A Quantitative Evaluation of Singing through Electromyography

Shan, Jing; Visentin, Peter; and Shan, Gongbing

Abstract — *Electromyogram (EMG) measures electrical activity associated with neural firings in musculature. Such bio-signals can be used to quantify muscle activity. Since singing is a human biocultural phenonmenon, there should exist a connection between musical properties like pitch and biological parameters such as the percent of muscle usage. This study explores the reliability of EMG in quantifying the activities of Rectus Abdominis, two muscles essential to respiration during singing. Such a quantitative method is desired by practitioners for identifying one's innate singing abilities, or talent. This study also proposes a method of quantitatively identifying efficient pedagogy by comparing pre-training and post-training EMG. Our goals were to validate the method and to provide reliable criticisms for analysis of strengths and weaknesses in singing. A NORAXON wireless EMG was used to measure the muscle activities of a female voice professor as she sang the notes F_3 (low pitch), F_4 (medium pitch) and F_5 (high pitch). The results showed a non-linear, but noteworthy and consistent increase in muscle activity, as the pitches became higher. They confirmed our hypothesis that EMG can be used as a quantitative assessment of singing and showed that there exists a reliable connection between the level of muscle activity and musical pitch. Most importantly, this study showed that EMG has the potential for better teaching method and could increase the reliability of talent searches in singing.*

Index Terms—*Maximal voluntary contraction, Muscle activity, singing pedagogy, Talent search*.

1. Introduction

Innate talent is essential in a voice career. In addition to well developed vocal, musical and phonetic ears, which are activities in the Central Nervous System, talent in singing refers to a physical ability to sing high pitched notes. Singing is partially powered by muscles, which have physiological limits that vary from person to person and is primarily determined by nature. It is generally, but not universally accepted that the variation in human muscle ability is caused by the existence of different muscle fibre types, which are genetically determined [2,3]. Training can manipulate the natural biological state only to a small degree, with slower gains near the ceiling of one's genetic potential [1]. The correct identification of innate physical talent is thus imperative, even under strict time constraints such as during auditions. Traditionally, talent searches have been done through subjective methods and are largely experience-based. The decisions about one's innate ability and their justifications are usually given in very vague terms, such as "beautiful" sounds and "good" control of dynamics. Consequently, there always remains some uncertainty. Many external conditions, such as illnesses, nervousness or impartial judgment may negatively affect the outcomes of an audition. Thus, a reliable objective method is desirable.

To the authors' best knowledge, no quantitative research currently exists that examines the biomechanics of singing. Given music as a human biocultural phenomenon (related to muscle activity and control of the Central Nervous System), and recent progress in bio-activity analysis technology (such electromyography (EMG) for exploring muscle action during any human activity and electroencephalogram (EEG) for detecting the electrical activity of the brain), it is time to use modern tools to provide supplemental and objective data that shows a student's biological capabilities, which is unaltered by temporary external conditions. Systematic, empirical inquiry into the biomechanics of singing holds the potential to inform and significantly facilitate talent searches by eliminating irrelevant influences and reporting innate physical talent as a number. Our study uses EMG to achieve this quantification of talent in singing.

Singing requires two muscles located at the abdomen, named Rectus Abdominis along with the other muscles (mainly the diaphragm and muscles between the ribs), to achieve the apogio (ital., a diaphragm tone support) and to support proper posture [4]. Previous studies have shown that the ability of the human body to maintain

Manuscript received March 30, 2005. This work was supported by NSERC (National Sciences and Engineering Research Council of Canada) and Westgrid / Canada.

J. Shan is with the Department of Biomedical Engineering, Columbia University, USA (e-mail:js2454@columbia.edu).

P. Visentin is with the Department of Music, University of Lethbridge, Canada (e-mail: visetin@uleth.ca).

G. B. Shan is with the Department of Kinesiology, University of Lethbridge, Canada (e-mail: g.shan@uleth.ca).

muscle activities is determined by the muscle intensity level and the duration of activity, ranging from 10 seconds at over 90% of the maximal muscle activity (physiological limit) to over 2 hours at 40% of the physiological limit [5]. One possible way of quantifying muscle intensity levels is EMG, which measures electrical activity associated with neural firings in musculature. It could be, therefore, an instrumental assessment of human potential related to musical pitch, length and loudness of tone, as well as control of vocal skills. One of our goals is to test this hypothesis.

In addition to talent search, this quantitative assessment of singing can be very useful in pedagogy. Long-standing traditions surrounding performance pedagogy have made it largely an arcane art. The primary instructional approach is based on an apprenticeship model whereby musical knowledge, skills, and attributes are passed from teacher to pupil. The product, that is the performance, defines and validates the success of the teaching and learning and the immediate end is often used to justify the pedagogical means [6]. Good training should result in better performance, which should also be accompanied by biological changes. Specifically, training should increase the biological efficiency of singing, thereby decreasing the amount of muscle activity required to sing. The extent of change depends on the effectiveness of the training received. Although different students respond to various teaching styles differently, one can identify generally successful pedagogy by comparing the change in EMG of different teaching styles.

The purpose of this study is to explore the use of EMG in quantitatively describing physiological and biomechanical phenomena associated with singing. The goals are to validate EMG as a quantitative tool for identifying singing potential and for reliable teaching evaluation. The method could also offer objective performance evaluation to voice professionals. This current research can be used to provide a framework for exploring these same issues in other performing arts.

2. *Method*

The current study uses electromyography to determine percent muscle usage. Electromyogram measures electrical activity associated with neural firings in musculature. A neural pulse train is transmitted by the muscle fibers associated with a desired movement and each neuron innervates several muscle fibers. The resulting raw EMG signal detected by surface electrodes is a summation over the ensemble of pulse trains associated with the muscle. The signal spectrum ranges from 0 to approximately 500 Hz. In the current study, eight-channel, wireless NORAXON (NORAXON U.S.A., Inc., Arizona, USA) EMG was used to determine selected muscle activity. NORAXON's hardware specifications provided raw signal recordings at a rate of 1080 Hz, with a band pass filter of 16-500 Hz, effectively minimizing environmental electrical noise.

In order to interpret EMG (a measurement of internal muscular activity) in a meaningful way, secondary processing of raw data must occur. A variety of EMG processing protocols exist and we chose the one most commonly found in the literature – enveloping [7,8,9]. The process involves full-wave rectification of raw EMG signals and low-pass filtering (Fig.1). We employed a Fast Fourier Transformation (FFT) low-pass filter of 6 Hz. Such filtering improves EMG sensitivity as a diagnostic tool by retaining dominant components of the signal while eliminating unstable high-frequency ones. The value of 6 Hz used in our study is a median of those found in the literature for light to normal activities. In our view this is appropriate for characterizing muscle activity during voice performance. Cut-off frequencies typically depend on muscle contraction rates as follows:

1. relative fast contraction - Parkinson's disease (15 Hz) [10] ,
2. normal activities such as gait (6-9 Hz) [9,11],
3. light lifting (3 Hz) [12],
4. posture control (Quiet stance 1.2 Hz) [13].

It must be noted that enveloping alone provides a *non-quantitative* way to assess neural muscle activity. In order to provide *quasi-quantification* and comparison between trials, normalization is needed. The normalization process expresses all EMG measurements as a percentage of a chosen reference value. Commonly used references include: 1) the maximum signal level during a trial, and 2) a Maximum Voluntary Contraction (MVC) determined in a separate trial under high-load conditions as a reference value. Using the first of these provides results of questionable quantitative utility as the "reference" may vary from trial to trial, and muscle capacity will likely be higher than the chosen reference. The second approach establishes the physiological limits of the muscle, a value that does not change from trial to trial. We use the latter to express load intensity as a percentage of the physiological limits of the individual. In the current study, MVC was determined using the average of maxima measured using three high-load trials. Figure 1 shows the complete procedure for processing EMG signals.

In the current study, EMG electrodes were positioned mid-muscle longitudinally on the left and right Rectus Abdominis. Wire leads to the electrodes were run under the clothing of subjects (t-shirts) to a preamplifier pack worn on the belt (weighing about 200 grams). Signals from the preamplifier were transmitted to the main amplifier. Subject wore a black stretch-material garment over top of her t-shirt, effectively eliminating the relative movement of the wires to the skin, yet providing for complete freedom of movement. The use of this kind of "wireless" system minimizes the laboratory-based constraints that normally occur with the use of "wired" EMG (where subjects' motor control patterns may be inadvertently altered due to the presence of umbilical wires between the measuring system and the subject).

The test protocol consisted of evaluating a common skill frequently asked for during auditions. The subject sang a F (tone) ten times, in groups of five, the first four of which lasted one second (brief period) each while the last one continued for four seconds (maintenance period). Three trials were conducted and data was examined for F_3, F_4, and F_5. This protocol permitted three different ranges—low (F_3), medium (F_4) and high (F_5)—to be evaluated, and resulted in capture times around 20 seconds in duration. One full-time, female voice professor participated in this study.

3. *Results*

Data was highly reproducible for all pitches. Figure 2 displays a typical EMG excursion for singing F_5. The EMG showed approximately the same peak intensity for all short (1 second) and long (4 seconds) F_5s, though the start of both brief (1 second) and maintenance (4 seconds) periods demonstrated lower EMG levels than their respective ends. The first note of the brief period always corresponded to the lowest EMG while the maximal EMG was found towards the end of the maintenance period. For this well-trained subject, singing F_5 reached, on average, 42% of her MVC with a standard deviation of 4%. The peak values ranged from 41% to 62% of MVC.

Figure 3 compares muscle intensity levels of Rectus Abdominis when singing F_3, F_4 and F_5. The muscles operated on an average of 10% MVC when singing the low pitch F_3 and 15%

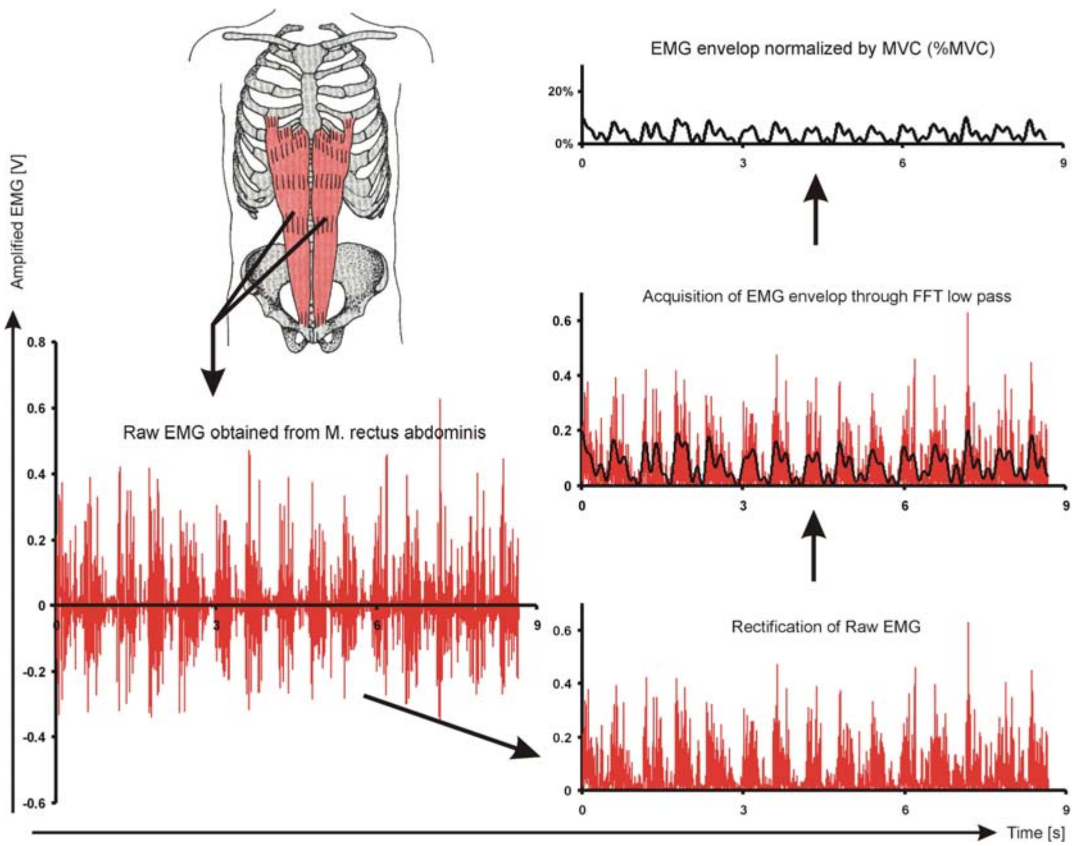


Figure 1. The process establishing enveloped and normalized EMG.

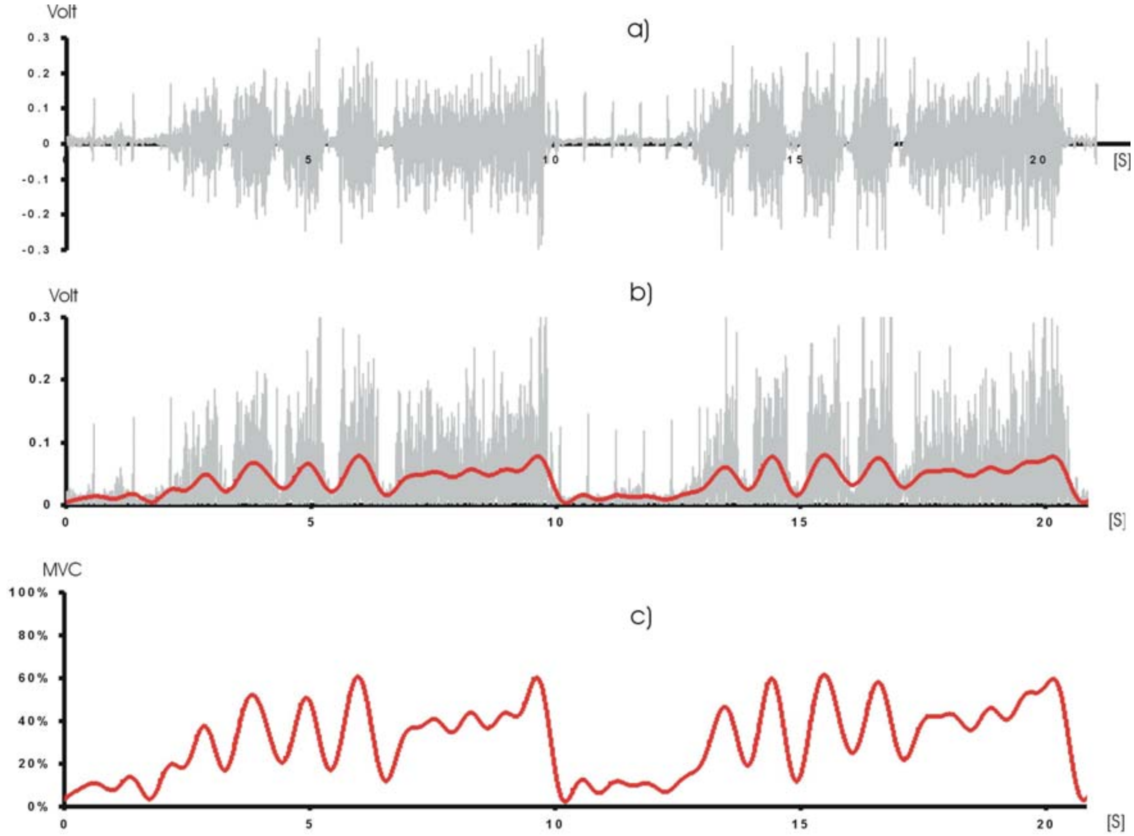


Figure 2. A typical EMG excursion of Rectus Abdominis during F5 singing. a) Raw EMG, b) EMG envelop, and c) Normalized EMG.

when singing the middle pitch F_4. Connecting these results to those found for F_5, a non-linear increase in percent of muscle usage can be seen—muscle activity increased at a greater rate than the pitch of the notes being sung.

For F_5, the four-second maintenance period can be clearly distinguished from the one-second brief periods while no such distinctions can be made for F_3 and F_4. In fact, from the muscle activities of the lower pitches, it is not even apparent the time at which a note is being sung. At the low pitch, the percent muscle usage ranges from 2% to 15% which is an intensity level that allows for hours of continuous work without fatigue. As the pitch increases, the range also expands—with higher maximal values observed. F_4 causes muscle activity between 3% MVC and 22% MVC, while F_5 returns values ranging from 2% to 61%. All three EMG had very small variations—the standard deviations were all below 5%.

4. Discussion

The results of this study confirmed our hypothesis that EMG can be used as a quantitative assessment of singing. They showed that there exists a reliable connection between the level of muscle activity and musical pitch. As such, we can speak of biological parameters (percentage of MVC) and musical properties (pitch) interchangeably. This numerification process of singing evaluation offers the advantage of converting a hitherto arcane art into a scientific procedure. We are not at all denying the importance of artistic expressions; we simply believe that vivid performance is based on solid technique, or basic skills. Given this, a quantitative evaluation of such skills will identify the basis of creating extraordinary music. Electromyography, therefore, has the potential to be a reliable way of demystifying the art of singing.

It should be noted that EMG is already an accepted daily evaluation tool in physical therapy and certain sports training [14]. Most recently, real time EMG has been used to adjust intensity levels of rehabilitation and sports training through bio-feedback [15]. This success can be partially attributed to the small and convenient size of the device (11cm×7cm×3cm) as well as its straightforward usage. Because the data collection apparatus obtains bio signals from the surface of the skin (surface EMG), it offers no intervention and negligible constraints on the subjects' motor control (singing) patterns, thus generating a realistic electromyogram.

We believe that EMG can be introduced into singing pedagogy with equal success. It can be used to facilitate learning as well as to offer objective evaluation of both training methods and student performance.

Motor control is generally learned in three phases—recognition, optimization and automation [16]. By allowing students to visualize the muscle activity of the teacher through EMG, the recognition process could be accelerated. Real time bio-feedback for the students will instantly identify improper motor control, allowing for immediate correction, which could then shorten the optimization process. It is well known that the first two phases are essential to obtaining the correct control patterns [17].

Many different styles exist in singing pedagogy. It is in the practitioners' best interests to identify the most effective approaches. To the authors' best knowledge, the area of quantitative research has yet to be introduced to singing. EMG has the potential to address this deficit through Pre- and Post-Training Analysis. In order to evaluate each teaching style, the following procedures could be followed.

Randomly assign subjects (students) to different groups, statistically ensuring equivalent bio initial conditions. Each group will receive one training method for the whole training season. The groups shall differ only in the teaching style; all other variables, such as length of training, should be identical. Prior to training, obtain the percentage of maximal voluntary contraction (MVC) required to sing a certain note for all subjects (pre-training measure-ment). Collect again the same EMG at the end of the training season (post-training measurement). Statistically significant differences among changes in the EMG of different groups will identify effective teaching methods.

On the other hand, this same evaluation can also provide students an objective assessment of their performance. Such an objective evaluation is very desirable because it eliminates subjectivity, which can be influenced by teacher-student relations as well as personal preferences.

Due to genetic variations, singing ability varies from person to person. Everyone has a physiological limit, which is primarily determined by nature. Training can manipulate the natural biological state only to a small degree, with slower gains near the ceiling of one's genetic potential. This is known by exercise scientists as the ceiling of adaptation [1]. It is clear that innate talent is essential in the music industry. Electromyo-graphy offers a scientific method for a reliable physical-talent search. For novices, it is conceivable how a subject using 70% MVC while singing F_5 has more physical potential than one using 90% MVC.

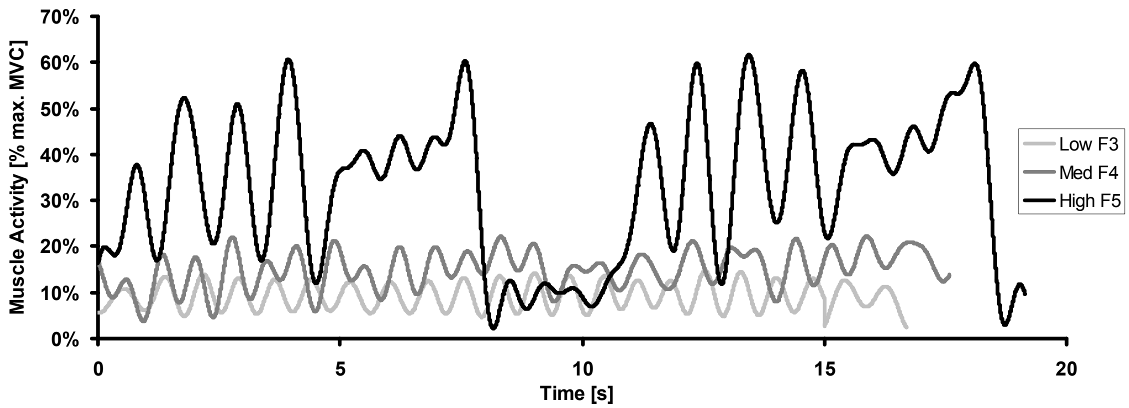


Figure 3. Comparison of muscle intensity levels during singings of different pitches (F3, F4 & F5).

One should note that, so far, this method can be interpreted only by a person educated in biomechanics, hardly by a singer. To address this, a software can be developed to automate the data interpretation and generate easily understood reports. For such a development, a multidisciplinary cooperation is necessary.

It should be noted that this research is only a case study. The authors understand that there are variations in singing techniques as well as natural variability from performer to performer. In order to justify and standardize this method, more trials and subjects are required to give statistical reliability. Future studies could concentrate on the influences of gender, age and race on singing. It has been established that such factors do indeed affect motor development and control [16]. Therefore, if we could establish databases based on these factors, we could provide more accurate evaluations and predictions of one's innate singing ability by comparing and contrasting the subject's EMG with the known EMGs of others with similar conditions.

5. CONCLUSION

This study suggests that electromyography can provide valuable objective information on singing evaluation, which may help better pedagogy and increase the reliability of talent search.

ACKNOWLEDGMENT

The authors would like to thank the Voice Professor Patrice JEGOU, Department of Music, University of Lethbridge, who donated her time as a subject and her expertise of singing to this research project.

REFERENCES

[1] Liu, Y., Lormes, W., Reissnecker, S., & Steinacker, J.M., "Effects of high intensity resistance and low intensity endurance training on myosin heavy chain isoform expression in highly trained rowers," *Thieme-connect*, International Journal of Sports Medicine, 2003, 24(4), pp.264–270.

[2] Costill, D.L., Coyle, E.F., Fink, W.F., Lesmes, G.R., & Wilzmann, F.A., "Adaptation in skeletal muscles following strength training," *The American Physiological Society*, Journal of Applied Physiology, 1979, 46, pp. 96–99.

[3] Gollnick, P.D., "Relationship of strength and enduration with skeletal muscle structure and metabolic potential," *Thieme-connect*, International Journal of Sports Medicine [Supplement], 1982, 3, pp. 26.

[4] Lassalle, A., Grini, M.N., Amy de la Breteque, B., Ouaknine, M., & Giovanni, A., "Comparative study of respiratory mechanisms between professional lyrical singers and beginners," *Karger Publishers*, Rev Laryngol Otol Rhinol (Bord), 2002, 123(5), 279–289.

[5] Berg, J., Tymoczko, J., Stryer, L., & Clarke, N., "Biochemistry (5th edition)". *W. H. Freeman and Company*, New York, USA, 2002, pp341–449.

[6] Babin, A., "Festivals and Examinations: Asset or Liability for the Preparatory Piano Student?" *University of Lethbridge*, Annual Conference of the Canadian University Music Society. 2004, pp.69.

[7] Winter, D.A., "Pathologic gait diagnosis with computer-averaged electromyo-graphic profiles," *Independence Square West Curtis Center*, Archive of Physical Medicine and Rehabilitation. 1984, 65(7): 393–398.

[8] Nandedkar, S.D., & Sanders, D.B., "Measurement of the amplitude of the EMG envelope," *Wiley*, Muscle Nerve, 1990, 13(10), 933–938.

[9] Shiavi, R., Frigo, C., & Pedotti, A., "Electromyographic signals during gait: criteria for envelope filtering and number of strides," *The IEE*, Medical & Biological Engineering & Computing, 1998, 36(2), 171–178.

[10] Andreeva, Y.A., & Khutorskaya, O.Y., "Application EMGs spectral analysis method for the objective diagnosis of different clinical forms of Parkinson's disease," *Elsevier*, Electromyogram of Clinical Neurophysiology, 1996, 36(3), 187–192.

[11] Arsenault, A.B., Winter, D.A., & Marteniuk, R.G., "Bilateralism of EMG profiles in human locomotion," *Lippincott Williams & Wilkins*, American Journal of Physical Medicine, 1986, 65(1), 1–16.

[12] Giroux, B., & Lamontagne, M., "Net shoulder joint moment and muscular activity during light weight-handling at different displacements and frequencies," *Taylor & Francis Ltd*, Ergonomics, 1992, 35(4), 385–403.

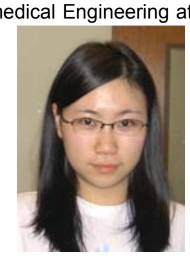
[13] Shan, G.B., Wu, G., & Haugh, L., "A method to determine the interdependent relationships between biomechanical variables in Artificial Neural Network models: the case of lower extremity muscle activity and body sway," *Elsevier*, *Neurocomputing*, 2002, 61, 241–258.

[14] Nordin, M., & Frankel, V., "Basic biomechanics of the musculoskeletal system," *Lippincott Williams & Wilkins*, Philadelphia, USA, 2001, pp. 440.

[15] Neblett, R., "Active sEMG training strategies for chronic musculoskeletal pain," *Association for Applied Psycho-physiology and Biofeedback*, Biofeedback, 2002, 30(3), 39–42.

[16] Magill. R.A., "Motor Learning Concepts and Applications (6th edition)," *McGraw-Hill*, Boston, USA, 2001, pp. 183–197.

[17] Newell, K., & Corcos, D., "Variability and motor control," *Human Kinetics*, Champaign, USA, 1993, pp. 223–381.



Jing SHAN is a junior, majoring in Biomedical Engineering at Columbia University in New York, USA. While in high school, she won numerous music awards at city and provincial competitions, including "Superior Standing in Piano Performance" at the Alberta Provincial Music Festival. In addition, she was the principle flute for her high school concert band.

Peter VISENTIN holds a Master of Music degree in performance from the University of Toronto, Canada. He is now an Associate Professor in the Department of Music, University of Lethbridge, Alberta, Canada.

Gongbing SHAN Obtained his PhD in biomechanics from the University of Münster, Germany. After his Ph.D., he was an NIH (National Institute of Health / USA) Post-Doctoral Fellow in the University of Vermont / USA. He is now an Associate Professor in the Department of Kinesiology, The University of Lethbridge, Alberta, Canada.