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Assessment of selected upper limb ranges of motion in violinists during instrument performance

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Original article

Abstract

Objective: Playing an instrument is a significant part of a violinist's life. Daily, they are exposed to specific, forced positions of the upper limbs while playing. Any injuries or overloading of the musculoskeletal system can adversely affect their ability to perform their profession or pursue their passion for playing the violin. The aim of this study was to determine the ranges of motion of selected upper limb joints in violinists during violin playing. A deeper understanding of the biomechanics of playing the instrument can contribute to the development of increasingly effective rehabilitation protocols, facilitate preventive measures, and support the maintenance of musicians' health and well-being.

Material and methods: Twenty-two violinists were recorded while performing a three-octave G-major scale. After selecting appropriate frames, an assessment of selected ranges of motion was conducted using the Angulus application.

Results: The ranges of motion achieved by violinists largely depend on their adopted playing technique. The greatest range of motion amplitude was observed in the sagittal plane in the shoulder joint and wrist joint of the bow-holding upper limb, as well as in the sagittal plane of the wrist joint of the violin-holding upper limb. The smallest ranges of motion were observed in the horizontal plane of the shoulder joint of the bow-holding upper limb and in the sagittal plane of the shoulder joint of the violin-holding upper limb.

Conclusions: Violinists work on average within the following ranges of motion: in the shoulder joint of the bow-holding upper limb: S: 0-15-87, F: 74-19-0, T: 0-47-63; in the elbow joint: S: 0-39-95; in the wrist joint: S: 34-0-35, F: 19-0-2. For the violin-holding upper limb, the ranges were: in the shoulder joint: S: 0-31-38, F: 22-6-0; in the elbow joint: S: 0-96-106; in the wrist joint: S: 17-0-25.

Keywords

- Angulus application
- goniometric measurements
- violinist occupational biomechanics
- ADL activities

Contribution

A – Preparation of the research project
B – Assembly of data
C – Conducting of statistical analysis
D – Interpretation of results
E – Manuscript preparation
F – Literature review
G – Revising the manuscript

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Introduction

Musicians continuously and often unconsciously use their hands and upper limbs, requiring them to perform highly specific actions. They assume positions and execute movements that enable them to play various instruments without considering the physiological aspects of muscular work or joint biomechanics. Understanding the movements involved in playing an instrument is impossible without at least a basic knowledge of anatomy, biomechanics, or physiology. Musicians, and especially their teachers, should be familiar with the fundamentals of the structure, biomechanics, and physical function of the hand and the entire upper limb.[1,2] However, this subject is poorly understood and often overlooked during education. It is crucial to comprehend proper movement mechanics to identify and correct improper movement patterns consciously.[2]

The first scientist to draw attention to the overuse and health issues of musicians was the Italian physician Bernardino Ramazzini, who in 1713 published a review of diseases observed in this professional group.[3] However, the medical and scientific communities only began to take an interest in musicians' health in the 1980s. Currently, both the level of knowledge on this subject and the functioning of specialized healthcare units are still developing, modeled after those found in sports medicine. For this reason, research on this topic has been undertaken.

Playing the violin is a significant aspect of the identity of those pursuing this profession, which often serves as their primary source of income.[4] It demands, on the one hand, maintaining an appropriate body and instrument position, and on the other, high precision in movement and optimal coordination of both upper limbs at a tempo dictated by the requirements of a given piece.[4-7] Violinists spend many hours daily in an asymmetric and non-ergonomic body position, performing repetitive, specific movements that may contribute to various musculoskeletal disorders.[8-10] These conditions can lead to the development of ailments and dysfunctions in the upper limbs, such as scapular dyskinesis, subacromial impingement, bursitis, tendonitis of the shoulder joint, compression syndromes of the median, ulnar, and radial nerves, sheath injuries of finger tendons, focal dystonia, and degenerative changes in the distal interphalangeal joints of the left upper limb.[8-12]

Any injuries or overuse of the upper limbs can hinder or even prevent violinists from performing at the highest level, and in extreme cases, may force them to cease their professional careers.[10,13] Therefore, it is crucial to deepen the understanding of upper limb biomechanics during violin playing.

One of the parameters facilitating motion analysis of activities such as playing the violin is the measurement of joint range of motion (ROM). To precisely assess ROM changes in joints during functional activities, researchers often use optometric systems. However, these systems are costly, time-consuming, and frequently inaccessible to an average therapist working in a clinical setting.[14] Recent technological advancements allow for the assessment of ROM using various smartphone applications, which enhance clinical usability while incurring minimal or no costs.[15] One such free tool available on the market is the Angulus application, which enables ROM measurements from photos or video frames. Its user-friendly interface allows users to measure ROM at any chosen point during movement. Scientific reports indicate that methods based on photo analysis are reliable for evaluating upper limb ROM, and the non-invasive nature of this measurement technique is an additional advantage, as it prevents alterations in movement patterns caused by direct contact with measuring devices (e.g., attached markers).[16,17]

The aim of this study was to evaluate the ROM in the shoulder complex, elbow, and wrist joints during violin playing.

Materials and methods

The presented study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. A total of 22 adult violinists aged 19–60 years (mean age: 27.91 ± 9.11 years) participated in the research. All participants had completed at least the first level of music school and were active violinists with playing experience ranging from 10 to over 30 years. They consented to participate in the study, as well as to have their image and musical performance recorded for research purposes.

The majority of participants (91%) were right-handed, while 9% were left-handed. Of the participants, 12 individuals (55%) were professional violinists. The remaining participants played as amateurs, occasionally, or were still students at music schools.

Regarding weekly time spent with the instrument, six participants (50%) reported playing professionally for 21–30 hours per week. Additionally, five participants (42%) spent an extra 5–10 hours per week playing the violin outside their professional work, such as during home practice or for leisure. A detailed description of the study group is presented in Table 1.

Table 1. Characteristics of the study group

Characteristics of the study group	Data
Age	19–24 years (n = 11)
	27–34 years (n = 9)
	45–60 years (n = 2)
Gender	Men (n = 6)
	Women (n = 16)
Music education	I or II level (n = 12)
	Higher music education (n = 10)
Years of playing the violin	10–15 years (n = 3)
	15–20 years (n = 9)
	20–30 years (n = 8)
	>30 years (n = 2)
Time spent on professional violin playing per week	5–10 h (n = 5)
	11–20 h (n = 4)
	21–30 h (n = 11)
	>30 h (n = 2)
Time spent on non-professional violin playing per week	<5 h (n = 7)
	5–10 h (n = 9)
	11–20 h (n = 4)
	21–30 h (n = 2)

The research was conducted in a quiet and peaceful room provided for this purpose by the orchestra conductor (in the case of studying members of the Krakow Philharmonic Orchestra and the Orchestra of the University of the Commission of National Education in Krakow) or in a room at the Kinesiotherapy Department of the University of Physical Education in Krakow (for violinists who scheduled individual appointments). Usually, two individuals were invited at a time. The first participant was given a personal questionnaire to complete, where they provided necessary information to later better characterize the study group. The second participant, at the same time, was recorded while performing a two-time scale exercise in the standing position, playing a 3-octave G-major scale back and forth at a tempo of approximately 60 beats per minute. A number associated with the personal questionnaire was placed on the floor near the person performing the piece, which was later handed to the participant to maintain the anonymous nature of the study while easily linking the completed questionnaire with the movement range measurements of the specific individual. After finishing the performance, the participants switched roles.

The violinist's performance was recorded using smartphones, simultaneously by three people from the following perspectives (Figure 1):

- from the front (camera 1) and back (camera 2), parallel to the frontal plane;
- from above, parallel to the horizontal plane (camera 3);
- from the side of the upper limb holding the bow, parallel to the sagittal plane (camera 4);
- two oblique angles, parallel to the working plane of the bow-holding limb (camera 5) and the working plane of the upper limb holding the violin (camera 6).

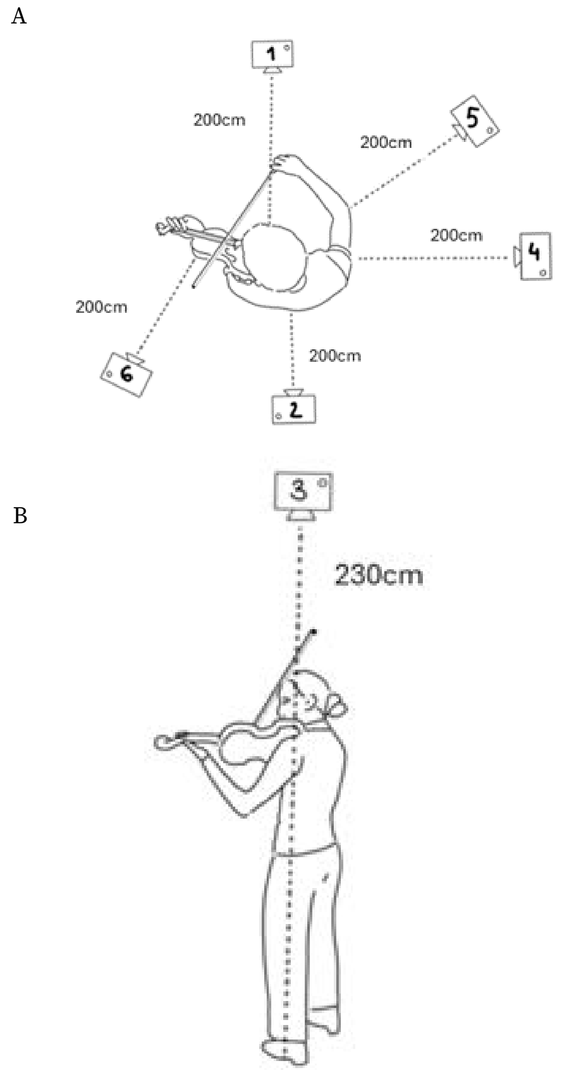


Figure 1. Placement of cameras. A – top view; B – side view

During the recording of the violinist in the horizontal plane (top view), the optical zoom-out option was used. This was due to the limited ability to capture the entire violinist in the frame. In the remaining recordings, this option was not used. The image was recorded at a frequency of 60 Hz, and the frames extracted from the footage for further analysis were saved at a resolution of 96 dpi. The recording was done handheld (simultaneously by three people), maintaining, as much as possible, a constant distance from the subject and a parallel alignment with the examined plane. The footage was recorded using a smartphone camera with the gyroscope enabled, and selected frames were later imported into the Angulus application to assess the obtained maximum angular ranges. The violinists, while moving during their performance, changed their position relative to the camera by no more than approximately 30 cm.

From the obtained recordings, individual frames were selected where the violinists reached the extreme ranges of motion in the analyzed joints (shoulder, elbow, and wrist joints). The selected images were then transferred to the Angulus application, which was used to assess the angular range of motion. Based on the obtained recordings, the following extreme ranges of motion for the bow-holding limb were determined:

a) in the sagittal, frontal, and transverse planes for the shoulder joint;
b) in the sagittal plane for the elbow joint;
c) in the sagittal and frontal planes for the wrist joints.

For the violin-holding limb, the following extreme ranges of motion were determined:

a) in the sagittal and frontal planes for the shoulder joint;
b) in the sagittal plane for the elbow joint;
c) in the sagittal plane for the wrist joints.

Results

Using Microsoft Excel, based on the collected data, the mean maximum ranges of motion obtained in each plane, as well as the minimum and maximum values, standard deviations, and the average total range of motion achieved in each plane, were calculated.

Ranges of motion achieved by the upper limb holding the bow

The obtained ranges of motion in the individual joints and planes are presented in Table 2 and Figure 2.

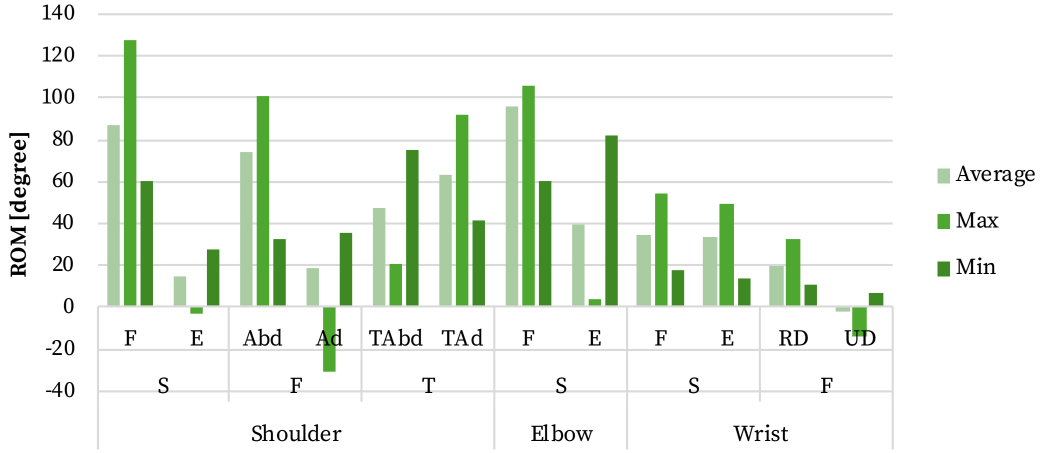
Ranges of motion achieved in the sagittal plane at the shoulder joint of the upper limb holding the bow

In the upper limb holding the bow (ULHB), at the shoulder joint in the sagittal plane, the average total range of motion (ROM) for flexion and extension was 72.45°. The participants achieved an average of 87.18° of flexion (±13.87°; max 127°, min 60°) and −14.73° of extension (±7.96°; max 3°, min −28°). Sixteen violinists (72%) achieved the maximum flexion range within the 80°–99° range. Only two violinists exceeded a flexion range of 100°, reaching 102° and 127° respectively. Seven participants achieved the maximum extension range from −16° to −20°, while 15 violinists (69%) reached flexion between 6° and 20°.

Table 2. Range of motion achieved in the upper limb holding the bow

Joint	Shoulder						Elbow		Wrist			
Plane	S		F		T		S		S		F	
Movement	F	E	Abd	Ad	TAbd	TAd	F	E	F	E	RD	UD
The number of participants	22	22	20	22	21	20	21	22	22	22	22	20
Average	87.18	−14.73	73.85	−18.86	−46.95	62.95	95.38	−39.41	34.77	33.64	19.32	1.95
Max	127	3	101	31	−21	92	106	−4	54	49	33	14
Min	60	−28	33	−36	−75	41	60	−82	18	14	11	−7
SD	13.87	7.96	16.13	14.18	14.86	12.76	10.27	16.39	9.57	11.73	5.80	6.34
ROM	72.45		54.99		16.00		55.97		68.41		21.27	

Where: F – flexion, E – extension, Abd – abduction, Ad – adduction, TAbd – transverse abduction, TAd – transverse adduction, RD – radial deviation, UD – ulnar deviation, S – sagittal plane, F – frontal plane, T – transverse plane, ROM – range of motion.



Where: F – flexion, E – extension, Abd – abduction, Ad – adduction, TAbd – transverse abduction, TAd – transverse adduction, RD – radial deviation, UD – ulnar deviation, S – sagittal plane, F – frontal plane, T – transverse plane, ROM – range of motion.

Figure 2. Minimal, maximal, and average ranges of motion in selected joints of the upper limb holding the bow

Ranges of motion achieved in the frontal plane at the shoulder joint of the upper limb holding the bow

In the ULHB, at the shoulder joint in the frontal plane, the average ROM for abduction and adduction was 54.99°. For two participants, abduction could not be determined from the recordings. The remaining participants achieved an average of 73.85° of abduction (±16.13°; max 101°, min 33°). All violinists were able to determine the adduction range, which was on average −18.86° (±14.18°; max 31°, min −36°). Sixteen violinists (80%) achieved the maximum abduction range within the 60°–89° range. Only two violinists achieved less than 60° of abduction, both falling within the 30°–39° range. Seventeen violinists (77%) achieved the maximum adduction range from −30° to −11°.

Ranges of motion achieved in the transverse plane at the shoulder joint of the upper limb holding the bow

In the ULHB, in the transverse plane, the average ROM for horizontal abduction and adduction was 16.00°. For one participant, the maximum horizontal abduction could not be determined. The remaining violinists achieved an average of −46.95° of horizontal abduction (±14.86°; max −21°, min −75°). For two participants, the maximum horizontal adduction could not be determined, while the remaining participants achieved an average of 62.95° (±12.76°; max 92°, min 41°). Twelve violinists (58%) achieved the maximum horizontal abduction between −50° and −31°, while 15 violinists (75%) achieved the maximum horizontal adduction within the 40°–69° range.

Ranges of motion achieved in the sagittal plane at the elbow joint of the upper limb holding the bow

In the ULHB, at the elbow joint in the sagittal plane, the average ROM for flexion and extension was 55.97°. The maximum flexion values could be determined for 21 participants, and the maximum extension range could be determined for all 22 participants. The participants achieved an average of 95.38° of flexion (±10.27°; max 106°, min 60°) and −39.41° of extension (±16.39°; max −4°, min −82°). Seventeen violinists (81%) achieved the maximum flexion range between 90° and 109°. Twelve violinists (54%) achieved the maximum extension range in this joint within the range of −40° to −21°.

Ranges of motion achieved in the sagittal plane at the wrist joint of the upper limb holding the bow

In the ULHB, at the wrist joint in the sagittal plane, the average ROM for flexion and extension was 68.41°. The participants achieved an average of 34.77° of flexion (±9.57°; max 54°, min 18°) and 33.64° of extension

(±11.73°; max 49°, min 14°). Nineteen violinists (87%) achieved the maximum flexion range at the wrist joint between 20° and 49°, while 15 violinists (68%) achieved the maximum extension range between 30° and 49°.

Ranges of motion achieved in the frontal plane at the wrist joint of the upper limb holding the bow

In the ULHB, at the wrist joint in the frontal plane, the average ROM for abduction and adduction was 21.27°. The maximum abduction could be determined for all participants, while maximum adduction could be determined for 20 participants. The participants achieved an average of 19.32° of abduction (±5.80°; max 33°, min 11°) and 1.95° of adduction (±6.34°; max 14°, min −7°). Eighteen violinists (81%) achieved the maximum abduction range between 10° and 24°. Seven violinists (35%) achieved the maximum adduction range between −10° and 0°, while 11 violinists (55%) achieved it between 0° and 9°.

Ranges of motion achieved by the upper limb holding a violin

The ranges of motion achieved in various joints and planes are presented in Table 3 and Figure 3.

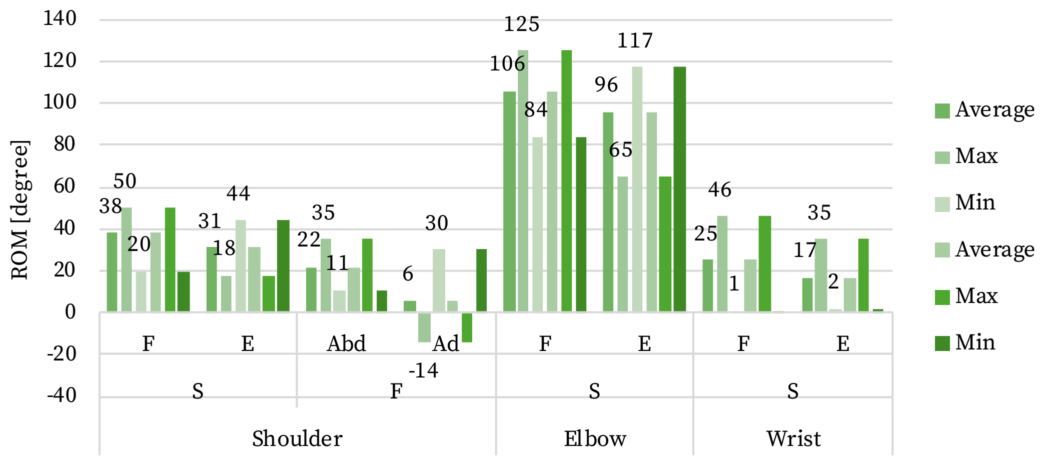
Ranges of motion achieved in the sagittal plane in the shoulder joint of the upper limb holding a violin

In the upper limb holding the violin (ULHV), the average ROM for flexion and extension in the sagittal plane of the shoulder joint was recorded at 6.73°. Participants

Table 3. Ranges of motion achieved in the upper limb holding a violin

Joint	Shoulder				Elbow		Wrist	
Plane	S		F		S		S	
Movement	F	E	Abd	Ad	F	E	F	E
The number of participants	22	22	22	22	22	22	22	22
Average	37.64	−30.91	21.64	−6.14	106.09	−95.59	24.77	16.64
Max	50	−18	35	14	125	−65	46	35
Min	20	−44	11	−30	84	−117	1	2
SD	6.40	6.81	6.49	12.10	9.91	10.83	11.89	7.41
ROM	6.73		15.50		10.50		41.41	

Where: F – flexion, E – extension, Abd – abduction, Ad – adduction, S – sagittal plane, F – frontal plane, ROM – range of motion.



Where: F – flexion, E – extension, Abd – abduction, Ad – adduction, S – sagittal plane, F – frontal plane, ROM – range of motion.

Figure 3. Minimal, maximal, and average ranges of motion in selected joints of the upper limb holding the violin

achieved an average of 37.64° of flexion (±6.40°; max 50°, min 20°) and −30.91° of extension (±6.81°; max −18°, min −44°). Seventeen violinists (77%) achieved a maximum range of motion for flexion between 35° and 45°. Eighteen violinists (83%) achieved their maximum range of extension between −40° and −21°, with 9 violinists falling within the range of −35° to −31°.

Ranges of motion achieved in the frontal plane in the shoulder joint of the upper limb holding a violin

In the ULHV, the average ROM for abduction and adduction in the frontal plane of the shoulder joint was recorded at 15.50°. Participants achieved an average of 21.64° of abduction (±6.49°; max 35°, min 11°) and −6.14° of adduction (±12.10°; max 14°, min −30°). Twenty violinists (90%) achieved maximum abduction within the range of 10° to 29°, with 8 of them (40%) falling within the range of 20° to 24°. Seventeen violinists (78%) achieved maximum adduction within the range of −20° to 9°.

Ranges of motion achieved in the sagittal plane in the elbow joint of the upper limb holding a violin

In the ULHV, the average ROM for flexion and extension in the sagittal plane of the elbow joint was recorded at 10.50°. Participants achieved an average of 106.09° of flexion (±9.91°; max 125°, min 84°) and −95.59° of extension (±10.83°; max −65°, min −117°). Thirteen violinists (59%) achieved a maximum flexion range between 100° and 119°, while fifteen (68%) achieved a maximum extension range between −100° and −81°.

Ranges of motion achieved in the sagittal plane in the wrist joint of the upper limb holding a violin

In the ULHV, the average ROM for flexion and extension in the sagittal plane of the wrist joint was recorded at 41.41°. Participants achieved an average of 24.77° of flexion (±11.89°; max 46°, min 1°) and 16.64° of extension (±7.41°; max 35°, min 2°). Seventeen violinists (77%) achieved maximum flexion within the range of 11° to 40°, while thirteen participants (59%) achieved maximum extension in the range of 11° to 20°.

Discussion

The thematic literature offers numerous reports on the ranges of motion required for performing everyday activities.[18-20] Examples include analyses of walking, dressing, combing hair, driving, vacuuming, and other daily tasks. Such studies help identify the physical demands of these activities, enabling more targeted rehabilitation for patients returning to normal functioning. Unfortunately, there is a scarcity of research focusing on the large and often overlooked professional group of musicians, who frequently suffer from various overuse disorders associated with their playing (PRMD – Playing-Related Musculoskeletal Disorders).

The aim of this study was to determine the ranges of motion in the upper limb joints of violinists utilized during playing. The obtained results can aid in the personalization of therapy programs for this group of patients, taking into account the ranges required for a full return to professional activity. Understanding the complete ranges of motion in which specific joints operate also allows therapy to be directed more effectively. This includes strengthening targeted muscles through appropriate functional positions and optimized muscular engagement.

For instance, the ranges of motion achieved in the left upper limb holding the violin are significantly smaller compared to those in the right upper limb holding the bow. This difference emphasizes the need for tailored rehabilitation approaches for each limb, addressing their unique functional demands and movement patterns.

Analyzing the playing technique, we observe that the violin is positioned almost horizontally, supported primarily on the (most commonly) left clavicle and lightly pressed down with the chin. The role of the left upper limb holding the violin is to maintain freedom of movement, smoothly adjust the position of the hand pressing strings II–V against the fingerboard while supporting the violin with the first finger. This involves predominantly dynamic work by the hand and forearm muscles, and static-dynamic work (depending on the pieces and playing techniques) by the arm muscles.[1] These observations align with the results of this study.

The findings clearly demonstrate the limited ranges of motion in the shoulder joint, averaging 7° in the sagittal plane and 16° in the frontal plane. The elbow joint exhibits an average of 11° in the sagittal plane, while the wrist joint shows a much broader range of 41° in the sagittal plane. A closer analysis of the working positions of these joints reveals that the required ranges of motion are:

- Shoulder: Flexion between 31° and 38°, abduction between 6° and 22°.
- Elbow: Flexion between 96° and 106°.
- Wrist: Extension around 17°, flexion around 25°.

The work of the right upper limb, which holds and maneuvers the bow, involves dynamic movement of the wrist, elbow, and shoulder muscles due to the high mobility of the joints within a closed kinematic chain. The required abduction of the shoulder should remain relatively small. In contrast to the left limb, the right upper limb exhibits significantly greater ranges of motion:

- Shoulder: 72° in the sagittal plane, 55° in the frontal plane, and 16° in the transverse plane.
- Elbow: An average range of 56°.
- Wrist: 68° in the sagittal plane and 21° in the frontal plane.

A detailed analysis shows that the ranges of motion include:

- Shoulder: Flexion between 15° and 87°, abduction between 19° and 74°, horizontal adduction between 47° and 63°.
- Elbow: Flexion between 39° and 95°.
- Wrist: Extension between 34° and 35°, flexion between 2° ulnar deviation and 19° radial deviation.

These results highlight the distinct demands placed on the left and right upper limbs during violin performance, suggesting the need for tailored therapeutic interventions to address their specific roles and functional requirements.

It is also important to note the obtained maximum and minimum values, which highlight that despite all violinists performing the same piece (a G-major scale spanning three octaves), there were inter-individual differences in playing techniques. This variability should be considered during therapy by individualizing rehabilitation programs and addressing the specific requirements necessary for returning to playing the instrument.

On the other hand, the diversity of violin-playing techniques provides an opportunity to explore compensatory mechanisms for violinists for whom a return to their previous playing method may not be entirely possible. It also offers a chance to identify a more optimal playing technique.

The findings of Konczak et al.[5] suggest that with increasing experience, violinists tend to minimize the movement of the shoulder joint of the bowing arm in the sagittal plane, a strategy deemed beneficial for optimizing the movement pattern. However, due to the small sample size in this study, it is difficult to confirm these tendencies, and further research is needed to validate these observations.

Ancillao et al.[21] in their studies indicate that violinists achieve the greatest ranges of motion in the elbow joint, followed by the wrist joints, and the smallest in the shoulder joint of the upper limb holding the bow. In the present study, for the limb holding the violin, the largest ranges of motion were recorded in the wrist joints in the sagittal plane, followed by the shoulder joint in the frontal plane, the elbow joint, and the smallest in the shoulder joint in the sagittal plane.

For the limb holding the bow, the order from the largest to smallest range was: the shoulder joint in the sagittal plane, wrist joints in the sagittal plane, the elbow joint, the shoulder joint in the frontal plane, wrist joints in the frontal plane, and the shoulder joint in the transverse plane.

The differences between the results presented may stem from differing study methodologies, including variations in the methods of assessing range of motion or the use of different musical pieces. In this study, a G-major scale spanning three octaves was played detache with the full bow, which requires utilizing the full range of motion. Additionally, the scale begins on the lowest string and ends on the highest string, engaging all hand positions relative to the strings.

In future research, it would be beneficial to include various musical pieces with differing levels of difficulty and tempo to further understand the impact of these factors on the ranges of motion required during violin performance.

It is important to remember that the body's movement during violin playing is heavily influenced by musical intentions. Glowinski et al.[22] report that less expressive playing results in restrained upper limb movements and increased amplitude of sacral bone movement. Conversely, when violinists aim for greater expressiveness, the range of motion in the upper body increases, while the sacrum acts as an anchor, showing minimal movement.

During the present study, it was similarly observed that some violinists displayed greater expressiveness, while others were more reserved, despite performing a musical excerpt that is generally perceived as neutral and not intended to evoke extreme emotions.

It is also crucial to consider that violinists, aside from playing the instrument, perform other daily activities. Magermans et al.,[18] Oosterwijk et al.,[20] and Pieniążek et al.[19] emphasize the importance of achieving a sufficiently large range of elbow flexion, as it is essential for basic tasks such as eating. Following this, proper wrist joint mobility is significant, with shoulder joint mobility being less critical in daily activities.

In the present study, the average elbow flexion was 95° in the bow-holding limb and 106° in the violin-holding limb, which corresponds to 63% and 71%, respectively, of the maximum possible range of motion for this movement.

The position of the wrist significantly affects finger movements, as the tendons of the external finger extensors and flexors are not sufficiently long to allow full finger flexion or extension without proper wrist coordination. Wrist extension enables full finger flexion, while wrist flexion allows for complete finger extension. Thus, changes in wrist position influence the functional length of the finger flexor tendons and the force they can generate during movement.

The maximum finger flexion force occurs with wrist extension combined with slight ulnar deviation, while the lowest force is observed with wrist flexion and radial deviation. In this study, the average wrist flexion range was 35° in the bow-holding limb and 25° in the violin-holding limb, with corresponding extension ranges of 34° and 17°. Radial and ulnar deviation ranges were 19° and 2°, respectively, in the bow-holding limb. For the violin-holding limb, it was not possible to evaluate the ranges of motion in the frontal plane.

A more detailed assessment of these motions, combined with the analysis of movements occurring in the fingers, requires further research.

Conclusions

1. In the studied group, violinists achieved the following average ranges of motion in the upper limb holding the bow:
   - Shoulder joint S: 0-15-87, F: 74-19-0, T: 0-47-63
   - Elbow joint S: 0-39-95
   - Wrist joint S: 34-0-35, F: 19-0-2
2. In the studied group, violinists achieved the following average ranges of motion in the upper limb holding the violin:
   - Shoulder joint S: 0-31-38, F: 22-6-0
   - Elbow joint S: 0-96-106
   - Wrist joint S: 17-0-25
3. Further studies on the kinematics of violin playing are needed to better understand the biomechanics of the body during this activity and to develop more effective rehabilitation protocols.

Limitations of the study

The conducted research has some limitations. Firstly, it was not possible to assess all the planned ranges of motion. Despite the advantages of the Anglus application, during the functional activity of playing the violin, it was not possible to measure rotational movements in the shoulder joint with its assistance. Some movements could not be assessed because the instrument obstructed the joints being measured in certain angles, particularly in the case of the upper limb holding the violin. As a result, fewer measurements were presented for this limb. Despite careful planning of camera placements and prior training for the recording staff, the presence of additional movements by some violinists (such as taking extra steps while playing) might have slightly distorted the obtained results. Another challenge was halting the video precisely at the moment when the measured movement was in its extreme position.

In this study, a three-octave G-major scale was used because it is frequently practiced by violinists and is well-known to them. However, it should be noted that with other pieces, tempos, and styles, the results obtained might differ, which requires further research. Although one might assume that a scale is a piece of music lacking emotional depth, the violinists were able to imbue it with sound and emotion characteristic of more complex works, which also influenced their body movements. Moreover, violinists were allowed to use vibrato at their discretion, which might have impacted the results obtained for the wrist joints of the hand holding the violin.

The study group was unfortunately small, with 12 of the participants having experienced some form of upper limb injury during their lifetime. However, due to difficulties in gathering even these 22 individuals, they were included in the study. Furthermore, 68% of the participants in the entire study group experienced pain related to playing, but these individuals were considered to represent the reality of everyday violin playing. This calls for further research on larger and more homogeneous groups.

The study did not include measurements of the length of individual body segments of the participants or their potential impact on the obtained ranges of motion. Taller individuals and those with longer fingers, forearms, or upper arms may have adopted different body positions and achieved different ranges of motion. This aspect also requires further research.

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