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Scapular Kinematics in the Right Shoulders of Violin Players

Abstract

Shoulder health is vital to the ability of violinists to play their instruments, but poor posture is considered a major risk of injury to violin players. For those who perform professionally, shoulder injuries endanger their careers. Therefore, finding shoulder postures that promote shoulder endurance and health are important. To this aim, the purpose of this study is to examine the scapular kinematics involved in playing on different strings of the violin. Five college-aged experienced violin players (male=1, female=4) with no recent history of shoulder surgery or severe shoulder pain volunteered to participate in this study. Kinematic sensors were placed on the sternum, humerus, and scapular spine. Participants played through three musical passages with varying string position requirements, during which data was collected on scapular kinematics. One musical passage required playing on the low-pitched strings, which involved an elevated right arm; another required playing on the high-pitched strings, which involves a lowered right arm; the third passage combined low- and high-pitched notes. Scapular upward rotation and anterior tilt were statistically significantly different between the low-pitch passage and high-pitch passage ($p<0.02$ for both). There was no significant difference between low- and high-pitch passages and the corresponding low and high sections of the third passage ($p>0.05$ for all). When playing on the lower-pitch strings, the scapula is more upwardly rotated but less anteriorly tilted than when playing on the higher-pitch strings. However, the speed of transition between string positions does not affect scapular kinematics.

1. Introduction

The health of the shoulder, the most unstable joint in the human body, is critical to violin players' ability to practice their skills and to perform for audiences (Islan et al., 2018). Among musicians, violinists are particularly prone to right arm musculoskeletal injury due to frequent repetitive motion (Islan et al., 2018; Reynolds et al., 2014). For violinists pursuing a career in performance, such injuries threaten their livelihood (Kok et al., 2018). Ackermann and Adams surveyed 26 professional string players and 10 health experts about the risk factors involved in violin and viola playing (2004). The musicians ranked poor posture as the third greatest risk factor to professional violinists, while the health experts rated it as the number one risk factor (Ackermann & Adams, 2004). Therefore, it is important that violinists seek the most ergonomically beneficial playing postures. When playing violin, the violinist must raise the right arm to draw the bow across the lower-pitched strings (D and G). Young classical violinists who learn an American or European style of playing are often taught to minimize scapular motion, so that the movements required for bowing are initiated by the wrist and elbow (Eddy, 1990). However, it is not clear whether minimal scapular movement is more effective for preventing right shoulder injury in violinists than unrestricted scapular movement while playing.

Very few studies have reported on the movement of and risk of injury to the right arm and shoulder of violin players (Ackermann & Adams, 2004; Islan et al., 2018; Kok et al., 2018; Yagisan et al., 2009). One study examined muscle activity in the right arm but did not consider scapular kinematics (Duprey et al., 2017). Only one study has examined the movements of violinists' right scapulae during violin playing, and none have yet determined whether minimal scapular motion is ergonomically optimal (Reynolds et al., 2014). Reynolds et al. found that increased speed of violin playing correlated with less scapular anterior tilt and less scapular upward rotation than slower playing (2014). However, they did not examine the effects of string position. Furthermore, the purpose of the study was to test the validity and reliability of exposure variation analysis in assessing shoulder kinematics, rather than to analyze healthy playing posture (Reynolds et al., 2014). The purpose of this study is to determine the effects of string position of the violin bow on the kinematics of the right scapula in experienced violin players. It was hypothesized that playing on the lower-pitched strings would significantly increase upward rotation and anterior tilt scapular motion compared to playing on the high-pitched strings.

2. Methods

2.1. Participants

To be eligible for this study, participants had to be at least eighteen years of age, and to have played the violin for at least five consecutive years. Violinists with right shoulder surgery or severe right shoulder injury within twelve months prior to recruitment, or right shoulder pain within two months prior to recruitment, were exempt from this study. Recruitment was conducted in Bellingham, Washington through email and word-of-mouth, and through announcements at orchestra rehearsals.

For this study, 16 violin players were recruited from the Symphony Orchestra and String Sinfonia at Western Washington University (WWU). Each of these individuals were students enrolled in the music department at WWU. Of the 16 violinists recruited, 11 did not participate due to scheduling conflicts and the social distancing restrictions imposed during the COVID-19 pandemic. Therefore, 5 participants (1 male, 4 females) were included in this study. **Table 1** shows participant demographics. During data collection, each participant used his or her personal violin and bow, in order to more closely replicate each violinist's typical playing experience. This study was approved by the Institutional Review Board, and each participant signed an informed consent form prior to data collection. Participants were also asked to fill out a video and photo release form. The rights of the participants were protected throughout the study.

	Mean	SD
Weight (kg)	61.5	12.3
Seated Height (cm)	90.3	4.0
Age	19	1
Years of Playing	11	3

Table 1. Participant weight, seated height, age, and years of violin playing experience, showing mean and standard deviation (SD).

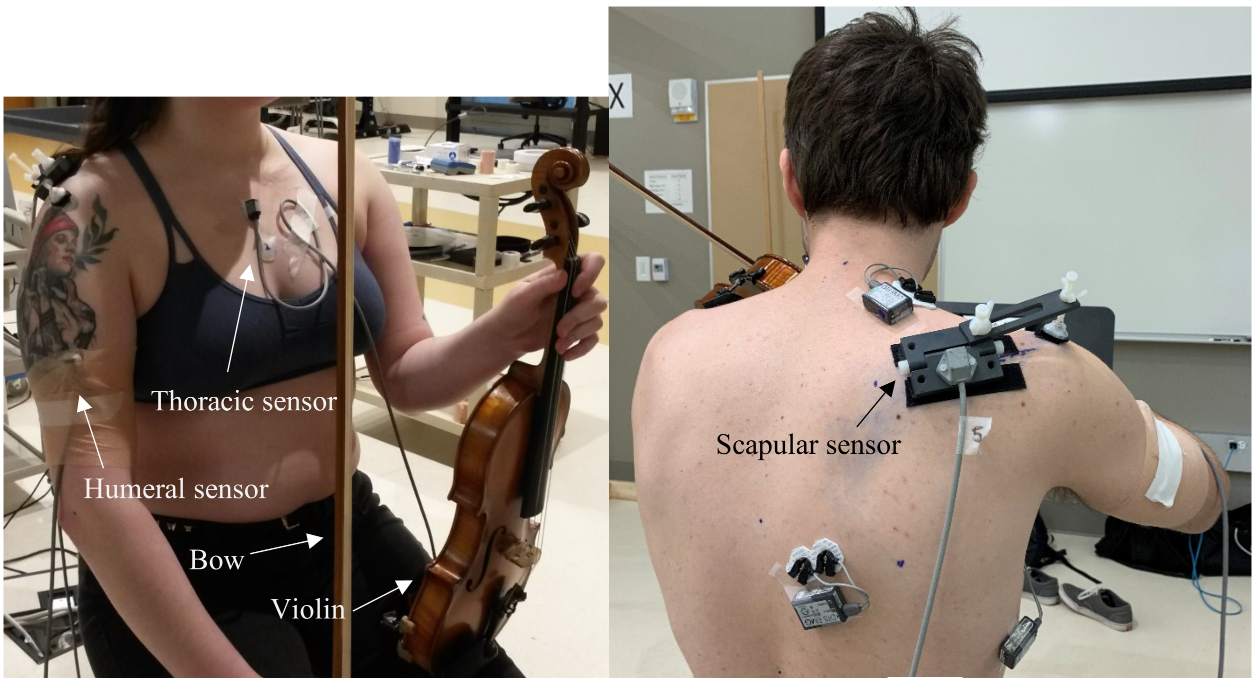
2.2. Written Screening

Upon coming to the lab for data collection, participants were asked to fill out a written screening asking whether participants had experienced right shoulder pain in the two months prior to data collection or serious right shoulder injury in the previous twelve months. Participants who answered "Yes" to either of these questions were excluded from the study.

2.3. Scapular Kinematics

Scapulothoracic and thoracohumeral kinematic data were collected using the Polhemus Liberty™ three-dimensional magnetic tracking device (San Juan et al., 2016). Sensors were placed on the sternum, the humerus at the deltoid tuberosity using a cuff made from gauze wrap and Transpore™ surgical tape, and the scapular spine using a plastic jig (San Juan et al., 2016). A fourth sensor was modified to create a digitizing stylus for orienting the Polhemus system to the thoracic, humeral, and scapular 3-dimensional coordinates of the participant (San Juan et al., 2016). The digitized landmarks were C7, T8, T12, the right medial and lateral epicondyles of the humerus, the xiphoid process of the sternum, the jugular notch of the sternum, the root of the right scapular spine, and the right scapular acromial angle and inferior angle.

The data were collected at the rate of 240 frames per second. Each collection period lasted approximately 45 seconds and included the placing of the violin on the left shoulder and the lifting of the bow prior to playing, the playing of one musical passage, and the setting down of the violin and bow upon the knee after playing.



a **b**

Fig. 1. Placement of the (**a**) thoracic sensor, humeral sensor (with humeral cuff) and (**b**) the scapular sensor. The electromyography electrodes visible in (**b**) were not used in this study.

2.4. Musical Passages

Two weeks prior to data collection, participants were provided with three musical passages, each written to last 30 seconds. The first passage requires the violinist to play only on the G string (Condition A) (**Figure 2**). The second passage is only on the E string (Condition B) (**Figure 3**). Left-hand fingerings between the first and second passages were identical. The third passage combined both low- and high-pitched notes, involving a bowing pattern called string crossing (Condition C) (**Figure 4**). The purpose of this third passage is to more closely replicate scapular movement during the performance of a typical piece of violin repertoire, in which changes between low notes and high notes may be frequent. All three passages were arranged by the primary investigator (PI) from a collection of études (technical studies) by Jacques-Féréol Mazas (Mazas, 1986). In preparation of data collection, participants were asked to practice these passages sufficiently to be able to play them at the speed of 60 beats per minute (bpm) without technical mistakes.

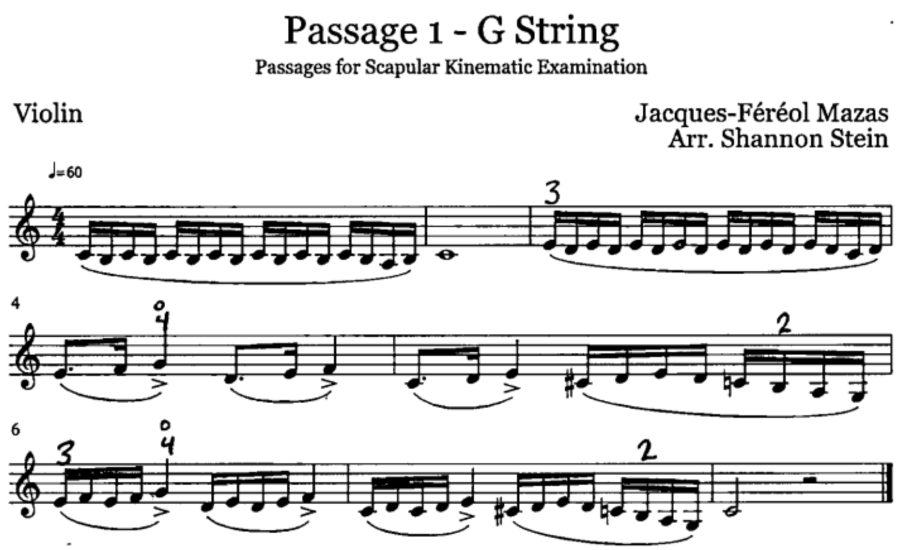


Fig. 2. Musical Passage 1, which requires the violinist to play only on the G string (low pitch).

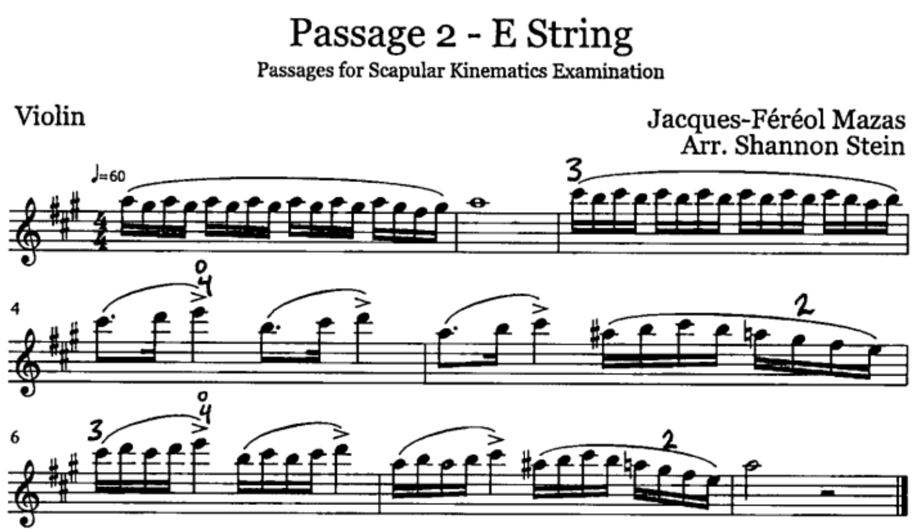


Fig. 3. Musical Passage 2, which requires the violinist to play only on the E string (high pitch).

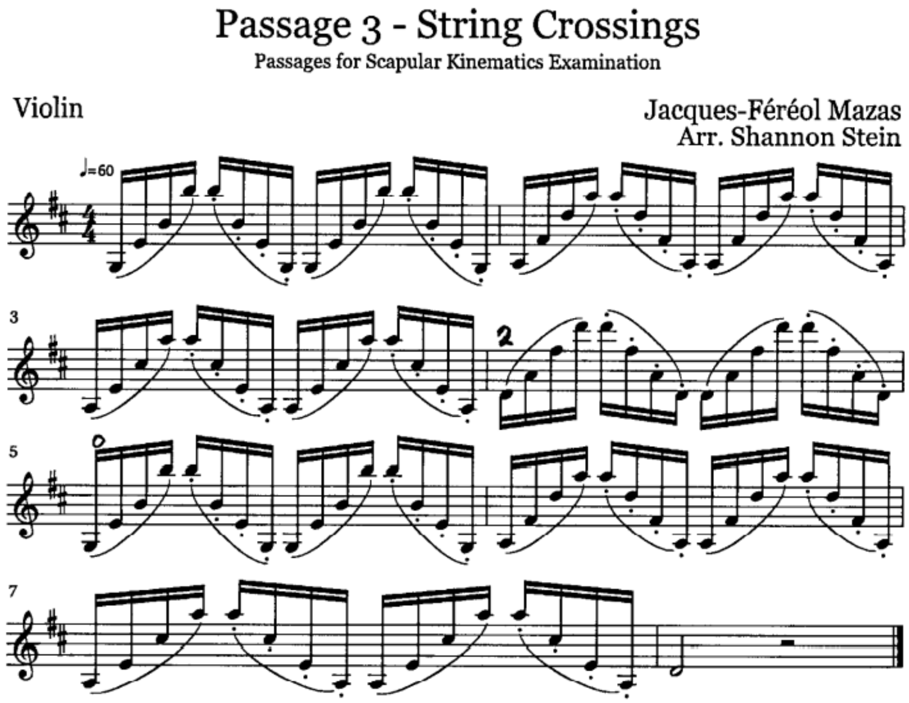


Fig. 4. Musical Passage 3, which involves crossing the strings from low-pitched to high-pitched notes.

2.5. Experimental Procedure

Data collection for each participant was completed within one day. After signing the informed consent form, the photo and video release form, and the written screening, participant weight and seated height were obtained. Age, sex, and years of playing the violin were then recorded (**Table 1**). Participants were then given 5 minutes to warm up on the violin. The warm-up routine included C, A, and D Major scales and c, a, and d melodic minor scales (two different scale patterns), as well as each scale's associated two-octave arpeggio. In musical terms, a scale is a collection of notes organized into a pattern of low-pitch to high-pitch or vice versa (Lloyd, 1968). An arpeggio is a series of notes in a chord played in sequence, rather than simultaneously (Lloyd, 1968).

Following the warm-up routine, participants played through each musical passage in the hearing of the PI, to check for technical mistakes that could cause outlying data points. During this play-through, a metronome was placed in front of participants, set at 60 bpm. Participants were instructed to listen to 4 beats from the metronome, before beginning the passage on the fifth beat.

Once the participant had played through the musical passages satisfactorily, kinematic sensors were placed on the sternum, upper arm at the deltoid tuberosity, and scapular spine. With the participant seated, the Polhemus Liberty™ system was oriented to the participant's position in space. Participants were then provided with the order in which to play the musical passages, which was randomized. During data collection, participants were instructed to play each musical passage with 1-minute rests after the first and second passage. As in the prior play-through, the metronome was turned on to 60 bpm, and participants waited until the fifth beat to begin playing.

Participants were instructed to take the violin off their shoulders during the 1-minute rests. Also during the 1-minute rests, the data collection period was terminated and a new collection period was prepared for the next musical passage.

2.6. Statistical Analysis

Two-tailed paired sample t-tests were conducted to determine differences in humerothoracic elevation (measured in degrees), upward and downward scapular rotation angles (measured in degrees), and anterior and posterior scapular tilt angles (measured in degrees) between conditions A (Passage 1, low pitch), B (Passage 2, high pitch), and C (Passage 3, string crossing) (Reynolds et al., 2014). A p value less than 0.05 was considered significant. The data for condition C, which included both low-pitch and high-pitch bowing patterns, were separated into C1, low-pitch data, and C2, high-pitch data.

3. Results

Mean values for humerothoracic elevation and scapular kinematic data are shown in **Table 2**. Upward rotation and anterior tilt are indicated by negative values. Downward rotation and posterior tilt are indicated by positive values. Between conditions A and B, significant difference was found in the downward rotation (p=0.012), anterior tilt (p=0.0090), and humerothoracic elevation angles (p=0.000064 for min angle, p=0.00024 for max angle, and p=0.0011 for angle range). **Figure 5** provides a comparison of humerothoracic elevation angles across conditions. Both minimum and maximum humerothoracic elevation angles were greater in condition A (61º and 81º, respectively) than the corresponding values in condition B (14º and 48º respectively). However, there was a greater range of elevation angles in condition B than in condition A (by 14º). Condition B yielded a greater degree of downward scapular rotation (16º), as well as greater anterior tilt (-15º).

Between conditions A and C1, significant difference was found in the humerothoracic elevation angles between conditions A and C1 (p=0.00040 for min angle, p=0.00047 for max angle, and p=0.0063 for angle range). However, there were no significant differences in scapular kinematics (p>0.05 for both downward rotation and anterior tilt). Condition A yielded greater minimum and maximum humerothoracic elevation angles than in condition C1, although, as in the comparison between conditions A and B, C1 yielded a greater elevation range (by 9º). No significant difference was found in either the scapular kinematics or the humerothoracic elevation angles between conditions B and C2 (p>0.05 for each variable).

Variable	Condition A		Condition B		Condition C1 (Low Pitch)		Condition C2 (High Pitch)		*P*-value (A-B)	*P*-value (A-C1)	*P*-value (B-C2)
	Mean (*n*=5)	SD	Mean (*n*=5)	SD	Mean (*n*=5)	SD	Mean (*n*=5)	SD			
Min HT Elev (°)	61	3.1	14	6.5	43	6.3	21	16	0.000064	0.00040	0.25
Max HT Elev (°)	81	4.2	48	8.9	71	2.4	48	14	0.00024	0.00047	0.93
HT Elev Range (°)	19	5.8	33	6.5	28	6.5	27	3.6	0.0011	0.0063	0.06
Up/Down Rot (°)	9.1	10	16	6.9	11	8.4	14	5.0	0.012	0.23	0.37
Ant/Post Tilt (°)	-7.9	3.4	-15	1.7	-5.7	10	-8.9	11	0.0090	0.63	0.27

Table 2. Minimum humerothoracic (HT) elevation, maximum HT elevation, HT elevation range, upward and downward scapular rotation (degrees), and anterior and posterior scapular tilt (degrees) across conditions A (low pitch), B (high pitch), and C (string crossing). Data are presented in mean and standard deviation (SD). Also shown are the *p*-values for comparison between conditions A and B, A and C1 (low-pitch sections), and B and C2 (high-pitch sections).

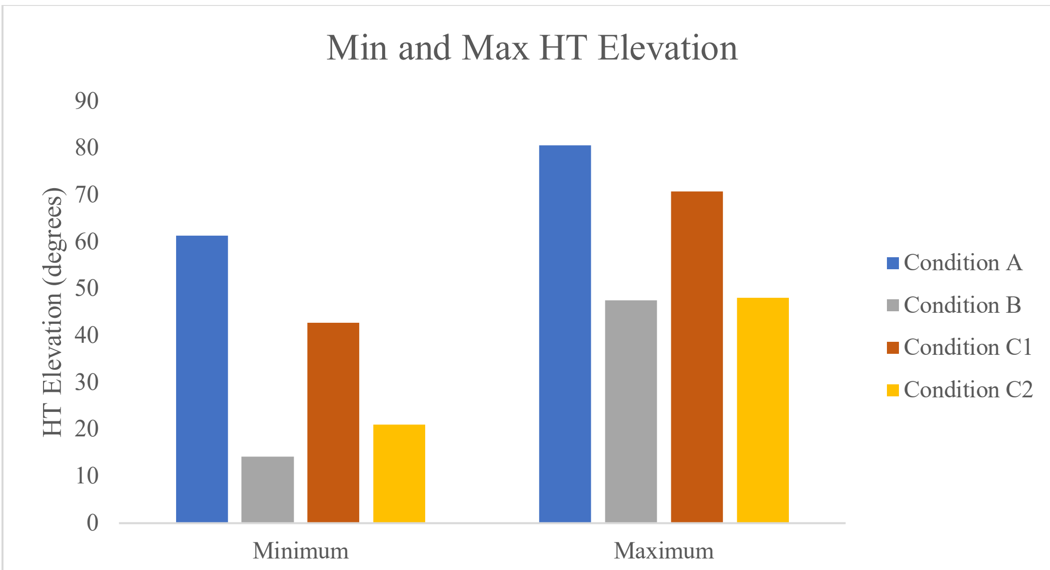


Fig. 5. Mean minimum and maximum humerothoracic (HT) elevations for each condition. Condition A is low-pitch, with a raised elbow. Condition B is high-pitch, with a lowered elbow. Condition C includes string crossings, which combine low- and high-pitch notes (signified by C1 and C2, respectively). HT elevation is measured in degrees.

4. Discussion

This study examined the movements of the scapula as it depended on different string placements of the bow during violin playing. The researchers hypothesized that when the violinist draws the bow across the lower-pitched strings, the scapula would undergo greater upward rotation and anterior tilt than when the violinist plays on the higher-pitched strings. The results reveal less downward rotation during low-pitch playing, which in turn indicates the scapula is more upwardly rotated than in high-pitch playing. However, it was found that playing on the lower strings yielded a lesser degree of anterior tilt. Thus, as the participants played on the higher-pitch strings, the scapula tilted further anteriorly. Experienced violinists typically spend many hours per week practicing their instrument (Ackermann & Adams, 2004; Islan et al., 2018;

Kok et al., 2018). It has been observed by the PI that many violin students have a tendency to play with rounded shoulders. It is possible these hours of practice in this position contribute to tight pectoralis muscles, which may explain the greater anterior tilt when the arm is lowered (Stull, 2014; Thielen, 2015). Tightness in the pectoralis muscles has been shown to affect healthy scapulohumeral movement, particularly during elevation of the arm (Ludewig & Reynolds, 2009; Turgut et al., 2017).

The lack of significant difference in scapular kinematics between conditions A and C1 and between conditions B and C2 indicate that speed of transition between low-pitch and high-pitch notes does not significantly affect scapular kinematics. In other words, going back and forth between string position yields the same respective scapular movement as simply playing for an extended period of time (i.e. 30 seconds) at each position.

Although no hypothesis was made regarding the effects of string position on humerothoracic elevation, the results show interesting differences in humerothoracic elevation, particularly between conditions A and B. The greater humerothoracic angles in condition A were expected, because violinists must raise the right arm in order to reach the low-pitch strings with the bow (Duprey et al., 2017). However, the difference in angle range was fascinating. It appears that when playing on the high-pitched strings (lowered arm), participants exhibited a greater humerothoracic range of motion. One explanation for this may be that, with the arm elevated for the low-pitch strings, the movement required for bowing originates from the forearm and elbow joint, instead of the upper arm and humerothoracic joint. To verify this, future studies should explore the differences in elbow joint range of motion between strings.

5. Conclusion

In college-aged experienced violin players with no recent history of severe shoulder pain or injury, playing the lower-pitched strings of the violin yielded more scapular upward rotation, less anterior tilt, and greater humerothoracic elevation than playing on the higher-pitched strings. However, no significant changes in scapular kinematics were found when speed of transition between string position was increased.

Limitations

There are a few limitations in this study which may have affected the results. The population size was very small (only 5 participants) due to suspension of data collection during a global pandemic. Also, the study examines only college-age violin players, and only one male participant was included. Therefore, the results of this study should not be applied to all experienced violin players. In addition, the researchers were relatively unfamiliar with the Polhemus Liberty™ system when beginning this research. Lack of experience with the research equipment may have contributed to inaccurate data points.

Conflict of Interest

The authors declare there is no conflict of interest that could affect the content of the study design, data collection, data analysis, or writing of this paper.

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