

ESTABLISHING A BIOMECHANICAL BASIS FOR INJURY PREVENTATIVE PIANO PADAGOGY*

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Abstract

This paper describes some of the issues and areas of study that are critical to establishing a relationship between piano pedagogy, piano technique and playing-related injuries. Studies report that a significant number of pianists suffer from playing-related injuries. Recent studies on the rates of occurrence of various types of playing-related injuries, the factors that contribute to the injuries and the impact of these injuries are briefly reviewed. The need for a broad multi-disciplinary approach is identified and the roles that musicians, medical professionals, experts in biomechanics and piano technicians have in establishing a basis for injury preventative piano instruction are presented. Both the piano and human hand are very complex systems. Several areas of current investigation in biomechanics that are relevant to establishing a basis for piano pedagogy that results in injury free playing are summarized. These areas include clarifying the impact of geometric and muscular redundancy, limb biomechanics, keyboard mechanics and neuromuscular control on playing the piano.

INTRODUCTION

A significant fraction of pianists will at some time experience pain while they play. More significantly, many will suffer injuries, playing-related health problems or playing-related musculoskeletal disorders. In some cases, these injuries will be serious enough that the individual will no longer be able to play the piano. These injuries are occurring in individuals who are very dedicated to their art, who practice carefully and who have had many years of private study. It is important to discover any relationships between the pedagogical and technical approaches and injuries. Numerous studies have been reported in the literature that identify the types of injuries that arise from playing the piano and their frequency of occurrence. It is not the purpose of this paper to provide an exhaustive summary of these studies but to present some examples to serve as a context for the investigation of the biomechanics of playing.

* As identified in this paper, research in piano pedagogy and the biomechanics of pianist-piano interaction is a highly multidisciplinary field. This work could not have been completed without the support and collaboration of the Prof. Gilles Comeau and the students and staff of the Piano Pedagogy Research Laboratory at the University of Ottawa, particularly, Mr. Jason Ray. I also acknowledge the financial support of the Natural Sciences and Engineering Research Council of Canada.

The biomechanical circumstances that give rise to these injuries are complex and the differences between playing techniques that allow these injuries to occur and those that prevent injuries may be subtle. The action of playing a piano involves the interaction of a mechanical device (the piano action) and a biomechanical system (the human arm). The purpose of this paper is to illustrate some of the biomechanical features of the human arm and hand and to relate these to pedagogical practice.

PLAYING-RELATED INJURY

Data on playing-related health problems has been gathered using a variety of approaches. In this section, a small sample of the results that have been reported will be presented with an aim of illustrating what is known in this area and the difficulties in obtaining applicable data. The published results are used here to address issues of injury rate, injury type, factors that may contribute to the injuries, and the impact of these injuries. Note that injured musicians are not always willing to admit their pain or injuries for a number of reasons including the fear that widespread knowledge of an injury may impact their careers or concern over the reaction of their teachers (Bressler, 2000). It is difficult to identify the numbers of these injuries that simply go unidentified and untreated, for example, some are hesitant to report pain or injury due to a fear of physicians and hospitals (Zaza, 1995). In some cases, the music simply stops.

Injury rates

The numbers of pianists that experience playing-related health problems, as reported in the literature, vary widely. A thorough review of injury rates of musicians in general has been performed by Zaza (1998). More recent results generally agree with her conclusion that the prevalence of playing-related musculoskeletal disorders ranges from 39% to 47% among adults and is lower (17%) among high school students. Variation in the reported figures is large and can be at least partially explained by differences in the approaches used to collect the data, the interpretation of what it means to have a playing-related injury, and the populations studied. Examples of more recent studies include Morse (Morse, Ro, Cherniack and Pelletier, 2000), who finds that 33% of keyboard players suffer upper extremity musculo-skeletal disorders. Cayea and Manchester (1998) examined university-level music students and found that 13.1% of pianists asked for medical care. This figure is lower than most other reported injury rates but this may be because the data only identified those who sought help through a specific pre-paid health plan. In a study of 341 pianists, both professional and amateur, aged 8 to 70, researches in Spain (Rosety-Rodriguez et al, 2003) found that 65.1% either currently had a repetitive strain injury or had previously had a repetitive strain injury. Overall, it can be reliably concluded that the rate of playing-related health problems amongst musicians in general and pianists in particular is high,

perhaps second only to the rate of occurrence of these types of injuries resulting from computer use (Morse, Ro, Cherniack and Pelletier, 2000).

Factors that may contribute to playing related injuries

In these and others studies researchers have worked to identify factors that may indicate an increased incidence of injury. For example, in a recent paper by De Smet, Ghyselen, and Lysens (1998), 28 of 66 (42%) pianists studied presented overuse syndromes of the wrist, hand or elbow. In this work researchers considered the factors that might indicate an increased likelihood of injury. The only factor that served as predictor of injury was small hand size. They identified no significant correlations with starting age, with other instruments played, with the use of warm-ups or stretching, with the intensity or duration of practice, with hypermobility or with gender. Cayea and Manchester (1998) also found no difference in injury rate between male and female students. They also found that organ students had a much lower rate of injury than pianists (7.2%) which is surprising as organ students usually spend considerable time practicing on the piano and when playing the organ the feet are generally not useful to provide postural support. Shields and Dockrell (2000), in a study of injuries in 182 pianists in Irish music schools, found that 25.8% suffered injury but that there was no significant difference between male and female students.

Types of injuries

Musicians typically search out a variety of medical professionals to help with their healing. These include physical and occupational therapists, general practitioners as well as specialists such as orthopedic surgeons. Because of the number of sources of help for injured pianists, it is difficult to get a good picture of the distribution of the various types of injuries. In a study examining the reasons that injured musicians¹ consult hand surgeons (Nourissat, Chamagne and Dumontier, 2003) three major groups of problems were identified. The researchers state that 18% of the patients showed signs of overuse, another 8.8% of the patients showed signs of misuse and 5.7% had dystonia². They also state that the level of dystonia among their sample population is probably significantly lower than that in the general population of musicians since individuals with dystonia general consult physical therapists and not surgeons. Overall two-thirds of their patients had musculo-skeletal disorders.

1 41% of the patients were pianists.

2 Dystonia is a state of abnormal muscle tone.

Sakai (2002) examines the different types of hand pain experienced by a group of 200 pianists. Pain due to tendon inflammation was found in 28% of the cases, enthesopathy³ was found in 24.5% of cases, and muscle pain in 19% of the cases. Neurological problems (including dystonia) were found in 14% of the patients, finger joint pain in 11% of the cases and neck pain or pain in the torso in 2.5% of the cases. It is also suggested here that the pain is often the result of hyper-abduction of the thumb and little finger as would be required in playing large chords.

Impact of injuries

The impacts of these injuries are varied and affect many aspects of the pianists' life as well as society as a whole. The injured pianist (Hochberg, Leffert, Heller and Merriman, 1983) may suffer from loss of control (34%), a diminished facility in playing (18%), reduced endurance (18%), or reductions in the maximum speed (18%) when executing fast, forte passages.

Economic losses include loss of income which is often compensated for by a change in career focus. Medical costs for treatment can be significant. Of serious injuries requiring the consultation of a hand surgeon, surgery was proposed for about 19% of the patients in an attempt to address the problem (Nourissat, Chamagne and Dumontier, 2003). Other cases require consultations with various medical professionals and generally involve some therapy (primarily physical therapy). While it is difficult to state the economic costs of these injuries to musicians some information is available on the general costs of this type of injury.

Within the federal workforce in the United States (Feuerstein, Miller, Burrell and Berger, 1998), the mean number of work days lost for individuals with carpal tunnel syndrome was 84 and for those with enthesopathy, 79. Injured musicians may seek alternate sources of income during this time. The mean treatment costs for carpal tunnel syndrome were \$4,941 while for enthesopathy the mean costs were \$4,477. The health care costs for mononeuritis and enthesopathy claims in this study were \$12,228,755 (in 1994 US dollars) with the average cost being \$2,849. A 1989 study by Webster and Snook (Webster and Snook, 1994) in the United States of upper extremity cumulative trauma disorder related insurance claims indicated that the average cost to an insurer for an injury was (in 1989 US dollars) \$8,070. Of this total, medical costs represented 32.9% and indemnity costs were 65.1%. The total cost of all such injuries in the United States was estimated at \$563 million during the study year, 1989. Considering that musicians may be the second largest group within this population behind computer users (Morse, Ro, Cherniack and Pelletier, 2000), the cost of these injuries is substantial.

3 Enthesopathy is disease located where muscle tendons and ligaments are attached to bones or joint capsules.

THE NEED FOR A MULTIDISCIPLINARY APPROACH

Gaining an understanding of the causes of playing-related injury in pianists requires a strong multidisciplinary approach. While some excellent research work (see, for example, Zaza [1995] and Bressler [2000]) has been done that begins to build an understanding of the causes of these injuries, many challenges still exist in coming to a complete understanding of the relationship between:

- the pedagogical approach used in the individual's piano training,
- the biomechanics of the movements involved in playing the piano,
- the injuries that result in a significant number of serious piano students, and
- the piano itself.

Remember that these injuries are happening both to individuals early in their piano studies as well as to those who have trained for many years under the private tutoring of accomplished musicians. In a study on the practices of piano teachers in preventing injury, Redmond and Tiernan (Redmond and Tiernan, 2001) found several interesting results. While piano teachers are generally skilled in both playing the piano and in teaching piano technique, they do not generally have a solid understanding of the relationship between the pedagogical approaches they use and the resulting biomechanical requirements. The survey found that piano teachers passed on the knowledge they had acquired from their teachers or from their own experiences on piano playing-related injuries but that there was also some indication that they showed hesitance in doing so. The hesitation is possibly due to the limited understanding of these relationships and the lack of formal training that pianists have in this area. This lack of training is not a surprise given the complexities of the biomechanics of the limb, with its complex and inter-related systems of nerves, bones, and muscles. In fact, as will be explained below, there are several areas of current research in the field of biomechanics that are key to understanding the relationship between pedagogy, playing technique and the biomechanics of any injuries that result.

Much existing work (for example, Zaza [1995]) focuses on the roles of two groups of people in dealing with playing-related injuries — the piano teacher and the medical profession. In order to gain a complete understanding of the relationships between the issues listed above, there are at least two additional groups of people that have a central role to play in the work — the biomechanical engineer and piano technicians. Below are the roles that these four groups of individuals can play in addressing these issues.

Musicians. Any study of the injuries that result from playing the piano must be done with a full appreciation of the art and those who teach it. The words we use to describe piano technique and approaches to specific technical challenges often imply body movements in an imprecise way (from the point of view of an engineer). A thorough understanding of pedagogical approaches and the various schools of piano technique

is required in order to make progress in understanding the biomechanical implications of the movements. The nature of the relationship between student and teacher is an important link in the chain that may lead to injury.

Medical professionals. Various groups of individuals within the medical profession serve as the primary sources of care for injured pianists. These people that see and treat large numbers of these playing-related injuries, have a unique perspective on possible relationships between causes and injuries. Their expertise goes beyond the statistics describing the rates of occurrence of these injuries. The collected anecdotal evidence that they possess can play an important role in gaining the required understanding. It is important to note that in most cases medical professionals are called upon only after an injury has occurred.

Biomechanical engineers and neuroscientists. Any study of human movement requires developing and understanding of the body as a complicated biomechanical system. The relationships between the motion of a limb, the muscles which cause the motion and the complex system of nerves that control the motion are mathematically involved and many counter-intuitive results arise from the analytical and experimental study of these relationships. These issues are all the more difficult in the case where the limb comes into contact with an object, in this case the piano key. Muscle and tendon properties are far more difficult to understand than typical engineering materials. These areas of study are progressing rapidly and are of critical importance in order to provide a solid biomechanical foundation for the development and presentation of sound approaches to piano pedagogy. Errors, misconceptions and a lack of awareness of these issues are common in the pedagogical literature⁴.

Piano technicians. We must not forget the important role of the piano itself. Changes in regulation of the piano may make a significant impact on the approach an individual may have to playing that piano. Piano technicians (and piano manufacturers) deal not only with the technical requirements of keeping instruments in good working order but in adjusting them to suit the demands of students and performers. They too have an extensive base of empirical, if sometimes anecdotal, knowledge which should play a role in the research.

All of these four groups have unique bodies of knowledge all of which must be incorporated into work that aims at gaining a complete and in-depth understanding of piano playing and playing-related injuries.

4 For example, Ortmann (in his book *The Physiological Mechanics of Piano Technique*), defines weight as mass per unit volume. This is completely wrong and makes it difficult to understand his discussion of the use of arm weight in playing.

BIOMECHANICAL ISSUES

The remainder of this paper will present a summary of some of the key biomechanical results and questions that are fundamental to relating pedagogy and the mechanics of piano performance to the injuries that occur. In some cases, the knowledge base is solid, and in others much work needs to be done. These issues will be illustrated by considering some of the critical events that occur between the brain “deciding” to play a note and the actual depression of the key.

Movement — Key depression

When the hammer hits the string it is moving as a projectile — the action in the piano has thrown it onto the strings. It is clear that after the hammer has been thrown there is nothing that can be done to change the sound that will result. A basic physical argument would require that the only critical variable in this event is the velocity of the hammer when it begins its flight toward the strings. If this is true then the only important feature of the motion of the key as it moves downward is its speed at this instant.

However, it is known (Askenfelt and Jansson, 1991) that the shank of the hammer is flexible enough that it bends as it accelerates towards the strings (during the time when it is in contact with the jack). There is mechanical energy stored in the bent shank that is released as it straightens (like using a long stick as a whip). If the shank bends during the motion, it will not only fly up and hit the string but it will be flexing as it does so. If this is significant in terms of the resulting hammer-string interaction, and it seems reasonable to think it might be, then the motion of the *key* during its entire movement is very important. The details of the time course of key depression will determine not only how much the hammer shank bends but also the relative timing of the release of the energy stored on flexing the shaft and the impact of the hammer on the string. These motions are very fast and careful study is required to determine the degree to which hammer vibration may allow a pianist control over the resulting sound.

It is said in many places that a piano technique that results in vertical motion of the finger is in some way *efficient*. This reflects a kinematic (motion-based) approach to building an understanding of playing. However, it is clear from mechanical studies that during contact it is often more efficient to push or pull in a direction in which motion does not occur. The basic (and subtle) reason for this arises from the fact that it is more efficient to push on the object using an “efficient” combination of muscles and relying on a constraint to direct the motion than to use a less “efficient” set of muscles to direct the forces and movements in a particular direction.

Geometry — Kinematic redundancy

While the key motion is mechanically well defined, the motion of the finger that causes it is not. Not only can the finger take on a variety of shapes during the motion but the different joints in the finger can be moved differently to create the depression of the key. Beyond the finger, the wrist, elbow, shoulder and the rest of the body can all contribute to the motion that results in the depression of the key. These motions are not random but are the result of the pianist's choice of technique and posture. Each configuration will place different loads on the joints and ligaments, will require different sets of muscles to create the motion, and, will place different requirements on the concentration and skill required to produce the movement. The different movements may all create an identical tone. The differences between the movements are thus critical in examining the demands on the performer and possible injuries that may result.

Some research has been performed in comparing these motions and their biomechanical implications. See for example Bejjani et al (1989) who studied the implications of three different piano techniques (finger shapes). This work was a pilot study that measured muscle activities, finger and arm movements as well as sound to assess a proposed technique for investigating the effects of different finger shapes. Noting that only one subject was used in their pilot study, they found that forces were minimized with a curved finger. Wolf et al (1993) looked at the relationship between joint forces and technique. Their study considered eight experienced professional pianists and they concluded that increased experience resulted in reduced key contact forces. In general, they also found that more rounded finger shapes resulted in lower tendon forces. The large number of configurations possible makes this a large area of study.

Geometry — Muscular redundancy

Unlike typical robotic systems, the human arm has many more muscles than movement degrees of freedom. In addition to the complexities inherent in muscle as an actuator, muscles also have complex geometric relationships to the motions of the joints that they move. Another challenge results from the fact that most muscles generate more than one movement. The biceps muscle has a role to play in lifting the forearm away from the keyboard. However, it also has a significant role in shoulder motion and forearm pronation / supination (the rotation of the forearm so as to move from a palm up to palm down position or vice-versa). When the biceps muscle contracts on its own all three of these movements can happen. Other muscles must also be activated to resist some of these motions in order for the others to happen. This is also true of most of the muscles that move the fingers. As they also pass the wrist, their contraction will also tend to cause the wrist to bend. This must then be counteracted by other muscles. Not only do single muscles cross multiple joints but in some cases they move multiple fingers.

While these anatomical features are well documented, the mechanical implications of these facts are complicated and in many cases counter-intuitive. Careful examination of various playing techniques is required to assess the impact of muscular redundancy on their likelihood of resulting in injury.

Muscular interaction — Stiffness effects

Muscles can only pull, they cannot push. In order for any joint to move in both directions at least two muscles are required — one to extend the joint and the other to flex the joint. In biomechanics this is referred to as an agonist-antagonist pair of muscles. The ability to move in both directions is one of the reasons for the muscular redundancy outlined above but a second, perhaps more fundamental mechanical attribute can be affected by this muscular redundancy. This attribute is the stiffness of the joint (or joints). When two muscles act in agonist-antagonist pairs, they can be activated so that no motion occurs — if they both pull an equivalent amount the joint will not move. When this occurs the major effect is that the stiffness of the joint increases. In most schools of piano technique, the stiffness of the limb is to be minimized — a relaxed and flexible wrist is generally considered ideal. This goal of relaxed movement has complex biomechanical implications. Muscle properties are such that, even when no neural input is activating a muscle, a force is required to change its length as a result of its passive stiffness.

An additional factor here is that muscles are arranged in a far more complicated pattern than simply having a set of two muscles acting as an agonist-antagonist pair about each joint. As an example, consider that there are stiffness implications when using the biceps supinate the forearm without flexing the elbow. When a third muscle is used to oppose the action of the biceps in flexing the elbow while still allowing the supination of the forearm there will be a net increase in the stiffness of the elbow joint. The situation is further complicated by the fact that the biceps also crosses the shoulder joint — flexing the biceps alone will also cause the upper arm to lift. To keep the shoulder from rotating additional muscles acting around the shoulder must prevent the motion. As a result, the shoulder will also stiffen.

The mechanical and geometric configurations of the muscles and joints of the arm and hand mean that in considering the muscular requirements for a given movement, the entire arm and the inter-relationships between all muscles must be considered. The implications of these facts can, again, be quite surprising and counter-intuitive. As well, it is important to recognize that, because of its properties, the human arm, hand and finger cannot be considered as either a pure motion generator or as a pure force generator.

Neuromuscular control

To add a final layer of complexity, the brain and spinal cord play a significant role in determining which muscles get used for a specific task. Once a desired movement is recognized, the brain, based on past patterns of behaviour, complex inter-relationships between past and future movements, and many other issues, selects the muscles that will create the movement. The manner in which this is done is another current and challenging area of research that must be considered when evaluating various technical approaches to piano performance.

Transmission of the neural signals from the brain to the muscles in the arm takes time as does the transmission of neural signals from sense organs in the hand or from the ears back to the brain. These delays depend on the muscles and senses involved but the total delay between the brain sending a command to a muscle and sense organs making the brain aware of the result of that command is at least $1/20$ of a second and can be as high as $1/5$ of a second. Whatever the precise delay time after the brain issues a command for a particular note, many other notes can be played before the brain is aware of the results of playing the first note. From a control engineering point of view, this dramatically increases the complexity of understanding how the brain might be controlling these rapid movements.

CONCLUSIONS

The mechanics of the piano and the biomechanics of the human limb can each form the basis of a complex field of study. In particular, in order to understand the links between technique, pedagogy, performance and injury in pianists it is important to:

1. Advance our understanding of the mechanics of the piano action;
2. Study the wide variety of limb configurations and their impact on the biomechanics of depressing a key or sequence of keys;
3. Study the impact of muscular redundancy on overuse injuries, and in particular, to examine various schools of piano technique in terms of their ability to take advantage of muscular redundancy;
4. Study the impact of muscular redundancy on limb stiffness in the context of technical requirements, and;
5. Consider the implications of neuromuscular control issues on the resulting motions and muscular contractions.

Each one of these areas is challenging. Much is already known about these areas individually but considerable research is required to integrate and understanding of all of these aspects of the biomechanical performance of the arm and hand in order to more completely assess the relative merits of various approaches to playing and teaching the piano.

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