). Principal component analysis did not resulted in clearly defined principal components so an alternative approach using a bagged trees classification algorithm with 10-fold cross validation was used. This gave us the predictor importance for each feature that we subsequently used to select timbre descriptors. This was further analyzed using a paired t-test, indicating which changes are significant for each experiment.

Results

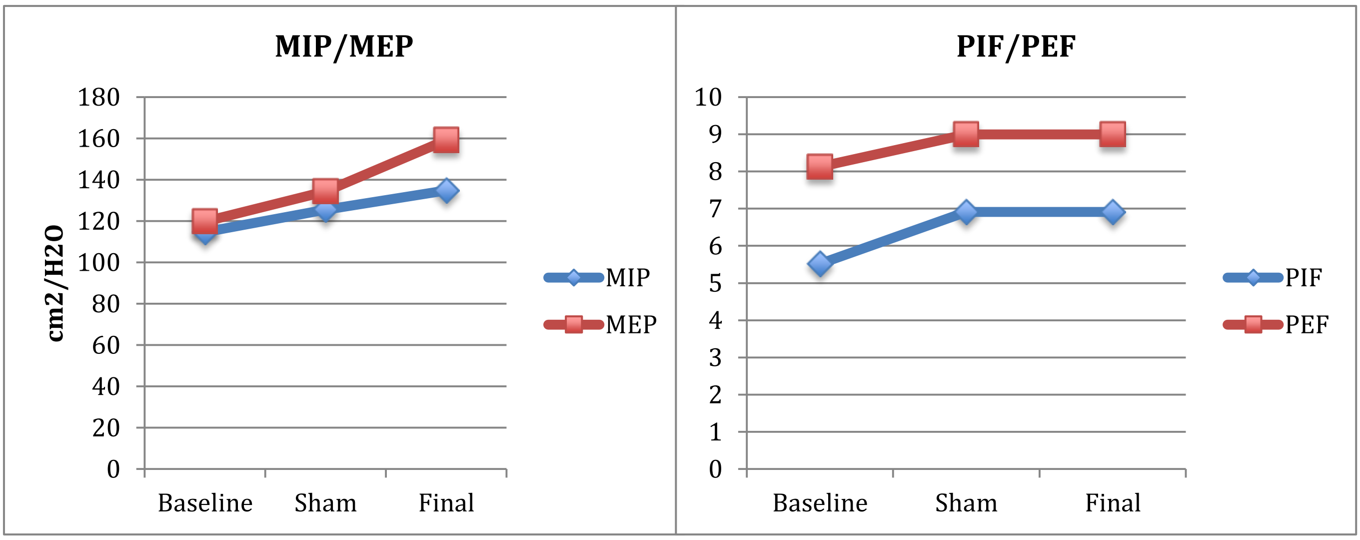
Saxophone playing routine and adherence

Lung function

Population

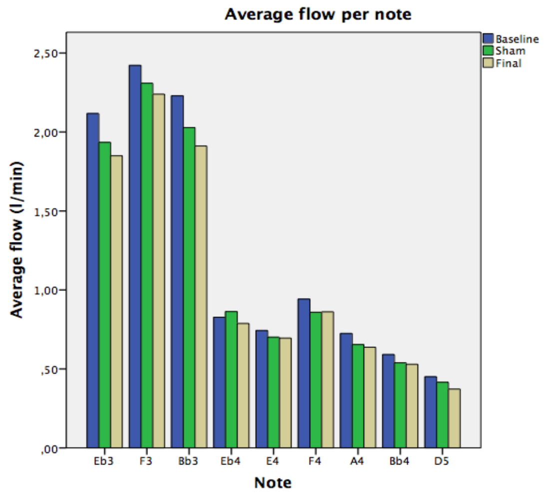
	Visit 1	Visit 2	Visit 3
TLC	6	6	6,01
MIPS	114,69	125,56	134,75
delta_Mips%		9% (p=0,01)	7% (p=0,023)
MEPS	119,75	134,31	159,06
delta_Meps%		12% (p=0,009)	18%(p=0,002)
PIF	5,52	6,91	6,94
delta_Pif%		8% (p=0,01)	-5% (p=0,459)
PEF	8,13	9	8,38
delta_Pef%		8% (p=0,013)	-4% (p=0,131)

We found significant increases in MIPS (9% sham, 7% training) and MEPS (12% sham, 18% training) for both sham and training programs. While there was a significant increase in both PIF (8%) and PEF (8%) in the sham period we did not find a significant change for PIF and PEF after training program. For the whole period of the trial, TLC remained unchanged.

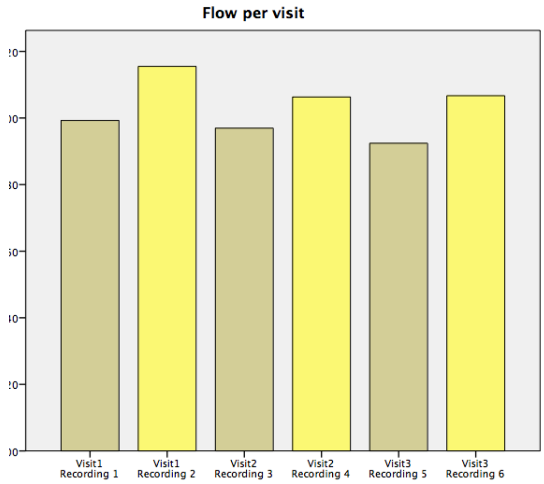


Flow Measurements

Each note has a specific flow requirement that is dependent of the pitch of the note and the configuration of the saxophone tube. The lesser keys a player uses, the lesser air a note requires. If we go to second octave (from Eb4 on), an octave key is pressed, significantly reducing required amount of air to produce a note.



Graph .... Average flow per note used at the start of each visit (baseline, sham and final)



Graph .... Average flow used during each recording session per visit.

As shown **in graph ...** the amount of air used during playing, decreases towards the end of the experiment. There is a significant reduction of 5% (p=0,005) in flow use after completion (recording 3 to recording 5). A smaller reduction from baseline to sham is not found statistically significant. There is a significant increase (p=0) in used flow as a direct result from training (visit 1: increase of 16%, visit 2: increase of 9%, visit 3: increase of 15%). It is to be noted that training within visit 2 was the first training at high resistance.

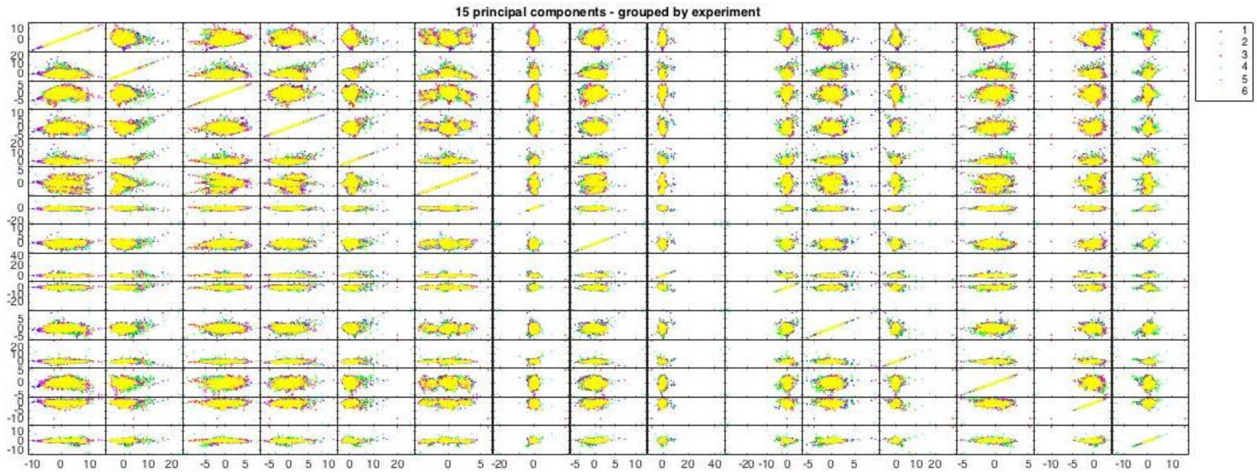
Flow per note (l/min)

Note	Visit1	Visit1	Visit2	Visit2	Visit3	Visit3
	Recording 1	Recording 2	Recording 3	Recording 4	Recording 5	Recording 6
Eb3	1,72	2,04	1,68	1,98	1,57	1,92
F3	1,93	2,31	1,94	2,17	1,85	2,21
Bb3	1,74	2,01	1,68	1,75	1,60	1,84
Eb4	,64	,77	,68	,75	,62	,73
E4	,59	,69	,58	,62	,56	,64
F4	,76	,89	,74	,80	,76	,79
A4	,63	,71	,57	,60	,55	,62
Bb4	,53	,56	,48	,50	,46	,49
D5	,42	,43	,40	,41	,35	,38

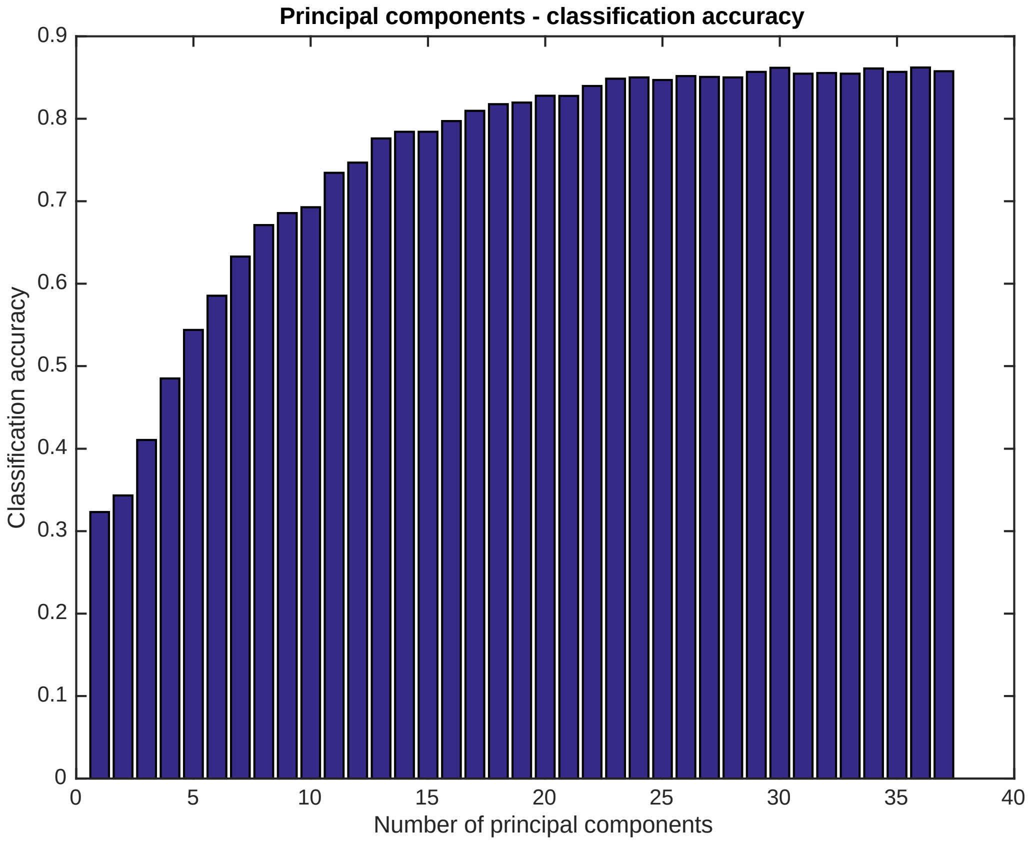
Table... Each visit has 2 recording sessions, seperated by a training with the breath training device. This documents the accute effects on flow use during playing of a training session. Recording 1, recording 3 and recording 5 are the baseline levels of each visit.

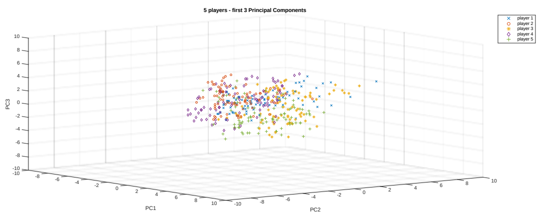
Sound analysis

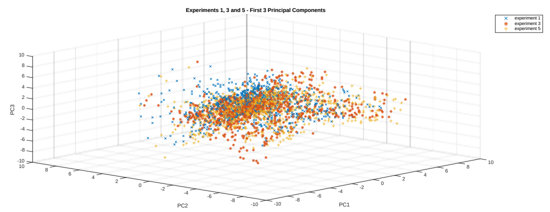
We want to classify the six experiments to indicate a clear difference in the timbre descriptors between the baseline of each visit and the acute effects of training. We standardized our dataset containing 37 predictors using Z-scores. After normalization we balanced the dataset, ensuring every sample has it's equivalent in all experiments. This resulted in a dataset of 8248 samples. Using a K-means classifier with 10 fold cross validation we obtained a classification accuracy of 77,2% for experiments.



Next we performed a principal component analysis on our dataset in an attempt to simplify our dataset and explain the importance of the descriptors. We scored classification accuracy starting with one principal component to a maximum of thirty-seven principal components or the same amount of predictors as our feature vector. As seen in graph… an acceptable classification accuracy of 77% was obtained using at least the first 13 principal components explaining 85% of variance in the data. As seen in the classification accuracy graph, classification is not dependent of the first components explaining most of the variance in the data. On a scatter plot with the first three principal components explaining for the perceptual audio features we can clearly see distinctions between players but not between experiments. This is explained due to the large variability in our dataset consisting of different players, having different levels of experience and all using different instruments, mouthpieces and reeds. Even if training has a significant effect on these perceptual audio descriptors such as loudness, sharpness, fullness and activity their variability is too high to allow for accurate experiment classification.


Principal components - classification accuracy
Classification accuracy
Number of principal components
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
5
10
15
20
25
30
35
40


5 players - first 3 Principal Components
player 1
player 2
player 3
player 4
player 5
PC1
PC2
PC3

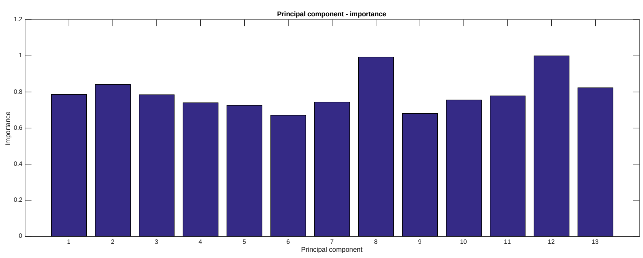

Experiments 1, 3 and 5 - First 3 Principal Components
experiment 1
experiment 3
experiment 5
PC1
PC2
PC3

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
'loudness'	0,23	0,10	-0,14	-0,17	-0,17	-0,08	0,20	-0,02	0,11	-0,05	0,06	-0,19	0,04
'sharpness'	0,25	-0,11	0,01	0,05	0,13	0,08	-0,12	0,23	-0,14	0,06	-0,14	0,03	-0,30
'spread'	0,22	0,25	-0,13	-0,12	-0,13	0,02	0,16	0,04	-0,07	-0,06	0,00	-0,01	0,07
'flux'	0,08	0,28	0,00	0,16	0,24	0,02	0,04	-0,08	-0,22	0,05	-0,21	0,10	-0,04
'flux_var'	0,02	0,23	-0,01	0,18	0,36	0,02	0,05	0,03	-0,08	0,22	0,03	0,16	0,10
'activity'	0,27	0,00	-0,17	-0,11	0,13	-0,01	-0,14	-0,10	-0,03	0,03	-0,13	0,01	-0,02
'activity_var'	0,19	0,04	-0,17	-0,09	0,16	-0,03	-0,29	-0,02	0,13	-0,12	-0,19	0,22	-0,01
'fullness'	0,01	0,35	0,02	0,18	0,19	-0,03	-0,02	0,16	-0,09	0,15	0,09	-0,17	0,02
'fullness_var	0,00	0,24	-0,01	0,17	0,30	-0,03	-0,07	0,16	0,01	0,25	0,29	-0,32	0,10
'autocorr'	0,03	-0,09	0,01	-0,18	0,28	0,11	0,38	0,02	-0,10	-0,07	-0,05	0,56	0,13
'autocorr_va	-0,21	-0,24	0,16	0,07	0,09	0,02	-0,23	-0,03	0,08	0,04	-0,02	0,00	-0,01
'mfcc1'	-0,21	0,17	0,04	0,06	-0,21	-0,04	0,24	0,25	0,07	-0,02	0,11	0,19	0,02
'mfcc2'	-0,08	-0,02	0,23	0,15	-0,01	-0,09	0,07	0,53	-0,04	-0,06	-0,41	0,14	-0,10
'mfcc3'	-0,05	0,19	0,09	-0,23	-0,06	-0,12	-0,23	-0,06	0,05	0,19	-0,02	0,29	0,56
'mfcc4'	0,02	0,14	0,10	-0,26	-0,10	0,00	-0,19	-0,08	-0,08	0,24	0,42	0,37	-0,47
'mfcc5'	-0,10	0,23	0,15	-0,09	-0,15	-0,07	-0,04	0,08	-0,17	-0,15	-0,10	0,00	-0,32
'mfc66'	-0,02	0,25	0,14	-0,17	-0,18	-0,01	-0,25	-0,01	-0,09	0,10	0,01	0,02	-0,07
'mfcc7'	-0,07	0,24	0,16	-0,03	-0,17	0,07	-0,25	-0,02	-0,05	-0,07	-0,36	-0,07	0,20
'mfcc8'	-0,03	0,16	0,04	0,09	-0,22	0,56	-0,14	0,03	-0,01	-0,01	0,02	0,06	-0,02
'mfcc9'	0,08	-0,01	-0,18	0,23	-0,14	0,52	-0,08	0,01	0,00	-0,04	0,03	0,08	0,11
'mfcc10'	0,07	-0,05	-0,25	0,38	-0,18	0,15	-0,08	0,02	-0,07	-0,04	0,10	0,19	0,05
'mfcc11'	0,06	-0,07	-0,25	0,35	-0,16	-0,30	-0,15	-0,04	-0,16	-0,05	0,06	0,16	-0,03
'mfcc12'	0,01	0,02	-0,18	0,28	-0,22	-0,48	-0,12	-0,06	-0,06	0,06	-0,05	0,16	0,01
'mfcc13'	0,06	0,07	-0,09	0,07	-0,17	0,03	0,18	-0,06	0,57	0,60	-0,35	0,05	-0,18
'centroid'	0,30	-0,11	0,14	0,01	-0,02	-0,01	-0,02	0,07	0,00	0,02	0,01	-0,02	0,02
'zerocross'	0,26	-0,06	-0,15	-0,07	0,12	0,05	-0,01	0,00	-0,04	0,08	-0,08	-0,03	-0,20
'rolloff'	0,26	-0,11	0,23	0,07	-0,07	-0,02	0,01	0,10	0,01	0,06	0,11	0,02	0,10
'regularity'	-0,13	-0,20	0,20	0,06	0,16	0,03	-0,34	-0,12	0,07	0,06	-0,11	-0,03	-0,05
'brightness'	0,30	-0,05	0,02	-0,11	0,00	-0,04	-0,12	-0,09	-0,01	-0,01	-0,04	-0,04	0,14
'spread_mir'	0,18	-0,09	0,32	0,16	-0,08	-0,03	0,08	0,08	0,05	0,11	0,19	0,06	0,12
'flatness'	0,06	0,05	0,31	0,22	-0,04	-0,02	0,20	-0,40	0,13	-0,14	0,04	0,05	-0,06
'skewness'	-0,27	0,09	-0,23	-0,04	0,07	0,01	0,04	-0,13	0,03	-0,03	-0,03	0,00	-0,03
'kurtosis'	-0,24	0,09	-0,27	-0,06	0,10	0,02	0,03	-0,11	0,00	-0,05	-0,09	-0,02	-0,07
'entropy'	0,25	0,17	0,16	0,07	-0,03	-0,02	0,03	-0,19	-0,04	-0,13	-0,10	-0,01	0,04
'inharmonici	0,01	0,21	0,22	0,23	0,11	0,00	0,09	-0,41	0,04	-0,17	-0,11	0,03	-0,17
'roughness'	0,16	0,21	-0,04	-0,09	-0,05	-0,07	-0,02	0,20	0,17	-0,31	-0,01	-0,10	-0,05
'roughness_\	0,03	0,15	-0,02	0,09	0,22	-0,05	-0,21	0,17	0,63	-0,38	0,22	0,18	-0,06

Long term effects

We selected the baseline of each visit (experiments one, three and five of our dataset) to find the most important features contributing to these visits. To determine the importance of principal components for classification we used a bagged trees classifier with 10-fold crossvalidation on this reduced data set with 13 principal components and the baseline of three visits. The three experiments were classified with an accuracy of 69,3%. We used the predictorImportance command in Matlab to determine the most important principal components fort his classification.

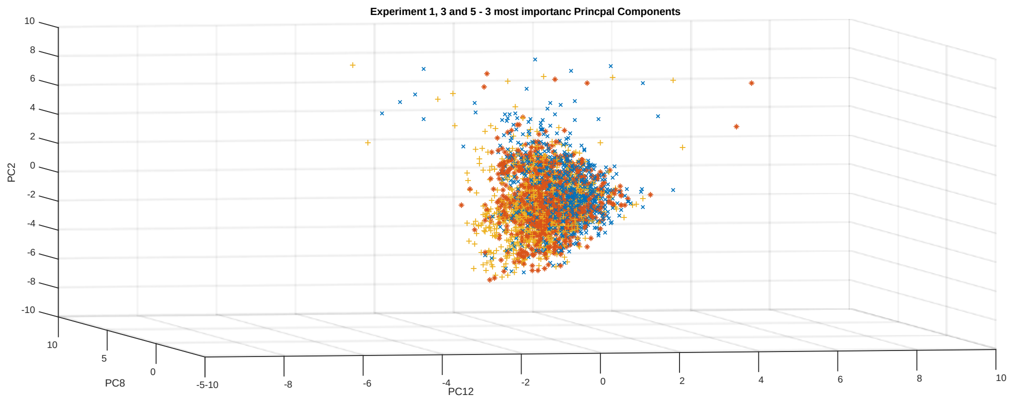
predictorImportance computes estimates of predictor importance for tree by summing changes in the mean squared error (MSE) due to splits on every predictor and dividing the sum by the number of branch nodes. If the tree is grown without surrogate splits, this sum is taken over best splits found at each branch node. If the tree is grown with surrogate splits, this sum is taken over all splits at each branch node including surrogate splits. imp has one element for each input predictor in the data used to train this tree. At each node, MSE is estimated as node error weighted by the node probability. Variable importance associated with this split is computed as the difference between MSE for the parent node and the total MSE for the two children.



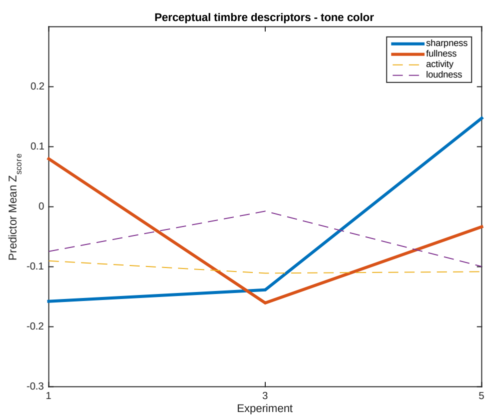
Principal components 12 and 8 are indicated as the most important predictors. All other principal components have a very similar contribution in the classification of samples and their relationship is less defined.

Principal component	Audio features	Mean principal component		
		Exp 1	Exp 3	Exp 5
PC12	autocorrelation (R=.56), MFCC4 (R=.37)	0,2319	-0,0094	-0,1487
PC8	MFCC2 (R=.52), inharmonicity (R=-.41), flatness (R=-.40)	-0,2716	-0,0614	0,3298

Autocorrelation is related to the periodicity of the signal, noise in a signal and is closely related to the power spectrum of a sound. MFCC4 and MFCC2 are also closely related to the power spectrum of the sound. These three features clearly indicate a timbre change but due to their nature this change is hard to explain. A lower inharmonicity indicates a more tonal harmonic series with less deviation from the peaks to the natural series of harmonics. A lower flatness indicates stronger peaks. We can conclude that the training makes harmonic series stronger and more tonal with less noise between peaks.



Since PC12 and PC8 indicate a change in the spectral composition of the sound we selected perceptual audio descriptors from our dataset directly related to tone color. We tested these for significant changes between the experiments and between baseline and the final visit of our trial.

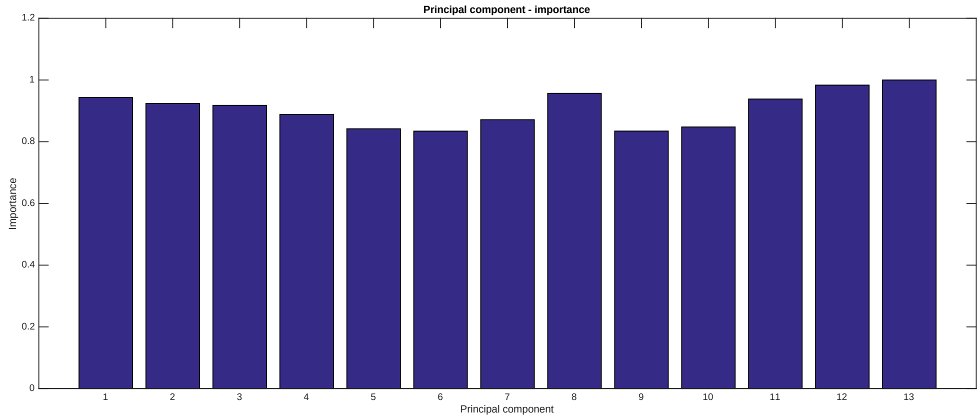


	'loudness'	'sharpness'	'activity'	'fullness'
p 1_3	0,07	0,55	0,55	0,00
p3_5	0,02	0,00	0,94	0,00
p1_5	0,51	0,00	0,63	0,00
mean experiment 1	-0,07	-0,16	-0,09	0,08
mean experiment 3	-0,01	-0,14	-0,11	-0,16
mean experiment 5	-0,10	0,15	-0,11	-0,03

This extra test illustrates that for a similar loudness, fullness of the sound decreases due to the sham training. In comparison to the sham training, the real training increases loudness, fullness and sharpness. This indicates a fuller and brighter sound due to the training program. In comparison to the baseline of the experiment fullness is decreased and sharpness increased for a similar loudness.

Acute effects

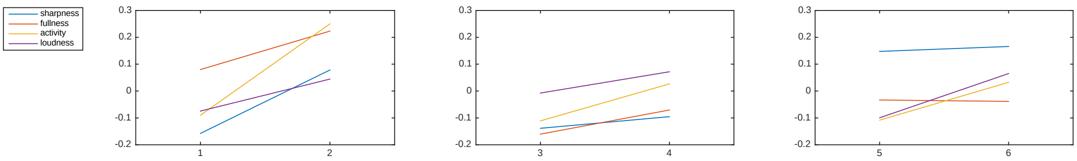
We used the same strategy as for the long term effects, but now we performed bagged trees classification on all six experiments with an accuracy of 57,5%. This resulted in following predictor importances, very similar to the former experiment. Classification accuracy is not very good and this also shows in the importance of the principal components for classification being less defined.



The three most important principal components suggest that there is a change in the structure of the sound. It also makes clear that the first SHAM training has a different effect on the sound than the real training. PC8 suggests that the acute effects of SHAM training decreases the strength of harmonic peaks and sound deviates more from the expected harmonic series. This can be interpreted as a more "noisy" sound.

Principal component	Audio features	Mean principal component					
		Exp1	Exp2	Exp3	Exp 4	Exp 5	Exp 6
PC13	MFCC3 (R=.56) MFCC4 (R=-.46) MFCC5 (R=.-32) sharpness (R=-.30)	0,0749	-0,1687	0,1905	0,1154	-0,1034	-0,1075
PC12	autocorrelation (R=.56) MFCC4 (R=.37)	0,2319	0,1946	-0,0094	-0,0128	-0,1487	-0,2546
PC8	MFCC2 (R=.52) inharmonicity (R=-.41) flatness (R=-.40)	-0,2716	-0,1402	-0,0614	-0,1473	0,3298	0,2865

We performed the same extra analysis on perceptual timbre descriptors as we did for the long term effects of the training and found significant increases in loudness for all three visits. Also the activity value, remaining unchanged in the long term, increases as an acute result of training. Fullness increases significantly only in the first two visits, while sharpness increases significantly only in the first experiment. This indicates that, due to training, the sound gets more active (increased fluctuations in the first and second overtone of the sound) while the basic timbre remains unchanged (experiment 5-6).



	'loudness'	'sharpness'	'activity'	'fullness'
p 1_2	0,00	0,00	0,00	0,00
p3_4	0,04	0,21	0,00	0,01
p5_6	0,00	0,67	0,00	0,89
mean experiment 1	-0,07	-0,16	-0,09	0,08
mean experiment 2	0,04	0,08	0,25	0,22
mean experiment 3	-0,01	-0,14	-0,11	-0,16
mean experiment 4	0,07	-0,10	0,03	-0,07
mean experiment 5	-0,10	0,15	-0,11	-0,03
mean experiment 6	0,07	0,17	0,03	-0,04

Discussion

Pulmonary function

This current paper did not document a clear distinction between the effects of SHAM training and a training program at 60% of MIP and MEP on lung function parameters. Although there was a significant increase in both MIP and MEP for participants, the effect was not found significant for PIF and PEF for real training. There might be several reasons for these observations. The low resistance settings for MIP and MEP training could result in a lower increase of lung function parameters. A training program with a higher register setting might result in a higher increase respiratory muscle strength and peak flows as demonstrated in literature (11). The increase in SHAM might be attributed to a learning effect in both the lung function tests and due to the training as well (Daniël Ref?).

Flow measurements

We demonstrated that the acute effect of training with a respiratory threshold device results in a significant increase in flow use during saxophone playing. We also found a lower use of flow after the completion of the real training program. This effect was not found statistically significant for the SHAM training. Our results also indicate that the effects are much clearly measurable in the lower register of the saxophone, as lower notes require more flow than higher notes.

Sound analysis

We showed that we could use K-means to discriminate between experiments with an accuracy of 77% using our entire feature set. In an attempt to clarify the most important changes in sound we performed principal component analysis, showing that SHAM training and real training both resulted in a stronger tonal sound with clearer peaks and less noise. We also demonstrated a significant increase in sharpness and fullness due the real training program, while we found a significant decrease in fullness for SHAM training. In comparison to the baseline of the experiment, participants played with a brighter, but less fuller sound after training. Accuracy might suffer due to the

heterogeneity of our participant group as demonstrated by the principal component analaysis. Most important predictors for classification were found in the higher principal components, while the first principal components clearly represent the unique timbral qualities of each player.
Documenting the acute effects of training was more complex since we needed to classify each of the six experiments with the set of 13 principal components. Classification accuracy was not very good and did not result in clearly defined features that can be used for classification. The acute influence of training on perceptual audio features decreased towards the end of the experiment, indicating that training for a longer period of time might limit the acute effects of one training session on a participants sound. The only two perceptual timbre descriptors that increased significantly due to the acute effects of training were loudness and activity.

Conclusion

We clearly indicated that a respiratory muscle training program using a threshold loaded device at medium resistance level increases maximum inspiratory and maximum expiratory pressure. The training program resulted in a decrease of flow use to produce a brighter sound with equal perceptual loudness. We also found that sound is more tonal, contains less noise and has stronger peaks due to the training program. Aditionally we demonstrated that immediately after a training session flow use increases, resulting in a sound with a higher perceptual loudness and more activity. Influence on sound decreases as a player completes several weeks of training.