PROCEEDINGS of ISMA 2019
International Symposium on Music Acoustics

13 - 17 September 2019 in Detmold, Germany

Proposal of a human-instrument interaction model and its basic examination using electromyogram

Ryo ITOIGAWA*

School of Integrative and Global Majors, University of Tsukuba, Japan

Abstract

In the production of musical instruments, prototypes are evaluated by professional performers. It is empirically known that evaluation of musical instruments differs depending on the evaluator. However, the mechanism how human evaluates a musical instrument is not revealed. In this study, I newly proposed a human-instrument interaction model when a person evaluates a musical instrument to reveal its mechanism. For a basic study of the model, I measured human muscle activity and verified its trend when controlling the plucking parameters for the guitar. In the experiment, 5 subjects were asked to play a simple task with a plectrum under control the plucked position and plucking dynamics. Subjects consist 4 experienced amateurs and 1 beginner. EMG of four muscles considered to be involved in the plucking motion using a plectrum and audio from the front magnetic pickup were measured simultaneously. As a result, the muscle activity due to the difference in the position has a large difference for each subject, and no specific trend was observed. The muscle activity due to the difference in the dynamics was found to have a certain tendency among subjects, such as muscle activity also increases and decreases with the increase and decrease of plucking dynamics.

Keywords: Interaction, Guitar, Evaluation, Electromyogram, EMG,

1 INTRODUCTION

How do humans evaluate musical instruments? The physical aspects of various musical instruments have widely investigated in a long history. While it is difficult to reveal the principle of sound production, the evaluation of musical instruments is also full of wonders and unknown things. Because the evaluation of the instrument is considered to be based on the cross- or multi-modal perception of the person who played the instrument, or the person who listened to the instrument, it can not be told only by the physical characteristics of the instrument. Thus, it is also necessary to consider the characteristics of people themselves. For violins as an example, it is suggested that the bias changes the evaluation of the instrument [1] and acoustical or mechanical analysis has been not conclusive to quantify the subjective evaluation of the instruments [2]. The perception related to the evaluation is thought to be not only auditory but also visual and haptic feedbacks. Several models have been proposed for this "performer-instrument interaction", incorporating control engineering insights [3, 4, 5]. In addition to human common perceptual characteristics, in particular, I believe that individual differences in perceptual characteristics are large, due to the difference in the level of performance skill and understanding of music itself in the case of musicians. It is also assumed that the breadth of the physical parameters given to the instrument, such as the velocity of the plectrum, differs depending on the performance skill. Even if the physical parameters given to the instruments are equivalent, the usage of body and muscle may differ due to differences in physique and skill. Its difference in the somatic sensation may affect the evaluation of the instrument.

Based on these points, it is expected that the followings interact with each other in a complex way in the evaluation of musical instruments; (i) Acoustic and physical characteristics of musical instruments and spaces, (ii) Human common physiological and perceptive characteristics (including illusion), (iii) Differences in player's performance skills and sensitivity to feedback from instruments. As for (iii) for example, advanced players may prefer instruments that respond sensitively to their input, but beginners may prefer to enjoy the musical performance itself, with less sensitive instruments where their performance can be heard well.

To clarify these interactions, it is necessary to not only measure physical phenomena and acoustical characteris-

*itoigawa.ryo@gmail.com

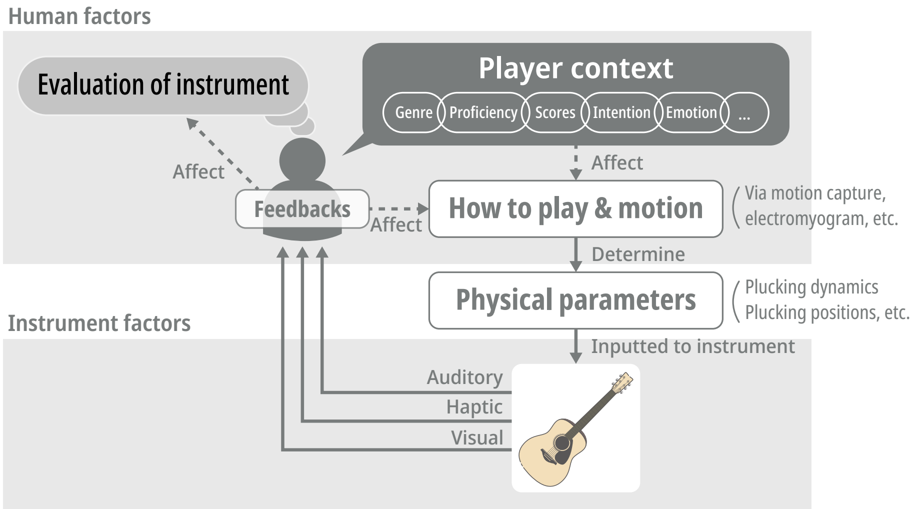

Figure 1. Outline of proposed Human-Instrument Interaction model.

tics of musical instruments but also comprehensively measure various subjective and objective characteristics of players, which includes subjective evaluation of musical instruments. However, there is little related research.

In this study, "Human-Instrument Interaction" which considers the player context is proposed. Figure 1. shows the outline of the Human-Instrument Interaction model. Here, "the player context" is defined as the combination of various implicit parameters such as the player's favorite genre and proficiency level. There is research on the difference in movement due to the difference in proficiency (e.g. [6]), however, a lot of questions about the relationship between the comprehensive player context and the actual human motion/muscle activity remains. (e.g. Does the player who likes a specific genre have a specific motion tendency?) Also, It has been clarified neither that the relationship between human motion and the physical parameters given to the instrument, nor the kinetics and kinematics of playing. By clarifying these relationships, for example, players who like certain genres may be more likely to produce instruments that understand human characteristics, such as being more likely to play certain instruments. Some injuries due to muscle fatigue have also been reported in musical instrument performance [7]. There is also a possibility that understanding the performance movement will lead to failure prevention and efficiency improvement in the performance education scene.

Based on these questions, in this study, I examined how human motion changes when the player context and proficiency differ during an electric guitar playing. The population of a guitarist is very large and the instructions are substantial. However, few mention the relationship between the player context (such as playstyle) and how to play, and intuitive explanations based on the author's rule of thumb are often seen. The acquisition of techniques is often done in one's way, and techniques and movements are not standardized. It may be needed to clarify the relationship mentioned above with how the actual technique is realized. The measurement and systematization of performance techniques and movements can be expected to provide scientific performance proficiency support as well as academic contributions in the related field.

I focused on electromyogram (EMG), which has been used as one of the embouchure measurement indicators in brass instruments [8, 9]. The plucking position and dynamics are set as control conditions. These two are considered to greatly affect timbre and to be relatively easy to be controlled by the player. While changing these conditions, the player's EMG at the time of plucking using a plectrum and the musical sound from the magnetic pick-up on the electric guitar are measured. In this study, the objective is to examine the player's muscle activities using EMG and their tendency during plucking.

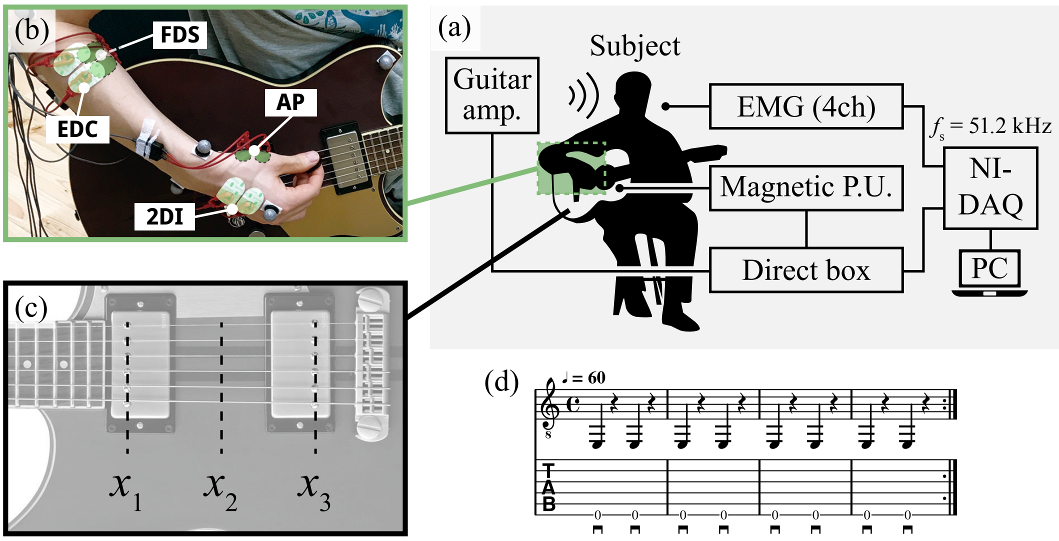

Figure 2. (a) Experimenal system and setup. Four EMG and audio signal from a magnetic pick-up on the electric guitar are measured simultaneously. (b) Four EMG measurement sites from right forearm to hand. (c) Specified plucked positions. (d) The music score for the performance task.

2 METHODS

2.1 Experiment

The experimental system is shown in Figure 2(a). The surface EMG using electromyograph (Wet bipolar EMG sensor, Oisaka Electronic Equipment Ltd.) and electrodes (F-150M, Nihon Kohden) and the signal output from the front pickup when the subject plays a specific task with a plectrum (INFINIX HARD POLISH JAZZ 1.20mm, MASTER 8 JAPAN) and electric guitar (REVSTAR RS820CR, YAMAHA Corp., factory initial condition) via the DI unit (BOSS DI-1, Roland) are measured simultaneously by data acquisition device (cDAQ-9174, NI-9234, National Instruments). A sampling rate was 51.2 kHz.

The measurement sites of EMG were four parts that would be related to the string-picking operation using a plectrum: Adductor pollicis muscle (AP), 2nd Dorsales interossei muscle (2DI), Flexor digitorum superficialis muscle (FDS), and Extensor digitorum muscle (EDC). Since the plucking motion is targeted only for down-picking (picking the strings from top to bottom) in this study, FDS is considered to be an antagonistic muscle during plucking motion. Figure 2(b) also shows the EMG measurement site.

2.2 Experimental setup

2.2.1 Subjects

The subjects of the experiment were a total of five, four amateur players who play the guitar daily and one beginner. The performance genres that each subject performs on a daily basis and the features (i.e. the player context) are shown below.

Subject 1 About 20 years of guitar playing experience. Playing rock or funk. Playing solid body electric guitars using plectrums and often play crisp mute strum with a slightly distorted crunch sound.

Subject 2 About 10 years of guitar playing experience. Playing pops focusing on solo guitar. In many cases, playing acoustic guitars in a fingerstyle. It is rare to use a plectrum, and strumming style is mainly played when using with a plectrum.

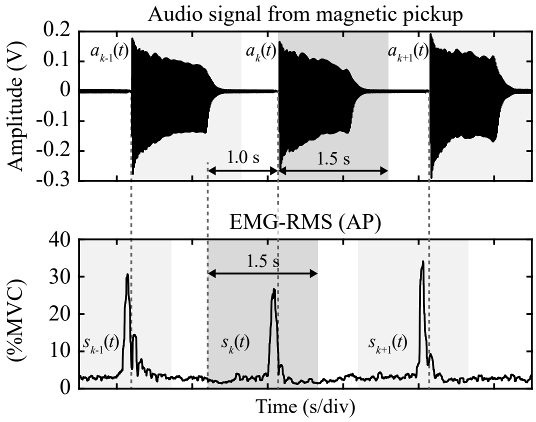

Figure 3. Typical example of audio signal from magnetic pickup and EMG-RMS (at AP). The peak position of the second derivative of the each audio signal is defined as the onset. The signal from the onset to 1.5 sec is used as the audio signal $a_k(t)$, and the corresponding EMG-RMS signal for 1.5 seconds isdefined as $s_k(t)$.

Subject 3 About 10 years of guitar playing experience. Playing modern jazz. Playing electric arched top guitars with plectrums, often playing single tones and chords with clean tones.

Subject 4 More than 10 years of guitar playing experience. Playing hard rock. Playing solid body electric guitars using a plectrum, and often distorting sounds. Holding the plectrum deep.

Subject 5 Beginner of playing the guitar. Having experience of violin.

2.2.2 Protocol

Each subject was informed in advance about the experiment and given a playing time to get used to the experimental guitar for several minutes. The subject can monitor the output of the electric guitar with a guitar amplifier (THR10, YAMAHA Corp.). The settings for the guitar and amplifier were the same throughout all trials.

As shown in the score of Figure 2(d), the subject performed the task of playing the sixth string (E2, approx. 82 Hz) with down-picking according to the 60 bpm metronome. In the rest, the strings were muted in any way.

The task was performed by controlling three levels of plucking dynamics (*p, mf, ff*) and three plucked positions (x_1, x_2, x_3). The dynamics were determined subjectively by each subject. The subject was instructed to play *ff* more strongly than *mf* and play *p* weaker than *mf*. The plucked position was determined as follows. The position of pole piece on the front pickup is x_1, the position of pole piece on the rear pickup is x_3, and their middle position is x_2. Figure 2(c) shows the approximate plucked position described above.

First, the subject performs the task with dynamics *mf* at position x_2. Next, after several seconds of rest, the subject keeps the plucked position x_2 and performs the task with dynamics *p*. Finally, the subject performs with dynamics *ff*. In the same way, the subject then performs the task at the plucked position x_1, and finally the task on the plucked position x_3. After performing the task under all conditions, EMG at maximum voluntary contraction (MVC) [10] was measured for about 3 seconds to normalize each subject EMG.

2.3 Analysis

The obtained EMG was rectified and smoothed by calculating the root mean square (RMS) in 50 ms steps with reference to the muscle activity measurement cases during musical performance [9, 11, 12]. Hereafter this is called EMG-RMS. Figure 3 shows the part of the audio signal from the pickup and EMG-RMS (at adductor pollicis muscle: AP) in a trial under a certain condition. The dotted line in Figure 3 is the peak position of the second derivative of each audio signal, which is defined as the onset of each sound. The signal from the onset to 1.5 sec is used as the audio signal $a_k(t)$. As shown in Figure 3, the corresponding EMG-RMS $s_k(t)$ is taken 1.5 sec from the point of 1 sec before the onset of $a_k(t)$ since the onset of EMG-RMS is thought to precede sounding [13]. For each subject, $S(t)$ shown in the following equation 1 is used as a representative value of EMG-RMS under each plucked dynamics and plucked position.

$$S(t) = \frac{1}{N}\sum_{k=1}^{N} s_k(t) \quad (0 \leq t \leq 1.5) \tag{1}$$

Here, N is the total number of trials (i.e. the number of plucking strings) in one experiment, and it was approximately $N = 16$ in most of the experiment.

3 RESULTS

Figure 4 shows each $S(t)$ under the condition that the plucked position is x_2. The upper part of Figure 5 shows the peak values of $S(t)$ obtained around the onset. The lower part of Figure 5 shows their time difference from the onset.

3.1 Changes in muscle activity due to differences in position: x_1, x_2, x_3

I describe the tendency of $S(t)$ and its peak value and timing when changing the plucked position. From Figure 5, the peak of EMG-RMS from the muscles considered to be related to plucking (i.e. AP, 2DI and EDC) tends to be observed before the onset regardless of the plucked position. However, changes in peak value were not observed among subjects. For example, focusing on the AP, Subject 2 has the highest %MVC at x_2, but Subject 5 has the same %MVC at all positions. Also in 2DI and EDC, there was no common tendency among subjects for peak value among the plucked positions.

3.2 Changes in muscle activity due to differences in dynamics: *p, mf, ff*

I describe the tendency of $S(t)$ and its peak value and timing when changing the plucking dynamics. The peaks of AP, 2DI and EDC also tend to be observed before the onset regardless of the plucking dynamics. In addition, there is common to all subjects that %MVC tends to increase as plucking dynamics increased. However, the gradient of increase varies depending on the subject and muscle. Also, the peak time difference from the onset tends to decrease as plucking dynamics increased.

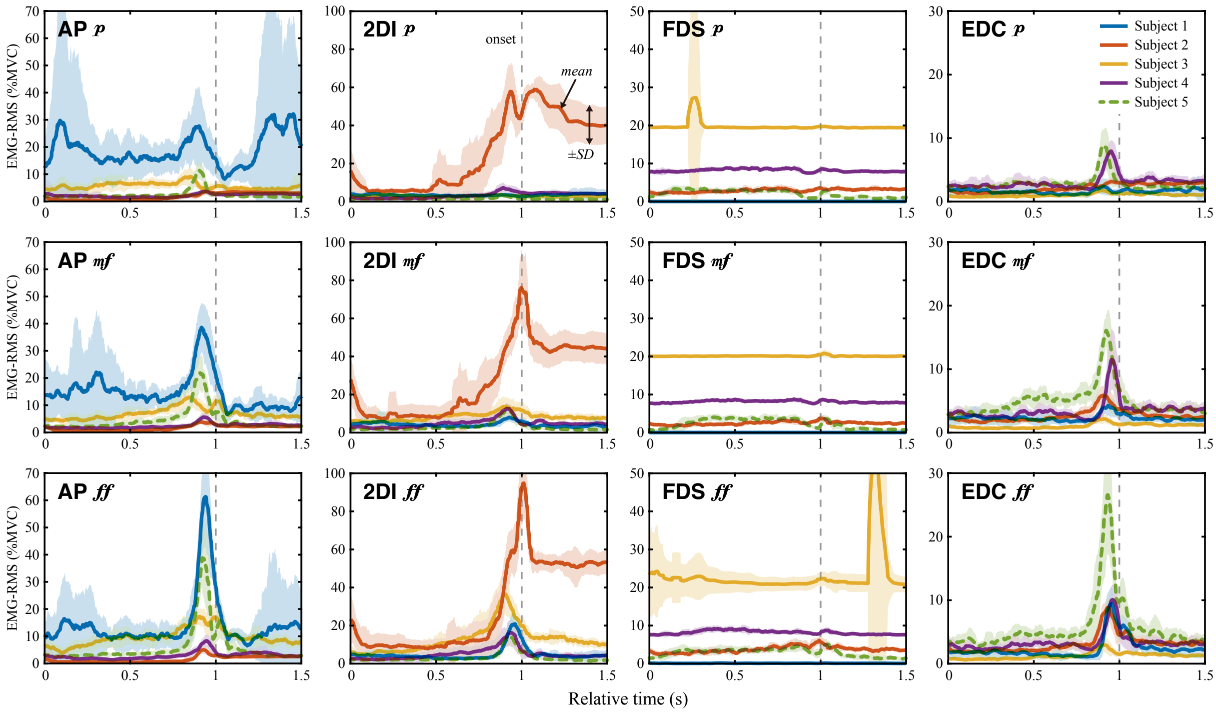

Figure 4. Results of EMG-RMS during plucking under the condition the plucking dynamics changed at position x_2. The colored lines show the $S(t)$ for each subject. Dotted lines at 1 second indicate the audio onset timing.

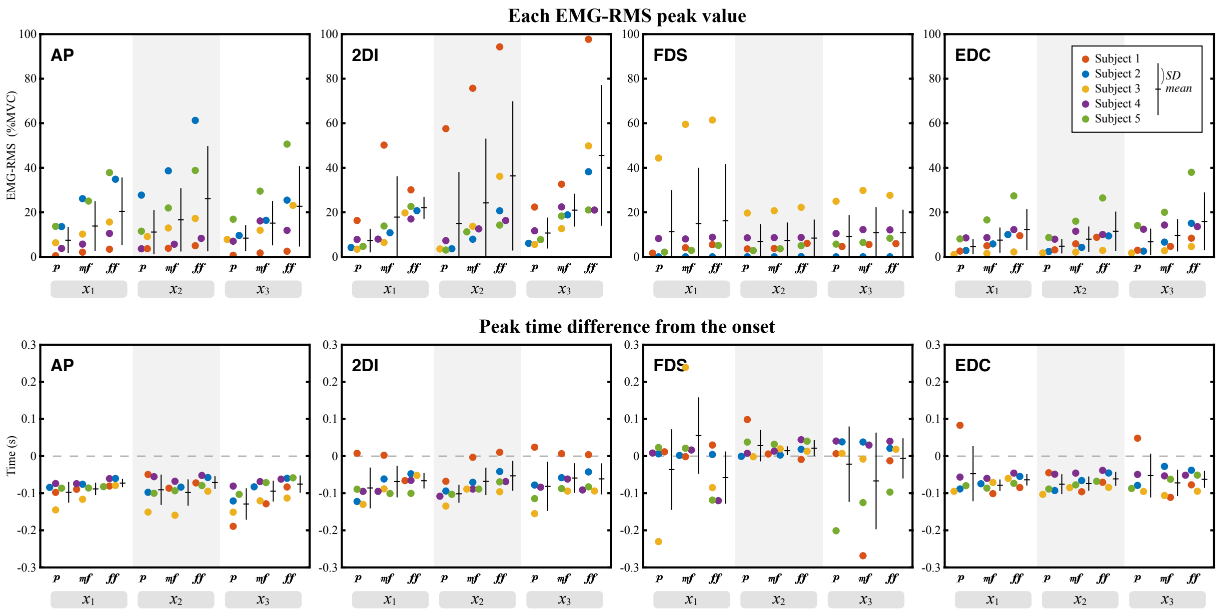

Figure 5. Results for peak values obtained from each EMG-RMS. The upper part shows the %MVC value of the EMG peak at each site, and the lower part shows the time difference from the audio onset of the peak.

4 DISCUSSION

A common tendency was observed among the subjects, with the AP mainly increasing/decreasing the muscle activity as the plucking dynamics increased/decreased. Also, the peak time difference from the onset tends to decrease as plucking dynamics increased. In particular, these tendencies were observed in AP and 2DI, which is considered to have a significant effect on plectrum gripping. On the other hand, there was no common tendency among the subjects about the peak value when the plucked position was changed. This suggests that the difference in the performance of each subject appeared in the muscle activity largely due to the difference in the plucked position. The subjects in this experiment tended to differ in the genres that they perform daily. Therefore, it is assumed that the performance movement differs depending on the daily habituation and the muscle activity is largely dispersed when the plucked position is controlled.

Although it was difficult to observe the feature of FDS throughout the trial, The lower part of Figure 5 shows that there is a peak timing at or after the onset. Since FDS is an antagonistic muscle of EDC, few peaks were observed during down-picking, and no co-contraction has occurred. This suggests that FDS muscle activity is weak during down-picking regardless of the player's years of experience and genre. Moreover, it may be hypothesized that FDS may contribute to fixation of the wrist after down-picking since some peaks are seen at or after the onset.

FDS of Subject 3 always has a high %MVC value, which is assumed to be the superposition of noise due to the misalignment of the EMG measurement electrodes during the experiment. Furthermore, electromyography often gives a restrained feeling to the subject as shown in Figure 2(b). For this reason, the experiment was conducted with a simple performance task in this research. However, an experimental method to eliminate these is important to measure the player's original behavior faithfully.

Besides, it is necessary to simultaneously obtain not only EMG but also to obtain joint displacements and angles using motion capture for detailed kinematics analysis. Simultaneous measurement of physical parameters given to strings by a player would also contribute to the elucidation of interaction. In this study, I targeted people with different player contexts and clarified the tendency of muscle activity at plucking in limited conditions. However, it will be necessary to investigate people with similar player contexts to clarify Human-Instrument Interaction.

5 CONCLUSION

In this paper, the Human-Instrument Interaction model including player context, performance motion, physical parameters given to the instrument, feedback given from the instrument to the player and its outline were presented to reveal a complex interaction between instrument and player. As a basic study, I measured the muscle activity using EMG when controlling the plucked position and plucking dynamics for the guitar. As a result, muscle activity due to the difference in the plucked position was largely different among subjects, and no specific tendency was found. Besides, muscle activity due to the difference in plucking dynamics indicated a certain common tendency among subjects such that the muscle activity increased/decreased with the increase/decrease of plucking dynamics and the peak timing also increased/decreased. Furthermore, it was suggested that the balance between the active muscle parts was different depending on different player contexts.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the R&D department at Yamaha Corporation for cooperation with the experiment.

REFERENCES

[1] Fritz, C.; Curtin, J.; Poitevineau, J.; Morrel-Samuels, P.; Tao, Fan-Chia. Player preferences among new and old violins. *Proceedings of the National Academy of Sciences*, Vol 109, 2012, pp. 760–763.

[2] Bassinger, G. Structural acoustics of good and bad violins. *The Journal of the Acoustical Society of America*, Vol 124 (3), 2008, pp. 1764–1773.

[3] Campbell, D. Murray. Evaluating musical instruments. *Physics Today*, Vol 67, 2014, pp. 35–40.

[4] Berdahl, E.; Smith, J.O.; Niemeyer, G. Feedback control of acoustic musical instruments: Collocated control using physical analogs. *The Journal of the Acoustical Society of America*, Vol 131, 2012, pp. 963–973.

[5] Papetti, S.; Saitis, C. Musical Haptics. Springer, Berlin (Germany), 1st edition, 2018.

[6] Baader, P.A.; Kazennikov, O.; Wiesendanger, M. Coordination of bowing and fingering in violin playing. *Cognitive Brain Research*, Vol 23 (2), 2005, pp. 436–443.

[7] Ranelli, S.; Smith. A.; Straker. L. Playing-related musculoskeletal problems in child instrumentalists: The influence of gender, age and instrument exposure. *International Journal of Music Education*, Vol 29 (1), 2011, pp. 28–44.

[8] Iltis, P.W.; Givens, M.W. EMG characterization of embouchure muscle activity: reliability and application to embouchure dystonia. *Medical Problems of Performing Artists*, Vol 20, 2005, pp. 25–35.

[9] Hirano, T.; Kudo, K.; Ohtsuki, T.; Kinoshita T. Orofacial muscular activity and related skin movement during the preparatory and sustained phases of tone production on the French horn. *Motor Control*, Vol 17, 2013, pp. 256–272.

[10] Merletti, R.; Di Torino, P. Standards for reporting EMG data. *Journal of Electromyography and Kinesiology*, Vol 9 (1), 1999, pp. 3–4.

[11] Fjellman-Wiklund, A.; Grip, H.; Karlsson, J.S.; Sundelin, G. EMG trapezius muscle activity pattern in string players: Part Iis there variability in the playing technique?. *International Journal of Industrial Ergonomics*, Vol 33 (4), 2004, pp. 347–356.

[12] Gotouda, A.; Yamaguchi, T.; Okada, K.; Matsuki, T.; Gotouda, S.; Inoue, N. Influence of playing wind instruments on activity of masticatory muscles. *Journal of Oral Rehabilitation*, Vol 34, 2007, pp. 645–651.

[13] Hodges, P.W.; Richardson, C.A. Relationship between limb movement speed and associated contraction of the trunk muscles. *Ergonomics*, Vol 40 (11), 1994, pp. 1220–1230.