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The Unique Demands of Playing Posture on Youth Violinists and Violists

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Abstract

The high prevalence of performing arts injuries is an acknowledged challenge facing the performing arts medicine community. The injuries seem to affect string players the most among orchestral musicians, specifically violinists and violists. The asymmetrical posture, head and neck displacement, and spinal displacement required by the posture to play violin and viola can lead to discomfort or injury in the performer. Performance related musculoskeletal disorders (PRMDs) can have an adverse impact on the life of a musician, preventing them from performing or making it uncomfortable. While there is a large body of research on PRMDs relating to adult musicians, there have been few investigations of the unique challenges faced by children playing violin or viola. The two instruments have similar posture, leading to similar potential risk factors. The muscular tissue, rapid bodily change and growth, general misfit between child and instrument, backpack use, and desk posture of children playing the violin and viola prevent unique risk factors that are not found in adults. Potential solutions to these risk factors include proper instrument sizing with a chin rest and shoulder rest and posture awareness with an emphasis on balance and pain treatment. The advancement of research into youth-related performing arts injuries could play a part in reducing the alarmingly high levels of performance related injury in adult violinists and violists.

Introduction

Injury in Violinists and Violists

Prevalence

The life of a performing artist is filled with creativity, expression, and fulfillment. But lurking in the background is the possibility for injuries that affect an individual's ability to perform their art. The most common injury seen in performing arts is aptly named Performance-related Musculoskeletal Disorder (PRMD). PRMDs are defined as pain, weakness, numbness, tingling, or other symptoms that interfere with a musician's ability to play their instrument at the level at which they are accustomed.[1] There have been numerous efforts to determine the prevalence of PRMDs among professional orchestras. These findings show a high prevalence of PRMDs in orchestral musicians, ranging from 73.4% to 87.7%.[2] The first large-scale survey that sought out PRMD prevalence was done by the International Conference of Symphony and Opera Musicians (ICSOM) in 1986. With a response rate of 55%, this survey found that 76% of all performers in ICSOM ensembles "reported at least one medical problem that was severe in terms of its effect on performance.[3] The issue of PRMDs is not unique to the professional orchestra setting. A study done by Dr. Kristen Burkholder and Dr. Alice Brandfonbrener examined the frequency of performance-related injuries at a specialized performing arts clinic among patients age 18 and younger. Among the 314 total students seen, 84.4% experienced pain as at least one

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[1] Nadine Rensign, Heike Schemmann, and Christoff Zalpour, "Musculoskeletal Demands in Violin and Viola Playing A Literature Review," *Medical Problems of Performing Artists* 33, no. 2 (June 2018): 265.
[2] *Ibid.*
[3] Hunter J.H. Fry, "Incidence of Overuse Syndrome in the Symphony Orchestra," *Medical Problems of Performing Artists,* 1, no. 2 (1986): 51.

of their symptoms.[4] Among the instrumentalists studied, string players have the highest prevalence of PRMDs, ranging from 65% to 85%.[5] The high prevalence of injuries in string musicians suggests that playing a string instrument puts strain on the body in a way that warrants future study.

Impact on Lifestyle

The presence of a performance-related musculoskeletal injury in a musician can have an adverse impact on that person's life. The most glaring impact is a loss of income. If a musician is unable to perform due to injury, then they are losing what is likely their most significant source of income. This can lead to a wide array of stressors that result from decreased income or the process of finding new work. Even when injury does not fully prevent performance, adverse effects can still be present. When musicians play through pain, their focus often shifts from the music they are performing to the pain they are feeling. In addition, many injured musicians may feel a loss of control. They can no longer play their instrument in a familiar manner, which can impact the quality of their performance, and perhaps lead to other injuries. Because PRMDs are often difficult to diagnose accurately, musicians often receive a vague or nonspecific diagnosis that contributes to their feeling that they have lost control. Musicians may also feel as if they lose a part of their identity and personality when they are facing an injury. Many musicians begin playing at an early age, and their instrument becomes an integral part of their identity. When they are unable to express themselves to the level they desire, or when they are unable to play at all, they lose a piece of who they are. The presence of an injury can also affect the recreational life of a musician. Many may stop participating in physical activities they once enjoyed because they

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[4] Kristen R. Burkholder, Alice Brandfonbrener, "Performance-Related Injuries Among Student Musicians at a Specialty Clinic," *Medical Problems of Performing Artists,* 19, no. 3 (2004):116.
[5] Rensign, "Musculoskeletal Demands in Violin and Viola Playing A Literature Review," 265.

are now painful, or because the musician is afraid that the activity will cause further injury. Injury can also diminish the mental health of a musician. The loss of control and identity due to pain often leads to depression.[6]

Contributing Factors

There are many factors that contribute to injury in violinists and violists. The two main factors are repetitive motion and postural demands of the instrument. These factors can be further described by intrinsic and extrinsic risks to the player. A musician's size, strength, flexibility, and presence of underlying disease are intrinsic risks that contribute to the potential for PRMDs. Performance technique as well as playing environment constitute extrinsic risks that can contribute to potential PRMDs. While repetitive motion is not the focus of this paper, its influence on injuries in violinists and violists should still be noted. In most classical settings, these musicians are required to play their instrument for long durations with limited rests. Overuse injuries due to repetitive motion are common in both the wrist and hand of the right (bowing) hand and the left (fingering) hand.[7] For example, repetitive motion of the bowing arm frequently leads to pain in extensor and flexor muscle groups, as well as pain and discomfort in the right shoulder. This shoulder pain is usually due to injury in the rotator cuff and is concentrated in the front of the shoulder.[8] The postural challenges of the violin and viola are the primary focus of the paper, and will be described in further detail in the following section.

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[6] Deanna Bourne, Amy Hallaran, and Jane Mackie, "The Lived Experience of Orchestral String Musicians with Playing-related Pain," *Medical Problems of Performing Artists*, 34, no. 4 (2019):198.
[7] Martin Fishbein, Susan E. Middlestadt, Victor Ottati, Susan Straus, and Alan Ellis, "Medical Problems Among ICSOM Musicians: Overview of a National Survey," *Medical Problems of Performing Artists*, 3, no. 1 (1988):5.
[8] *Ibid.*

The high prevalence of injury in violinists and violists caused by repetitive motion and postural challenges can lead to negative effects away from the instrument. For this reason, the underlying causes are a major point of study.

Postural Demands of Violin/Viola

Neutral Posture

The postural deviations caused by playing the violin and viola are best understood in the context of neutral posture. When standing, neutral posture is best observed when observing the body from the side. Good standing posture is confirmed if a straight vertical line could pass through the earlobe, front part of shoulder, lumbar spine, hip joint, knee, and ankle joint. Observed from the front, the shoulders and hips are level, and the body is symmetrical with minimal swaying or movement to one particular side.[9]

When sitting, many of the same principles apply. The vertical alignment should be similar, as well as level hips and shoulders. The main difference between sitting and standing is the removal of the legs from the vertical alignment. This places more force on the spine of the individual.[10]

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[9] Lynn S. Lippert, *Clinical Kinesiology and Anatomy*, Philadelphia, PA: F.A. Davis Company, 2011, 331-333.

[10] Fishbein, Middlestadt, Ottati, Straus, and Ellis, "Medical Problems Among ICSOM Musicians: Overview of a National Survey," 5.

Asymmetric Arm Posture

In order to understand the causes behind many violin and viola playing-related injuries, it is important to understand the playing posture. The technique for holding a violin and a viola is roughly identical. The musician's arms are required to be in an asymmetrical position. The right arm—which is the bowing arm--is extended outward in front of the body. In order to bow, the lower portion of the right arm is flexed and extended about the elbow. To change strings, the player raises the whole arm from the shoulder, with the shoulder remaining relaxed. In contrast, the left arm is rotated upward and flexed at the elbow. This arm helps support the instrument and this hand fingers the instrument. Oftentimes, the left elbow is extended forward with the shoulder and hand remaining in the same position in order that the left hand is positioned correctly to finger the instrument. In the case, the elbow is said to be supinated. The imbalanced posture of the instrument leads to differences in the mobility and strength of each arm. For example, the left shoulder in violinists and violists has been shown to have greater internal and external rotation than the right shoulder.[11] The increased external rotation of the left shoulder causes an increase in activation of the trapezius muscle, increased activation of the anterior and middle portion of the deltoid, and increased activation of the supraspinatus muscle.[12] However, both right and left upper trapezius muscles show similar levels of fatigue both before and after a playing session, possibly due to compensation from the right trapezius as the left fatigues. Studies have also demonstrated that the left wrist has greater mobility than the right, however the differences are not as significant as in shoulder mobility.[13]

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[11] Bronwen J. Ackermann, and Roger Adams, "Physical characteristics and pain patterns of skilled violinists," *Medical Problems of Performing Artists*, 18, no. 2 (2003):69.
[12] Anke Steinmetz, Wolfram Seidel, and Kay Niemier, "Shoulder Pain and Holding Position of the violin: A Case Report," *Medical Problems of Performing Artists*, 23, no. 2 (2008):79.
[13] Ackermann, and Adams, "Physical characteristics and pain patterns of skilled violinists," 69.

Head and Neck Displacement

In order to allow the left hand to move freely along the fingerboard, the instrument itself is supported by the player pinching the body of the instrument between their chin and left shoulder. In order to accomplish this, the head is rotated to the left and lowered so that adequate pressure is applied to hold the instrument in a stable position. The distance of movement required by the head is dependent on the unique physiology of the individual player and is variable. Ideally, the head remains in a neutral position, so that the neck experiences only axial rotation. However, this axial rotation of the neck should be minimized in order to reduce discomfort and injury.[14] Because the instrument is uniform in size and shape, the player must find ways to adapt to the instrument. Recently, the use of chin rests and shoulder rests that do not affect the sound of the instrument have been adopted to allow for individuals to customize the fit of the instrument somewhat so that it may be held in a more comfortable manner.[15]

Spinal Considerations

Because of the asymmetrical loading of the violin/viola on the musician's body, the spine is required to stabilize the body and find balance. This balancing act poses problems that can increase the potential for PRMDs which will be discussed in the next section. However, even in the healthy player, the spine undergoes slight changes to account for posture. Violinists and violists are expected to sit or stand, depending on the context of their playing. Despite the

[14] Kyue-nam Park, Oh-yun Kwon, Sung-min Ha, Su-jung Kim, Hyun-jung Choi, and Jong-hyuck Weon, "Comparison of electromyographic activity and range of neck motion in violin students with and without neck pain during playing," *Medical Problems of Performing Artists,* 27, no. 4 (2012):188.

[15]Marco Rabuffetti, Rosa Maria Converti, Silvano Boccardi, and Maurizio Ferrarin, "Tuning of the Violin-Performer Interface: An Experimental Study about the Effects of Shoulder Rest Variations on Playing Kinematics," *Medical Problems of Performing Artists,* 22, no. 2 (2007):58.

different overall positions, the effect on the range of motion of the spine is limited. The main difference between sitting and standing is the way that weight is distributed throughout the body. In the standing position, weight is generally spread evenly, with neither side being favored. In order to determine the weight distribution while seated, the position of the chair relative to the music stand must be considered. When seated to the left of the music stand, weight is spread evenly throughout, similar to the standing position. However, when seated directly in front of or to the right of the music stand, the weight becomes distributed unevenly throughout the body. Even distribution of weight does not mean that force-loading is evenly distributed between sitting bones while seated. When standing, the feet experience pressure evenly. But when seated, the left sitting bone experiences more pressure than the right. This can be explained by the asymmetrical nature of the instrument. Because the right arm is more dynamic than the left arm in order to bow the instrument, the left side of the body must experience more pressure to bring balance.[16] Violinists and violists also tend to have a slightly increased amount of curvature in their lumbar spine, called lumbar lordosis, when compared to a control group.[17] This suggests that the playing posture required by the violin and viola creates an environment in which the player cannot adequately support their lumbar spine, leading to deviation from normal curvature.

The postural demands of the violin and viola can put the body into positions that deviate greatly from their neutral position. Specifically, the arms, neck, and spine undergo changes that can lead to injuries discussed in the following section.

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[16] Claudia Spahn, Céline Wasmer, Franziska Eickhoff, and Manfred Nusseck, "Comparing Violinists' Body Movements While Standing, Sitting, and in Sitting Orientations to the Right or Left of a Music Stand," *Medical Problems of Performing Artists,* 29, no. 2 (2014):89-90.
[17] Katarzyna Barczyk-Pawelec, Tomasz Sipko, Ewa Demczuk-Włodarczyk, and Agata Boczar, "Anterioposterior spinal curvatures and magnitude of asymmetry in the trunk in musicians playing the violin compared with non-musicians," *Journal of Manipulative and Physiological Therapeutics,* 35, no. 4 (2012):323.

Posture-related Injuries/Pain in Adult Violinists and Violists

Left Shoulder

The asymmetric arm posture as well as the shoulder and arm elevation required when playing the violin or viola can lead to pain or injury. Specifically, when it comes to posture, the left shoulder is greatly affected. All of the muscles used to support the shoulder and instrument must be operating efficiently in order to avoid injury. For example, low levels of upper trapezius activation have been found to correlate with left shoulder pain in professional violinists and violists.[18] Berque and Gray found that the muscle weakness was due to playing, as the injured group showed higher levels of upper trapezius activation during a rest period compared to when playing. Another aspect of performance posture that can lead to shoulder pain and injury is extreme left shoulder external rotation. A case study done by Steinmetz et al. showed this problem in a professional violinist with persistent shoulder pain to the point that he was no longer able to perform. They identified the source of the problem as his atypical playing posture, as the left shoulder was experiencing more external rotation than normal. Playing the violin and viola also puts the performer at a higher risk for shoulder impingement. Shoulder impingement is a condition in which the shoulder's bursa and/or rotator cuff tendons are intermittently trapped and compressed during shoulder elevation movements.[19] Rabuffetti, Converti, Boccardi, and

[18] Patrice Berque, and Heather Gray, "The influence of neck-shoulder pain on trapezius muscle activity among professional violin and viola players: an electromyographic study," *Medical Problems of Performing Artists,* 17, no. 2 (2002):74.
[19] M. Moore, L. DeHaan, T. Ehrenberg, L. Gross, and C. Magembe, "Clinical Assessment of Shoulder Impingement Factors in Violin and Viola Players," *Medical Problems of Performing Artists,* 23, no. 4 (2008):161.

Ferrarin found that a significant correlation could be established between being a professional violinist or violist and increased risk of shoulder impingement.[20]

Spine and Neck

As mentioned previously, the main role of the spine in violin and viola posture is to stabilize and support the asymmetrical balancing done by the rest of the body. The required alterations of the spine can lead to injury in the player. Musicians with PRMDs are very likely to have problems with their lumbo-pelvic and cervicothoracic stabilization systems. In a study done by Steinmetz et al., 85% of the musicians had impaired scapular stabilizers, and 71% had dysfunctional lumbo-pelvic stabilizing muscles.[21] This lack of stabilization was found to be connected to the asymmetry of the musician's posture, as the study found a statistically significant higher rate of impaired lumbo-pelvic stabilizing muscles in upper and lower string musicians when compared to symmetrically played instruments.[22] Another challenge of back and spine injuries in violinists and violists is the presence of pain without objective findings. The difference in perceived lower back pain and objective findings can be as large as almost 50% among all musicians.[23]

The neck is also the site of frequent pain in violinists and violists. Similar to the spine, any deviation away from normal position presents the possibility for injury. In violinists and

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[20] Rabuffetti, Converti, Boccardi, and Ferrarin, "Tuning of the Violin-Performer Interface: An Experimental Study about the Effects of Shoulder Rest Variations on Playing Kinematics," 58.
[21] Anke Steinmetz, Wolfram Seidel, and Burkhard Muche, "Impairment of postural stabilization systems in musicians with playing-related musculoskeletal disorders," *Journal of Manipulative and Physiological Therapeutics*, 33 no. 8 (2010):606.
[22] *Ibid.*
[23] Helene M. Paarup, Jesper Baelum, Claus Manniche, Jonas W. Holm, and Niels Wedderkopp, "Occurrence and coexistence of localized musculoskeletal symptoms and findings in work-attending orchestra musicians–an exploratory cross-sectional study," *BMC Research Notes*, 5, no. 541 (2012): n.p. Accessed January 9, 2020. https://doi.org/10.1186/1756-0500-5-541.

violists with neck pain, there was found to be greater angles of left lateral bending and leftward rotation of the neck and cervical spine when compared to uninjured violinists.[8] Neck pain in musicians can also lead to other sensory impairments. As found by Steinmetz and Jull, violin players with neck pain showed sensory impairment. These musicians had significantly lower heat and significantly higher cold pain thresholds, as well as decreased pressure pain threshold. However, this study did not find any significantly decreased motor functions along with the neck pain when compared to non-musicians.[24]

Mandible

Another area of the musician's body susceptible to posture-related injury is the mandible. Along with the left shoulder, the left side of the mandible is used to secure the instrument in place. The asymmetrical loading of the instrument on the body can lead to various injuries and problems within the mandible and left jaw. In a clinical examination done by Rodríguez-Lozano et al., violinists had significantly more pain on maximum mouth opening, parafunctional habits such as nail biting, and occurrence of Temporomandibular Joint (TMJ) sounds.[25, 26] These findings suggest that violinists and violists are more susceptible to TMJ disorders. TMJ refers to the temporomandibular joint that acts as a sliding hinge that connects the jawbone to the skull. TMJ disorders can cause pain in the jaw and in the muscles that control jaw movement.[27]

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[24] Anke Steinmetz, and Gwendolen A. Jull,"Sensory and sensorimotor features in violinists and violists with neck pain," *Archives of Physical Medicine Rehabilitation*, 94 no. 12 (2013):2525.
[25] F.J. Rodríguez-Lozano, M.R. Sáez-Yuguero, and A. Bermejo-Fenoll, "Orofacial problems in musicians: a review of the literature," *Medical Problems of Performing Artists*, 26, no. 3 (2011):154.
[26] F.J. Rodríguez-Lozano, M.R. Sáez-Yuguero, and A. Bermejo-Fenoll, "Prevalence of Temporomandibular Disorder-Related Findings in Violinists Compared with Control Subjects," *Elsevier* 109, no. 1 (January 2010): 16.
[27] S. Ingawalé, and T. Goswami, "Temporomandibular Joint: Disorders, Treatments, and Biomechanics," *Annals of Biomedical Engineering*, 37 (2009): 977.

Another clinical examination done by Steinmetz et al. found that craniomandibular disorders could be diagnosed in 74% of the 31 violinists in their study. The examination also showed that 90% of the subjects had deviation of the mandible, 65% had pain on palpation of the masticatory muscles, and 58% had joint sounds. The mandible of 63% of the subjects was found to have deviated to the right, and was found to have deviated to the left in 30% of the subjects.[28]

The left shoulder, spine, neck, and mandible of violinists and violists are especially prone to injury due to the posture required by the instrument. Shoulder impingement and TMJ disorders are especially noteworthy, as is lumbar lordosis. These specific areas and conditions provide an outline for areas of interest to investigate when identifying unique risks faced by youth violinists and violists.

Anatomical Considerations

Muscular Tissue

In order to better understand the physical nature of posture-related injuries in youth, it is important to have a basic understanding of the musculature.

Tendons and Tendon Sheaths

A key to understanding muscles is understanding tendons. Tendons are fibrous bands or sheets that connect muscle to bone, and are crucial in stabilizing joints. Often times, muscles are not long enough to reach the entire distance of the bone. Tendons bridge the gap. This is an

[28] Anke Steinmetz, P.H. Ridder, and A. Reichelt, "Craniomandibular dysfunction and violin playing: prevalence and the influence of oral splints on head and neck muscles in violinists," *Medical Problems of Performing Artists,* 21, no 4 (2006):186.

example of indirect attachment. The Achilles tendon—or Achilles heel—is an example of a tendon that participates in indirect attachment that is easily observed and touched. There is also direct attachment in which there is little observable distance between the end of a muscle and the beginning of a bone. However, at the microscopic level, collagen fibers can be seen connecting the end of the muscle to the bone, providing extra strength to prevent ripping of the bones.[29]

Due to limited space for muscles, tendons, fascia, bones, blood vessels, etc. to fit together, there are components that provide guidance systems or tracks so that everything can move without interfering. One such component is a bursa, which is a fibrous sac filled with synovial fluid, located between adjacent muscles, where a tendon passes over a bone, or between bone and skin. Bursa can take the form of a tendon sheath, which is an elongated bursa wrapped around a tendon. They enable tendons to move more freely in tight spaces, especially the ankle and wrist. These types of interactions are very relevant to violinists and violists, as they occur at every joint in the shoulder, elbow, wrist, fingers, and jaw.[30]

The tendons or tendon sheaths can be injured in several ways when playing violin or viola. Tendinitis is inflammation of the tendon caused by a specific event or activity that produces immediate inflammation of the tendon. This could be the result of an intense day of practicing or a dramatic change in practice load. Tendinosis is degeneration of the tendon, and is more common and more serious than tendinitis. Unlike tendinitis, tendinosis occurs over a longer period of time. Usually, it happens because tendinitis did not have adequate time to heal.[31]

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[29] Kenneth Saladin, *Anatomy Physiology: The Unity of Form and Function* (New York, NY: The McGraw-Hill Companies, Inc., 2011), 284-285.
[30] *Ibid.*
[31] Jenna O'Neil, "A study of performance-related injuries among BMus violin students in South Africa," (MMus Thesis, University of Stellenbosch University, 2019), Retrieved from http://hdl.handle.net/10019.1/105845.

Cell Components of Fibrous Connective Tissue

To better understand tendons and their role in performance and performance-related injuries, it is important to understand their composition. Tendons are a type of fibrous connective tissue. Specifically, they are dense regular connective tissue. Fibrous connective tissues are the most diverse tissue type in the human body, so it is important to be able to differentiate between them.[32]

At the cellular level, fibrous connective tissues can have any combination of fibroblasts, macrophages, white blood cells, plasma cells, mast cells, and fat cells. Tendons are almost exclusively made up of fibroblasts, with the exception of blood vessels and sensory nerve fibers. The next level of organization in fibrous connective tissues is the fibers themselves. Tendons are made of collagen fibers, making them tough, flexible, and resistant to overstretching. Finally, fibers are organized into various types of fibrous connective tissue. As previously mentioned, tendons are classified under dense regular connective tissue. This type of fibrous connective tissue has two distinctive properties. First, the collagen fibers are closely packed and leave relatively little open space. Second, the collagen fibers are parallel to each other. The second point is especially relevant to tendons because they are pulled in predictable directions, providing greater tensile strength. However, because tendons have few blood vessels, injuries are slow to heal.[33]

Basic Muscle Function

Muscles are crucial to everyday actions such as walking, typing, or playing the violin. To better understand the role that muscles play in violinists and violists, it is crucial to understand

[32] Saladin, *Anatomy Physiology: The Unity of Form and Function*, 154.
[33] *Ibid.*

basics of their function. Muscles can provide movement as well as prevent movement in order to create stability. Other muscles act against gravity so that we can sit up straight or not fall over. This category of muscle function is the most relevant to posture-related injuries in youth violinists and violists.[34]

There are functional groups that work together to create or prevent movement. The first functional group is the prime mover, or agonist. This muscle is the one that produces the most force in the muscle activity. For example, as a violist flexes their elbow in order to bring their instrument to their shoulder, the agonist is the bicep. Another functional group is the synergist. Synergistic muscles serve to aid the agonist. This can be done by parallel or similar movement, but not necessarily. They often provide stability if an agonist rotates a joint or causes other undesirable movement. Next, there is the antagonist. The antagonist opposes the agonist in order to prevent hyperextension around joints or to provide stability. An example of an antagonist pair of muscles is the biceps and the triceps. As the arm is extended or flexed, the biceps and the triceps work in an unbalanced fashion so the movement can happen without harming the body. Finally, there is the fixator, which stabilizes joints so that a bone higher up the lever can serve as a fixed base for movement. Oftentimes, a fixator will hold a bone in place so that another muscle attached to it can pull on another bone.[35]

Muscular tissue plays an important role in injury and injury prevention. Playing the violin requires synergy between various muscle groups with different actions, as well as the tendons that provide support to the joints. Knowing the form and function of these muscular components

[34] Saladin, *Anatomy Physiology: The Unity of Form and Function*, 313.
[35] *Ibid,* 318.

is crucial in understanding the context of the unique challenges the growing youth body encounters.

Changes of the Youth Body

Rapid Growth

The human body undergoes immense change during the school-age years and into adolescence. From changes in proportions, development of motor skills and coordination, to sexual development there is much for a young violinist or violist to adapt to while they are developing their artistic skills. Changes to the youth body will be examined at the beginning of what is generally called school-age, or age five. This age range ends around age twelve when adolescence begins. The school-age range is the time in a child's development in which activities such as sports and music begin. It is the changes that occur from this point forward that could pose challenges unique to children and adolescent violinists and violists. The end point of what will be referred to as "youth" is the end of sexual development which occurs at the end of adolescence, which occurs in the early twenties. It is at this stage that most physical changes in the body have ceased.[36]

During the time between school-age and the end of adolescence, the human body experiences various changes in proportions. First, the head becomes smaller in proportion to the rest of the body. However, the brain grows in size during this time as well, reaching adult size at around age twelve. The largest contributing factors to the changes in proportions and growth in general are the long bones found in the arms and legs. The significant increase in long bone length is derived from activity of the epiphyseal plate, commonly known as the growth plate.

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[36] Catherine E. Burns et al., *Pediatric Primary Care,* 5th ed. (Philadelphia, PA: Saunders, 2012), 92, 110.

Growth plates are found on either end of each major bone in the body. Growth plates present a risk unique to children in that they are particularly sensitive and subject to damage through fracture. Epiphyseal plates are similar to tendons in that they play an integral part in the structure and function of the bone, but they are much weaker than bone and prone to injury. A bone fracture that runs through the growth plate can lead to limited growth, or cause growth to stop altogether. Another part of the bone that is a potential risk in youth violinists and violists are apophyses. This rounded part of the bone connects to tendons, which are connected to muscle. These areas also help facilitate muscle growth and are weaker than bone.[37]

While physical growth is not as pronounced during adolescence as it is during school-age, there are still changes in the body worth noting. Both males and females experience a growth spurt which will be their last significant change in height. This change in height is accompanied by various other physical changes, such as an increase in muscle and body fat, as well as broadening of the hips and shoulders.[38] As children move through school-age, they also experience a straightening of the back. The rapid development of the shape of the spine leads to risks. For example, adolescents have a risk of developing scoliosis, lateral deviation of the spine, as their growth continues. The specific challenges imposed by the spine and posture of youth violinists and violists will be explored later.[39]

Motor Development

Throughout the school-age years and adolescence, children develop their ability to perform motor skills. Motor skills can be broken up into two categories: gross motor skills and

[37] Catherine E. Burns et al., *Pediatric Primary Care,* 929-931.
[38] Catherine E. Burns et al., *Pediatric Primary Care,* 112.
[39] *Ibid.*

fine motor skills. Gross motor skills refer to motor skills that require the use of large muscle groups. For example, running is an example of a gross motor skill. Fine motor skills refer to smaller, more precise muscle movements such as typing or fingering the viola. School-age children are typically good at gross motor motions. Those at the beginning of this age range can skip, jump rope, throw and catch a ball, etc. Later, they are able to swim, ride a bike, skate, and play sports. As kids grow into adolescence and become bigger and stronger, their motor skills also develop. Both gross and fine motor skills progress to the point of adult level in the late teens.[40]

Changes in Coordination

Another important area of change in youth violinists and violists is the progression of coordination. An important aspect of pediatric development is the development of hand-eye coordination. Formally termed fundamental motor skills (FMS), this proficiency plays a critical role in health, as motor skill ability is a key predictor of health, as well as fitness and sports participation. While the coordination necessary to play the violin and viola is different than the catch-and-throw coordination often used in studies of FMS, the development of hand-eye coordination remains important. Wicks et al. carried out a longitudinal study to measure development in eye-hand coordination in children ranging from age 8 to 16. The rates of coordination development in males and females occurred at very similar rates, with rapid increase from age eight to twelve and a limited increase from twelve to sixteen. This data was obtained measuring single arm coordination. When Wicks et al. also measured coordination involving two arms, proficiency was less than coordination involving one arm. A similar pattern

[40] David R. Lubans, Philip J. Morgan, Dylan P. Cliff, Lisa M. Barnett, and Anthony D. Okely, "Fundamental Movement Skills in Children and Adolescents," *Sports Medicine,* 40 (2010):1020.

of development between males and females emerged. Both developed the skill at similar rates.[41] The object control measured in this study is a rudimentary activity compared to playing the violin or viola, but progression of the skill is noteworthy.

Differences in Males and Females

Although growth through school-age (five-twelve) is mirrored between the sexes, changes begin to emerge at the onset of adolescence. Here, male and female development begins to diverge. The development of sexual features is the most significant of these differences, but it is insignificant in regards to posture related injury risk. Still, there are physical differences that emerge through puberty relating to an individual's frame. While both sexes experience a growth spurt during this time, males experience it at a slightly later time.[42] This highlights a theme in the developmental differences between males and females in puberty: males tend to develop anatomically at a later time than females.

There are also differences in the development of motor skills between males in females. During the school-age years, the progression of motor skills is fairly even.[43] However, during adolescence, females reach their peak in coordination at about age fourteen. Their skills may still develop if they are being trained through sports, music, or another activity requiring refined and practiced movements. This contrasts with the motor skill progression of boys throughout adolescence. Boys continue to naturally develop their motor skills until about age twenty. They continue to gain running speed, throwing strength, jumping height, and endurance.[44]

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[41] Lennon J. Wicks, Rohan M. Telford, Ross B. Cunningham, Stuart J. Semple, and Richard D. Telford, "Longitudinal patterns of change in eye-hand coordination in children aged 8-16 years," *Human Movement Science*, 43 no. 7 (October, 2015): 63.
[42] Catherine E. Burns et al., *Pediatric Primary Care*, 111-112.
[43] David R. Lubans et al., "Fundamental Movement Skills in Children and Adolescents,"1020.
[44] David R. Lubans et al., "Fundamental Movement Skills in Children and Adolescents,"1020.

A similar pattern was observed in the development of hand-eye coordination in males and females. While both sexes experience similar patterns of development, males had higher overall levels of coordination through both school-age and adolescence.[45]

Youth violinists and violists face numerous obstacles to healthy performing posture. Growth creates the need of constantly adapting to the instrument. Motor skills continue to become refined with age, adding another variable that could complicate their ability to effectively play the instrument. Another challenge, is the distinction between female and male development. Males and females develop at different rates, and grow into different proportions, adding to the complications already created by standard growth and development.

Youth Posture

Effect of Backpack Loading

A common reality in the lives of school children is the backpack. Negrini and Negrini conducted a study to examine the change in biomechanics that occurs when a twelve-year-old student wears a backpack. They found that loading the spine of a student always results in postural variation, regardless if the loading is symmetric or asymmetric. Specifically, they found that the symmetrical loading caused the subject to lean forward and caused an increase in lumbar lordosis. For the asymmetrical load, Negrini and Negrini found that the shoulder carrying the load was raised and brought backward. This change in shoulder posture led to a deviation of the spine in the lateral direction away from the load. The loading of the spine also contributed to fatigue in the subjects. Negrini and Negrini had already determined in a previous study that the

[45] Lennon J. Wicks et al., "Longitudinal patterns of change in eye-hand coordination in children aged 8-16 years," 63.

average walk to school for their subjects was about seven minutes. When this walk was simulated on a treadmill, they found that the effects of the loading were increased. The results of this study are concerning. The spinal displacement cited can lead to problems such as kyphosis, scoliosis, and lumbar lordosis.[46] These conditions are not ideal for young violinists and violists as they can compound to create issues with back pain in the future. The spine plays a crucial role in stabilizing the asymmetric posture of the instrument. Any deviation from standard spine function or shape can lead to discomfort or pain that can persist. There are currently no laws or regulations setting a limit on the maximum weight of a child's backpack, while there are laws limiting the weight an adult can carry in the workplace.[47]The spinal loading imposed by the backpacks of school children pose a unique challenge to young violinists and violists.

School Desks and Posture

Another difficulty in the spinal health of children is school desks. Children throughout the school-age and adolescent years spend around six hours a day sitting at a desk while at school. Even with perfect sitting posture, this extended time sitting presents a danger to the disks in the spine.[48] The effects are more pronounced with poor posture. For example, if the head is brought forward while sitting, the pressure on the upper part of the spine around the neck experiences three times as much pressure than when the head is in a neutral position.[49] The extra strain that can be put on the spine while in poor posture is concerning for school-age children

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[46] Stefano Negrini, and Alberto Negrini, "Postural effects of symmetrical and asymmetrical loads on the spines of schoolchildren," *Scoliosis.* 2, no. 8 (2007): n.p. accessed January 10, 2020. https://doi.org/10.1186/1748-7161-2-8.
[47] *Ibid.*
[48] Hylton I. Lightman, "Good Posture Why It Matters in Children," Totalfamilycaremd.com, https://www.totalfamilycaremd.com/good-and-bad-posture-why-it-matters-in-children/ (accessed February 8, 2020).
[49] Lippert, *Clinical Kinesiology and Anatomy*, 335.

and adolescents because of the ongoing growth. Bad posture can lead to abnormal growth of the spine, pain, and even arthritis later in life.[50] But the problems extends beyond the classroom. The high prevalence of children with cell phones provides another risk fairly unique to children. By putting the head forward to look down at a phone screen, they are putting more pressure on their spine that could cause problems in the future.[51]

The posture required by the violin and viola already puts considerable strain on the body. Poor posture reinforced by wearing backpacks and sitting in desks all day at school adds to the challenge of maintaining healthy posture. The habits being reinforced in the classroom could potentially bleed into the practice room, creating the possibility for injury.

Suggestions to Alleviate Youth Challenges

Given the inherent physiological difficulties of playing the violin/viola and the particular physical risks imposed upon children, consideration of possible solutions to alleviate these challenges seems warranted.

Proper Instrument Sizing

The postural challenges of the violin and viola are in part due to the static nature of the instrument. That is to say, the player must adapt to the shape of the instrument and the standard technique. However, there are various instrument sizes available to the player, especially during the youth years because of the rapid growth. The violin is typically available in sizes including quarter, half, three-quarter, seven-eighths, and full size. Typically, the proper instrument size is

[50] Children's Health, "How and why to help your child develop good posture." Children's.com, https://www.childrens.com/health-wellness/good-posture-builds-back-strength-now-and-reduces-health-risks-later (accessed January 10, 2020).
[51] Lightman, "Good Posture Why It Matters in Children."

determined by holding the violin under the chin, and extending the left arm so that it is fully extended. If the fingers are able to curl around the end of the instrument, the instrument is a proper fit. Violas have much more variability in terms of sizing, with no true full-size instrument. Violas tend to be larger than the violin and are sized based on length, not fraction of full-size. For example, a 14-inch viola is approximately the same size as a full-size violin. However, violas can be as large as 16 to 16.5 inches long.[52] The proper instrument size allows for the arms to be as comfortable as possible based on their length. But there is still a problem regarding the use of the chin and shoulder to secure the instrument in place.

The general relative shape of the instrument is preserved at each size, presenting similar ergonomic problems. The trunk, left shoulder, left arm and hand, and head are primarily responsible for holding the instrument during performance. The action of the dynamic right arm is mostly consistent between players. In light of observations from studies illuminating the impact of asymmetrical postural loading and considering the high prevalence of injuries among violinists and violists, it is reasonable to conclude that bodily adaptations required to play these instruments may present a specific risk. The task of solving the problem of violin and viola shape is difficult because changes need to be made in such a way that does not alter the sound quality of the instrument. Recently, the introduction and widespread use of chin rests as well as shoulder rests have made it possible to personalize the instrument to a unique body. However, the process of selecting proper chin rest and shoulder rest heights is crucial to achieve maximum comfort.[53] This process becomes more difficult in youth players. As mentioned above, the youth body is

[52] Michael Allen, Robert Gillespie, and Pamela Tellejohn Hayes, *Essential Elements for Strings*, (Milwaukee, WI: Hal Leonard Corporation, 2004), 260.
[53] Rabuffetti, Converti, Boccardi, and Ferrarin, "Tuning of the Violin-Performer Interface: An Experimental Study about the Effects of Shoulder Rest Variations on Playing Kinematics," 58.

undergoing constant change, the head becomes smaller in proportion, arms and legs grow immensely, shoulders widen, and the spine straightens. These rapid bodily changes make it more difficult for young players to find a chin and shoulder rest accommodation that reduces shoulder elevation, as well as head and neck displacement. It is very crucial that the instrument-body interface is evaluated with the help of the performer's private teacher to ensure that the shoulder rest and chin rest are a proper fit.

Posture Awareness

There are various actions young violinists and violists can take to deter the progress of injuries and bad habits. The first is being aware of their playing posture and learning to find balance. An example of this is playing in an orchestral setting. Many young orchestral violinists and violists are taught to sit up straight with limited movement. They are told that playing too relaxed or slouching is bad. While this is true, there is a middle ground where the posture allows for relaxation, as well as control of the body. Developing this skill is important to do early before the habit is formed and will have to be un-learned later in life. Finding this middle ground between tension and relaxation is a great skill for young violinists and violists to learn not only because it helps in injury prevention, but also because it leads to better musical expression and creativity. The distinction between what is comfortable and what is familiar needs to be made early on. A private teacher can help the student find a posture that provides this balance. According to Physical Therapist and violinist Diana Rumrill, another way to relieve tension while playing is to think of the support system of the violin being a collaboration between the chin and shoulder, and the left hand. While using the chin and shoulder to clamp the instrument

like a shelf provides freedom in the left hand, the neck experiences a great deal of tension.[54] Using the left hand to assist in stabilizing the instrument ensures that no individual part of the body does too much of the work of playing the instrument.

An important consideration in finding ways to improve posture is the use of a strength training program. The asymmetrical usage of the arms has the potential to develop strength imbalances. Specifically, an agonist muscle and antagonist muscle can become imbalanced, leading to asymmetrical strength. Muscle imbalance can also lead to exacerbation of the asymmetrical tendencies of the instrument. This can lead to stiff neck and shoulder muscles because of weakness in the muscles that move and support the shoulders.[55] Incorporating minor strength training into a practice routine during the youth years would lay the groundwork necessary to preventing any muscle imbalances that could arise due to the asymmetrical posture required to play violin and viola. The training could range from the use of weight machines, or functional training using Thera-Bands or Swiss balls.[56] Working with a physical therapist or exercise trainer would benefit the youth, as the trainer would know how to perform strengthening exercises in the safest possible manner.

Another helpful habit for youth violinists and violists to develop is proper hydration. As mentioned above, tendons are a location of frequent injury and discomfort. In children, tendons are growing which leads to greater chance of injury. In order to ensure proper tendon health, hydration is crucial. Specifically, hydration has the greatest effect on the tendon sheaths that

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[54] Laurie Niles, "Interview with Diana Rumrill: Preventing and Treating Violin-Related Injury," Interviews (blog), Violinist.com, March 10, 2010, https://www.violinist.com/blog/laurie/20103/11026/.
[55] Christiane Wilke. "Motor Activity as a Way of Preventing Musculoskeletal Problems in String Musicians." Medical Problems of Performing Artists 26 (March 2011): 27.
[56] *Ibid.*

surround the tendons. When properly hydrated, tendon sheaths provide tracks so that tendons can move easily in areas like the hand and wrist. If not hydrated, there will be more friction between the tendons and tendon sheaths causing pain and discomfort. according to data from the Institute of Medicine of the National Academies, children need anywhere from seven to fourteen cups of water each day, depending on their age.[57] Staying adequately hydrated is essential in maintaining healthy tendons and tendon sheaths.

These postural considerations lead into the significance of receiving help and input from a private teacher. Youth violinists and violists tend to have underdeveloped technique, so it is important that before changes to posture are made their teacher is consulted to make sure that they have proper technique. While an experienced adult performer may be able to correct their posture by looking in a mirror while playing or by watching a video of themselves playing, a young musician may not. The teacher is there to provide feedback on posture that may go unnoticed by the student.

Another important consideration in player safety is the treatment of pain or discomfort. Young violinists and violists must be taught to recognize this pain and discomfort and disclose it with their parents or teacher. While private instructors have great insight, they may not know that their student is in pain without the student expressing that pain. Being comfortable disclosing discomfort and pain as soon as possible is important so that measures can be taken to alleviate the problem.

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[57] Esther Ellis, "Water: How Much Do Kids Need?" eatright.org, Academy of Nutrition and Dietetics (June 22, 2020), Accessed March 11, 2020, https://www.eatright.org/fitness/sports-and-performance/hydrate-right/water-go-with-the-flow.

Treatment of Pain in Children/Adolescents

Another important consideration in alleviating the unique problems of youth violinists and violists is the treatment of pain. While this area of interest in pediatric medicine applies more closely to post-surgical pain or acute pain, the general challenge remains for chronic or extended pain that may be experienced by a young musician. The habits and mindset the player has about pain will set the foundation for their relationship with pain in the future. It is important for pain to be recognized and addressed early because early and prolonged pain may affect a child's pain systems, stress response and behavior, and learning resulting in increased pain sensitivity.[58] The child, their family, and the physician involved need to be able to communicate effectively in order for treatment to be as effective as possible. Part of this is helping the physician understand the unique challenges. First, it is crucial to demonstrate playing posture with the instrument in hand. Oftentimes, physicians will be inexperienced with performance-related injuries and will need to observe the patient playing their instrument. Furthermore, the physician needs to understand the culture surrounding injury in the performing arts community. First, the pain experienced may be subclinical in nature. This means that the pain is not present in everyday activities, but reveals itself when holding or playing the instrument. While this type of pain may not seem like a concern to the physician, it should be addressed. Another cultural consideration is that musicians often attempt to hide their pain. While this habit may not be ingrained in the young violinist or violist, it is crucial to overcome it or prevent it from happening. While the treatment of pain is not unique to youth violinists and violists, it provides an opportunity to form healthy habits and prevent further pain later in life.

[58] Catherine E. Burns et al., *Pediatric Primary Care*, 415-416.

In order to combat the complications caused by rapid growth and poor posture maintained at school, youth violinists and violists must learn to adapt to their instrument and be aware of their posture. As the child grows, the instrument, shoulder rest, and chin rest should be adapted so that playing posture is as safe as possible. Adjustments must be made depending on the rate of growth. Learning to be aware of their posture and the balance between tension and relaxation will help the youth performer to identify incorrect posture that could potentially lead to injury. Furthermore, being able to have frank conversations about pain and pain management is crucial in communicating with a teacher or health professional so that injury or discomfort does not persist throughout a performer's entire career.

Conclusion

The high prevalence of injury in professional string musicians points to the need to find underlying risks of the profession in order to prevent future injury. Preventing injury is a necessity because of the psychological, professional, and financial strain that it can put on an individual performer and the other people in their life. Injury can prevent the musician from working, and it can cause them to lose a significant part of how they value themselves.

Within the string family, violinists and violists are the most likely to sustain a performance-related injury. This suggests that there is something about playing the violin and viola that makes it riskier than most other instruments. Simply holding the instrument puts the body in an unnatural position that is prone to injury. The arms are held in asymmetrical positions with one supporting and fingering the instrument while the other holds and controls the bow. The head and neck are rotated and displaced so that the instrument can be supported between the left shoulder and chin. The spine is responsible for supporting asymmetrical loading while at the

same time being distorted from neutral alignment through rotation or leaning. These unnatural positions may lead to the broad injury category of performance-related musculoskeletal disorders (PRMDs). Specifically, violinists and violists are prone to temporomandibular joint (TMJ) disorders, shoulder-impingement, and spine disorders such as lumbar lordosis.

The injuries and performance related discomfort of the violin and viola are well documented in adult players, but the unique struggle of youth players is an area with less exploration. Youth players are at a unique risk of injury because their body is undergoing constant growth and development, and these students also exhibit poor posture habits that are reinforced at school. The constant growth makes posture-related injuries more of a risk because of the need for constant adaptation of the performer-instrument connection. As the body grows and changes, instrument size and fit, as well as posture must be constantly re-evaluated so that the body is placed in as safe of a position as possible, while at the same time allowing for artistic expression. Children also experience detrimental influence on their posture due to school backpacks and poor posture while sitting in a desk. The poor habits and stress that these situations create carry over into the practice room or rehearsal space.

Being able to identify youth risk factors and finding solutions is crucial in maintaining their health into the future. Introducing injury prevention and containment into the minds of youth performers and teachers would help to prevent the development of poor habits. Beyond poor technique, poor habits could include muscle imbalance due to the asymmetrical posture required by the violin and viola. Introducing a minor strength program with an aim at helping balance and posture could be monumental in preventing discomfort of the shoulders, neck, and back. Being aware of the risk that constant growth presents would help prevent a student's technique and understanding of the instrument to lag behind their growing size and coordination.

Keeping posture and technique more in line with growth could help alleviate the development of poor posture and related injury. Perhaps the most important implication of this information is the potential it has to reduce the prevalence of injury in violinists and violists across the board. Spreading awareness of injury could change the culture in the string world in regard to injury and injury prevention.

Limitations

There is limited availability of literature regarding youth biomechanics as it pertains to playing musical instruments. Thus, for this literature review, information was drawn from more traditional pediatric contexts such as sports, and expanded into the world of music. This paper would have benefitted from longitudinal data collection on growth throughout childhood compared to the prevalence of injury, in young violinists and violists, and the general public.

Additionally, the use of a blog source introduces information that is independent of the peer review process. This could mean that the information incorporated from the source is not up to the academic standard of a more traditional source. However, the information was included because of the background of the individual being interviewed, as well as its relevance to the topic of the paper.

In any literature review, the ability to draw generalized conclusions is limited by the methodologies of the individual studies consulted conclusions. Additionally, methodological limitations may compound when drawing conclusions across sources. This is a drawback of a literature review because conclusions must be drawn from a large patchwork of information derived from studies of different research participants and populations. There is also a limitation associated to the range of resources available from consulted data bases. Google Scholar,

Medscape, and the Medical Problems in Performing Artist archives were used to compile information of risks associated with youth violin and violists.

Considerations for Future Research

The field of performing arts medicine is an area with immense potential. Specifically, pediatric performing arts medicine is an area that has great potential for exploration. In order to effectively understand the effects of playing an instrument on the posture and health of children, longitudinal studies measuring the biomechanics of youth musicians is required. The advancement of 3-D mapping technology has allowed for closer examination of movement and posture in musicians. Posture over time, as well as bow-arm movement patterns over time could be measured and compared for any student involved. This would provide crucial data on the longitudinal changes in youth violinist and violist mechanics and posture over time. This information paired with growth information on students involved would allow teachers and physicians to compare the rapid growth found during this time with any detrimental changes in posture and technique. The data could identify times when posture and technique lag behind growth, potentially leading to the creation of bad habits or injury. This information would be immensely informative to a teacher, who could better adapt their teaching to the physical demands of their student. This research might also be applicable to other instruments within the string family. While they do not share the same asymmetrical loading required by the violin and viola, the cello and bass involve unnatural posture as well as repetitive motion in the right arm and hand, as well as the left hand.

This study could be carried out by local Youth Symphonies or in conjunction with the American String Teachers Association. Teachers and orchestra directors could be provided with

a kit containing biomarkers and software used to map out posture and body movements. This data could be uploaded onto a national data base so that it could be analyzed for patterns and used to help teachers and physicians. The data entered would be entered anonymously in order to protect the health information of the student being measured. A challenge of this research venture is limitation of funding and support for youth symphonies, limiting the number of students that could be involved as research participants. The technology required to carry out 3-D mapping research is expensive to attain, potentially limiting the number of subjects that could be involved.

The vast majority of studies done measuring the changes in youth coordination over time have been done through the lens of sports. Often, the measurement of coordination is the child's ability to throw and catch a ball with one or both hands. A study that measures coordination on a more precise scale would be much more beneficial in the study of child musician injury development. Understanding the relationship between coordination and development of poor posture and habits could greatly increase the tools a teacher has to develop their student.

There is also a wealth of research to be done on repetitive motion injuries in children, specifically, actions of the bow arm and left hand. There is a multitude of pediatric knowledge on other dynamic injuries such as Little League Elbow and other sports related repetitive motion injuries.[59] However, there is little information on the risk of repetitive motion from bowing the violin or viola.

Increased research in the area of performing arts medicine, specifically in childhood injuries, should lead to better representation in the pediatric literature. While music-related activities are recognized as a key childhood milestone, their impact on the body of children is not

[59] Catherine E. Burns et al., *Pediatric Primary Care*, 959.

examined closely. Incorporating performance-related musculoskeletal disorders and other performance-related injuries into pediatric medical literature would make communication between performer and provider much easier. This in turn would lead to better prevention, as a physician would be able to identify possible threats or warning signs before the performer could identify them as problematic. Being able to identify and prevent injuries in young musicians might help to stem the alarmingly high incidence of performance-related injuries and lead to a lifetime of healthy and productive musicians well into the future.

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