OVERUSE INJURIES AND PIANO TECHNIQUE: A BIOMECHANICAL APPROACH

by

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A DISSERTATION

IN

FINE ARTS

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

DOCTOR OF PHILOSOPHY

Approved

August, 1998

ACKNOWLEDGEMENTS

I would like to extend my sincerest gratitude to Dr. Lora Deahl: teacher, mentor, and friend. Her constant guidance and encouragement has been truly invaluable, both in the writing of this document and throughout the course of my graduate study. I am truly indebted for her personal concern and the sharing of her keen intellect and musicianship.

I would also like to thank Dr. Roger James for his expert assistance in the area of biomechanics; without it, this dissertation would have been impossible.

Deepest appreciation is extended to all members of my dissertation committee–Dr. Lora Deahl, Dr. Roger James, Dr. Paul Cutter, Dr. Donald Tanner, and Dr. Daniel Nathan–for their constant willingness to read and offer suggestions and support.

I am especially appreciative of Dr. Jane Ann Wilson for her guidance in teaching class piano, her unwavering encouragement, and her many acts of generosity.

I am also sincerely grateful to Dr. Wayne Hobbs for sharing his expertise and insights concerning musicology and for providing valuable career advice.

Finally, I would like to thank all of the faculty and staff members from the Texas Tech School of Music for their many kind expressions of caring and words of encouragement during the course of my doctoral study.

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ABSTRACT

Of the total number of musicians seeking medical help each year for injury, over half are pianists. Inappropriate playing technique is a contributing factor to the development of an injury. Pedagogues did not begin to concern themselves with the physiological aspects of piano playing until the twentieth century. Even then, recommendations for building technique were primarily based on the playing techniques of famous performing artists and were often idiosyncratic. These observations are opinion-based and are not applicable to all players; furthermore, in many cases they are biomechanically and ergonomically insupportable.

This dissertation is the first study to approach the combined motions comprising specific pianistic tasks from a biomechanical perspective, taking into account environmental, anatomic, and biomechanical constraints. Twentieth-century pedagogical views concerning piano technique are surveyed, and the debate concerning the appropriate use of exercises is explored. The kinesiology of the playing apparatus is detailed. A theoretical biomechanical norm is offered for seven different pianistic tasks: scales, arpeggios, trills, double-third scales, octave scales, broken chords, and broken octaves.

Mechanical factors of muscles and tendons and their responses to force application are described. Common sites and types of injuries suffered by pianists are also discussed. Advice for the prevention of keyboard injuries is offered based upon both empirical and quantified data from the medical, biomechanical, and ergonomic sciences. Certain practice habits and movements are identified as having the potential to cause injury.

The dissertation culminates with instructions for performing a qualitative biomechanical analysis of a given pianistic task on an individual pianist using checklists developed for that purpose.

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CHAPTER I

INTRODUCTION

Justification

In the last decade, interest in injuries caused by music-making activities has dramatically increased. Performing Arts Medicine has evolved into a distinct medical specialty in response to these concerns. Books, articles, and videotape series concerning overuse injuries and other medical problems of musicians are appearing at an exponentially increasing rate. Unfortunately, while writings and research concerning music-related injuries have proliferated in the medical community, the professional music world has only just begun to focus attention upon this problem.

The focus of the majority of articles that have been written on music-related injuries is upon treatment of these problems. Fewer are the articles that discuss prevention of injuries, and fewer still, those which discuss the correlation between injury and piano technique.

Among piano teachers, a debate has arisen in the midst of the rising tide of injured players as to the appropriateness of using technical exercises. Technical exercises and etudes have been emphasized by performers and teachers as the best way to build a strong technique for the past two hundred years. Piano pedagogy experts are beginning to challenge that view, in the belief that misuse of these exercises is all too common and leads to injury. This divergence of opinion is epitomized in a series of discussions between Fernando Laires and Dorothy Taubman which appeared in *Piano Quarterly* in 1987 concerning Isidor Philipp's "Exercises for the Independence of the

Fingers."[1] Laires, a student of Philipp, claims that these exercises are not in and of themselves hazardous. Taubman, who has experience in helping rehabilitate injured pianists through modification of technique, disagrees. She points out that there are certain notated features in the exercises which can be physically damaging. This debate over the appropriateness of using exercises in the development of piano technique is but one facet of a larger issue: How can the risk of sustaining a piano-related injury be minimized? Much of the advice given by well-known piano pedagogy experts is not built upon a correct understanding of anatomical function and is therefore suspect. Though some of this advice may well be effective and helpful, some of the recommendations by pedagogues may be viewed as potentially hazardous; following such advice might lead to the development of an overuse injury.

Opinions from the fields of medicine and ergonomics tend to suggest that some physical motions are inherently dangerous. For instance, Alice Brandfonbrener of the Medical Program for Performing Artists in Chicago has stated that exercises which require prolonged use of the hand in fully outstretched position unnecessarily strain tissues, leading to injury.[2] This notion of some motions being more hazardous than others seems to be borne out by a study conducted by Sakai, in which 30 of 40 pianists with hand and forearm overuse attributed the development of their physical malady directly to practicing a particular keyboard skill.[3]

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1 Frank Wilson, "Dorothy Taubman and Fernando Laires: Interview with Dr. Frank Wilson," *Piano Quarterly* 35 (Fall 1987): 56-59.

2 "Harmful Practices That Cause Injury," *Clavier* 33 (February, 1994): 18- 20.

3 Naotaka Sakai, "Hand Pain Related to Keyboard Techniques in Pianists," *Medical Problems of Performing Artists* 7 (June 1992): 63.

There has always been a fascination with the physical characteristics of musicians' hands. For example, in *The Physiological Mechanics of Piano Technique* , Otto Ortmann discusses various hand shapes in terms of angle of abduction between the thumb and the fifth finger and stretch between various fingers.[4] Ortmann was one of the first piano pedagogues to point out that although hand shape and characteristics varied from person to person, common pedagogical practice dictated that one "correct" hand position be imposed on and used by every piano student. Yet, among piano pedagogues, tendencies to recommend one and only one "correct" way to accomplish any given technique are only too frequent. Some of these recommendations are well thought out, based upon human anatomy and common laws of physics. Others seem to be merely the insistence upon a particular way of playing that has proven successful for the teacher. Individual differences in body morphologies are not taken into account. Indeed, some pedagogues seem to imply that if a student does not fall into a predetermined hand and body size and shape, then failure at the piano is inevitable.

In recent years, the science of biomechanics has had an impact upon how we view the human body. There is a growing interest in finding ways to accomplish all activities which place a minimum amount of strain upon body tissues and structures. Scientists have begun to conduct studies which examine the motions employed at the piano from a biomechanical perspective. For the most part, these studies have been conducted in the areas of the pure sciences and in biomechanics. Musicians have been slower to join in this investigation of the biomechanics of piano technique.

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4 Otto Ortmann, *The Physiological Mechanics of Piano Technique* (Toronto: E.P. Dutton and Co, 1962), 311-321.

The motions used in piano playing are distinct from many of the skills used in sports. For instance, while motions used at the piano can be considered as goal-directed, the goal may not be merely the execution of a scale, trill, or passage of double thirds. Unlike other skills such as shooting baskets in basketball or serving tennis balls, the execution of any motion at the piano is complicated by added elements of musical expression, such as the desire to produce varied tonal and dynamic effects. The means by which the goal is achieved are as important as the goal itself. The aesthetic result, comprising both the visual effect of the motion itself as well as the tones sounded, are essential ingredients of the musical product. Therefore, piano playing may have more in common with sports such as gymnastics or dance.

Due to the many aesthetic variables involved in piano playing, it can be assumed that it would be impossible to quantify a definitive "position" or "method" of executing any given motion at the keyboard. Moreover, as Otto Ortmann pointed out, our individual morphologies vary; all bodies have idiosyncratic differences. However, at the most basic anatomic level, our bodies are constructed in the same way. All healthy humans have the same basic construction of bones, muscles, ligaments, tendons, and joints. Each of these anatomic parts has basic biological tolerances, and, when these tolerances are exceeded, injury results. Thus, it is certainly possible to establish biomechanical norms for any given motion or combination of motions at the piano.

It is reasonable to view piano technique as a factor in preventing overuse injuries. A need thus exists for the careful examination of physical and ergonomic forces as they apply to the execution of motions employed in piano technique. Such a need would best be met by analyses which take into account both intricacies of physical anatomy and subtleties of piano technique. The techniques we use to play the piano must be reevaluated–not on the basis of what we think might be true, or what has proven successful for us as individuals, but based instead on human anatomy with its physical constraints.

Review of Related Literature

There are some precedents for undertaking a study of piano technique from a biomechanical perspective. Anytime a given motion is analyzed with a biomechanical or ergonomic approach, one of the usual underlying motivations is to prevent injury, especially overuse injuries which may arise from use of the anatomy beyond biological limitations. A biomechanical approach might also be used to improve the efficiency of an already healthy technique. Several studies, mostly conducted in the areas of pure science, have addressed specific isolated motions employed at the piano. These studies have generally concentrated on one small part of the anatomy or one clearly defined type of technical motion. Other studies have attempted to draw a correlation between a specific motion and the occurrence of overuse injuries.

Biomechanical Models of Fingertip Position

David Harding developed a mathematical model of the finger which was then used in conjunction with a force-calibrated digital keyboard in order to determine the finger positions that minimized biomechanical forces in tendons and joints during piano playing.[5] The joints selected for force minimization were the metacarpophalangeal (MP–at the base of the hand) and distal interphalangeal (DIP–next to the fingertip) joints. Harding then measured the joint forces in four subjects who had a range of zero to 39 years of experience playing the piano. He found that over a wide velocity range, the finger force generated by the subject with no piano experience was about 20% greater than that of the more experienced subjects, suggesting that joint forces can be minimized through developing proficiency and technical fluency. This finding was later validated by B.M. Hillberry, whose study found an inverse correlation of keystrike force with number of years of experience.[6] Since most of the motion of the index finger is in the sagittal plane during piano play, Harding used a two-dimensional static index finger model to find the position which would minimize tendon forces in that finger to the greatest degree. He determined that a curved finger having key contact angle=5°, DIP flexion angle= 85°, PIP (middle finger joint) flexion angle= 5°, and MP flexion angle=59° attenuated tendon stresses to the greatest degree.[7] However, this position involves a nearly vertical finger and is physiologically difficult to attain; it is not generally used in piano playing. However, using the same model, Harding determined that using a gently curved finger having contact angle= 5°, DIP flexion angle= 35°, PIP flexion angle= 20°, and MIP flexion angle= 40° reduced tendon forces by 50% in

5 David C. Harding and others, "Minimization of Finger Joint Forces and Tendon Tensions in Pianists," *Medical Problems of Performing Artists* 4 (September 1989): 103-8.

6 B.M. Hillberry and others, "Joint and Tendon Forces in Pianists' Hands," in *Current Research in Arts Medicine*, ed. Fadi J. Bejjani (Chicago: A Cappella, 1993): 170.

7 Harding, 105.

comparison with playing with a flattened out finger.[8] Harding further notes that since the fingertip force imparted to the key after it "bottoms out" makes no contribution to the sound, finger joint and tendon forces would be further minimized by the pianist's acceleration of the key during its downward motion and release of the finger immediately before the key reaches the end of its travel.[9]

Benjamin Hillberry conducted a study which analyzed finger tendon and joint forces in the hands of eight professional pianists, whose years of experience ranged from twelve to 59 years.[10] His aim was to find the most appropriate position of the finger for reducing tendon and joint forces. Each pianist was given one week to practice a passage from Mendelssohn's *Song Without Words* op. 19, no. 2. Ten notes from the passage were selected for analysis. Presumably, the notes analyzed were the same for all eight pianists. Dr. Hillberry does not include his criteria either for his selection of the musical passage or for his choice of which ten notes were analyzed. Fingertip force is determined by the key mass and its acceleration.

Both Harding and Hillberry used a MIDI (Musical Instrument Data Interface) connection in conjunction with a digital keyboard to measure fingertip force. Since digital keyboards determine volume of a tone by the rate of acceleration of the key, the rate of key acceleration is easily determined by means of MIDI interface. Unfortunately, this method of analysis fails to take into account the differences in key weight and strike force between digital

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8 Ibid., 106.

9 Ibid., 107.

10 Benjamin M. Hillberry, "Dynamic Effects of Work on Musculoskeletal Loading," in *Repetitive Motion Disorders of the Upper Extremity* (Rosemont: Academy of Orthopaedic Surgeons, 1995): 99-109.

keyboards and acoustic grands. Though digital keyboards may be weighted, they do not have the same key responsiveness as an acoustic piano.

Hillberry found that the distal interphalangeal (DIP) joint force (the joint closest to the fingertip) in a gently curved finger was less than half that of a straight finger. Hillberry notes that the pianists' musical expressiveness and use of varying dynamics within the passage resulted in very large variability in the magnitude of keystrike force, which he attributes to the unique nature of musical performance. He also found that the pianists with the fewest years of experience struck the keys with notably greater force than did the more experienced players, confirming the assumption that greater experience and practice leads to increased proficiency. His results emphasize the importance of technique in minimizing biomechanical forces and stresses in the fingers.

Biomechanical Models of the Hand

A group led by F.J. Bejjani conducted a pilot study aimed at measuring the quantitative parameters that define the different patterns of muscle and joint strain related to the use of three hand positions for piano playing.[11] Since this was a pilot study, one professional pianist was asked to perform three pianistic tasks from a selected piece using three hand positions. The three positions employed were: (1) flat hand and extended fingers; (2) arched hand with rounded fingers and slightly flexed wrist; and, (3) quasi-right angle flexion at the knuckles and slightly ulnarly deviated wrist. Three tasks of five seconds each were selected from Bach's Prelude IV in D Minor from Book 1 of

11 F.J. Bejjani and others, "Comparison of Three Piano Techniques as an Implementation of a Proposed Experimental Design," *Medical Problems of Performing Artists* 4 (September 1989): 109-13.

the *Well-Tempered Clavier*, which features arpeggiated chords in the right hand throughout. Task 1 featured a jump of one and one-fifth octaves; task 2 required a repetitive pattern of the thumb and index finger; and task 3 began with one held note and ended with double held notes. Muscle activity of the upper extremity was measured via eight sets of surface electrodes placed on the anterior deltoid, posterior deltoid, triceps brachii, biceps brachii, flexor carpi radialis, extensor digitorum communis, extensor carpi radialis, and flexor carpi ulnaris. Dark markers were placed on selected joints of the pianist's right hand and were tracked with the aid of two camcorders. Sound output of the keyboard was measured with a microphone through a MIDI interface. In the pianist analyzed, position 1 required less flexor carpi radialis activity, probably due to a neutral wrist position. Range of wrist ulnar-radial deviation was significantly greater in position 3. Bejjani emphasized that this particular study was a pilot study and therefore without statistical significance. He does, however, believe that this particular analysis suggests that a professional pianist can efficiently and rapidly alternate between different hand positions while accurately abiding by their specific postural requirements.[12] The achieved purpose of the study was to validate the experimental design for measuring muscle activity in conjunction with sound output.

The aim of a study undertaken by C. Wagner was to obtain an overall view of the variation of hand size and joint mobility in professional pianists.[13] He measured 20 dimensions of hand size, 17 ranges of active movement, and 11 features of passive joint mobility on both hands of 127

12 Ibid., 112.

13 C. Wagner, "The Pianist's Hand: Anthropometry and Biomechanics," *Ergonomics* 31 (1988): 97-131.

male pianists ranging in age from 17 to 63, and 111 female pianists aged 16 to 64. The males' hands were significantly greater in mean values in terms of absolute hand-size variables than those of the females, with the exception of fingertip prominence. Variability of hand shape dimensions, except in the case of fingertip prominence, was less than 10%. Five of the 20 finger spans (stretches between all fingers) measured were significantly greater on the left than on the right. Ranges of active movement (where the subject moved his/her hand using muscles of the hand itself) were on average greater in the women subjects. Variability in ranges of active movement was between 5% and 26%. Women also had significantly greater mean values of passive mobility (where the subject's hand was moved by another person, without the muscles of the subject's hand being activated). With one exception, passive mobility ranges were greater for the left hand. Variability of passive motion was between 11% and 38%. There was a weak correlation between decreasing joint mobility and age, which was calculated only in the male subjects. The study elicited many negative relationships between hand size factors and mobility. The study also demonstrated greater hand mobility in pianists as compared to non-musicians. Wagner concluded that joint mobility and finger spans, not the hand shape and size, had a positive correlation with success at pianistic tasks. However, Wagner points out that the relevance of results of evaluation of hand size and mobility when data on muscle strength is lacking is questionable. However, from his results, Wagner was able to generate a biomechanical hand profile which he suggests be used as a basis for individual assessment by evaluating measurements from an individual in relation to percentile values from a comparison group.[14] Potential problems in the anatomy, such as a very short finger, may be thus identified and the technique of the individual can be modified in order to prevent injury. Wagner also suggests that his data may also contribute to the development of an ergonomically improved keyboard.[15]

Dr. Sang-Hie Lee built upon the work of Wagner in conducting his study at the University of Alabama. Lee's study concerned itself with whether or not pianists' hand ergonomics affected temporal and dynamic touch control.[16] The study developed a methodology to examine the impact of eight essential hand ergonomic variables upon five piano performance variables. Thirteen skilled pianists submitted to detailed hand measurements and then performed two technical prototype exercises by Cortot. Their performances were evaluated via a MIDI interface between a Yamahã digital keyboard and the software program *Total Music* which displays: (1) pitch, duration, and dynamics in histogram form; (2) a grand staff in which the section of music played appears in standard notation; and (3) raw MIDI data displayed in alphanumeric form which provide the pitch by number and name, a reading on temporal key events by a clock time of 96 beats per quarter note, and the velocity of key descent. The first exercise played was a five-finger pattern for the right hand with a polyphonically sustained note on F, held with the fourth finger. The second excerpt was a left-hand arpeggio requiring hand spread, crossing the hand over the thumb, and upper arm rotation at the shoulder. Lee found that in performance of both exercises, the size of the hand itself had little influence on touch control. Joint mobility

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14 Ibid., 127.

15 Ibid.

16 Sang-Hie Lee, "Pianists' Hand Ergonomics and Touch Control," *Medical Problems of Performing Artists* 5, (June 1990): 72-8.

and hand weight were the only two ergonomic aspects found to be associated with temporal and polyphonic control in the playing of the five-finger exercise. Pianists with greater wrist mobility played the passage with faster tempo but with less sustaining force on the fourth finger.[17] Though further findings of the study were not statistically significant, some tendencies were observed which could provide hypotheses for future studies. For example, wrist mobility had a high correlation with dynamics and articulation evenness. In playing the arpeggio exercise, finger length and hand length both had inverse impact on articulation evenness.[18] Wagner's correlation with finger span and pianistic success was not confirmed; however, Lee's study examined the relationship between functionally defined hand ergonomic variables and specific piano touch variables while Wagnér compared measurements of pianists' hands apart from actual piano performances.

Correlation of Hand Characteristics With Overuse Injuries

David Ong undertook an investigation to determine whether or not a link could be established between some measurable characteristics of the right hand, practice habits, and overuse injuries.[19] He measured hand grip strength, hand pinch strength, hand stretch and span, hand grip endurance and hand pinch endurance in 59 subjects recruited from post-secondary institutions in the Edmonton, Alberta area. The subjects also completed a

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17 Ibid., 76.

18 Ibid., 77.

19 David Ong, "The Association of Right Hand Characteristics and Practice Habits with the Prevalence of Overuse Injury among Piano Students" (M.S. thesis, University of Alberta, 1992).

questionnaire detailing their practice habits. Ong found that the overall prevalence of overuse among the student population he surveyed was 53.7%.[20] Though literature concerning overuse injuries has reported more right hand injuries, Ong found that the discomfort experienced by the group he surveyed was bilateral. Hand dominance did not seem to be a factor, since the majority of the subjects were right-handed yet demonstrated an equal tendency to develop overuse in both limbs.[21] General hand flexibility did not correlate with the tendency to develop overuse injury, and the hypothetical assumption that students without overuse injuries have larger hand spans was not supported.[22] Ong found that students who had been injured demonstrated more strength and endurance than students who had never been injured.[23] Neither the age of the pianist or the number of years of experience in playing seemed to influence the rate of injury. The study showed an association between overuse injury and greater number of hours and frequency of practice.[24] Ong also established that students who had suffered overuse injuries had a tendency to practice beyond the onset of physical discomfort. He was, however, unable to determine the relationship between a "tense" manner of playing and overuse injuries.[25]

Wrist Motion

In-Seol Chung of the Orthopaedic Biomechanics Laboratory at the Texas Tech Health Sciences Center, El Paso, studied nine pianists to

20 Ibid., 74.
21 Ibid., 75.
22 Ibid., 77.
23 Ibid., 77-78.
24 Ibid.,86.
25 Ibid., 87.

determine how the wrist was being used in performing four different techniques: arpeggios, octaves, broken octaves, and trills.[26] This study was the first to define the average ranges of motion for the wrist in the performance of selected motions at the piano.[27] These selected techniques were performed by the subjects both as isolated exercises, and within the context of standard repertoire pieces. The subjects, consisting of two concert pianists/professors of music and seven doctoral students, executed each technique at slow, medium, and fast tempos as designated by use of a digital metronome. After having active and passive ranges of wrist motion measured, each subject was fitted with an electrogoniometer to measure wrist motion during the performance of the selected techniques. These data were displayed on a monitor, recorded by customized computer software, and later analyzed with *MathCad* software. The subjects were divided into two groups based upon their generally different methods of practicing and performing at the piano. Members of group 1, the "weight-playing" group, had concentrated on increased use of the intrinsic muscles along with forearm rotation and reduced usage of wrist flexor and extensor tendons for a period of at least ten years, believing that these measures would reduce the risk of developing an overuse injury. Chung termed group 2 the "traditional" group, but does not elucidate their general practicing tendencies or beliefs about how the anatomy should be utilized. In performing isolated exercises, the greatest range of wrist motion was required for arpeggios while trills required the least amount of motion. In the exercises, the average minimum/maximum range of

26 In-Seol Chung and others, "Wrist Motion Analysis in Pianists," *Medical Problems of Performing Artists* 7 (March 1992): 1-5.

27 Ibid., 5.

flexor-extensor motion (up and down) was 26° extension (E) to 16° flexion (F) in the right wrist and E16° –F19° in the left wrist. In radioulnar movement (side-to side), the range was from 53° ulnar deviation (U) to 28° radial deviation (R) in the right wrist and U28°–R12° in the left. In performing repertoire, average flexor-extensor wrist range was E29°–F18° in the right wrist and E20°–F23° in the left. Average radioulnar movement in the repertoire was U54°–R28° in the right wrist and U33°–R27° in the left.[28] Thus, repertoire required greater wrist usage, in both directions (flexor-extensor and radioulnar) than the performance of the exercises. Results indicated that group 1 used less motion than group 2 in the exercises and in the repertoire pieces.[29] The researchers therefore concluded that the "weight-playing" style required less wrist motion than did the "traditional" style of playing; however, whether or not the weight-playing style would reduce the incidence of overuse injury was not determined. Chung did not discuss the effect of the two different styles upon tone quality.

Lillian Upright, a pianist, surveyed the various uses of the wrist in her doctoral dissertation at the University of Alberta.[30] Her work is not quantitative, but is rather a qualitative assessment of the general motions of the wrist and how they may be used to accomplish certain musical goals in passages from Beethoven's *Bagatelles*. She first examined the anatomy of the wrist and then applied basic principles of physics in making her recommendations. She concluded that use of the wrist impacts the speed at

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28 Ibid., 3.

29 Ibid., 3.

30 Lillian Upright, "The Pianist's Wrist: Its Use, 'Dis-use' and Mis-use With Illustrations from Beethoven's Bagatelles" (D.M. diss., University of Alberta, 1988).

which the hammer of the piano mechanism strikes the string, causing either retardation or acceleration of the hammer. Moreover, stability at the wrist can be both the means of achieving lightness, when the fingers play from the "hand knuckles" using the stable wrist as a fulcrum, and as the means of producing a "sturdy sound," when the wrist is fixed and the elbow serves as the fulcrum. A "resilient" wrist can be the means of achieving a weighty tone by transmitting the weight of the torso, shoulder, upper arm, and forearm to the fingers. The wrist can also aid in releasing muscle contraction by flexing and allowing the hand to "float" off the keys.[31]

Upper Arm and Torso

In Milano, Italy, Grieco investigated the relationship between piano playing and musculoskeletal disorders with the aim of improving subject health and piano performance.[32] The study had two parts: a questionnaire analysis of 117 subjects aged eight and up, and an electromyographic study of six piano students in their final year of study. The questionnaire indicated that hours of practice per week ranged from 14 in younger students to more than 30 in older students. Eighty-seven percent of the students distributed their practice evenly throughout the week.[33] Eighty-two percent took breaks during piano practice lasting an average of 11 minutes every 70 minutes; however, 32% practiced for excessively long periods (more than two hours) without a break.[34] Sixty-two of the subjects complained of one to five injuries

31 Upright, 55.

32 A. Grieco and others, "Muscular Effort and Musculo-skeletal Disorders in Piano Students: Electromyographic, Clinical, and Preventive Aspects," *Ergonomics* 32 (1989): 697-716.

33 Ibid., 701.

34 Ibid., 702.

involving the lumbar back, dorsal back, cervical neck, upper trapezius, shoulders, forearm and wrists.[35] The six subjects studied in the electromyographic study performed exercises selected from Hanon which involved different use of the hand/forearm. Each subject performed the exercise at the minimum speed specified by the score and at his/her own personal maximum tempo. In addition to the selected exercises, each subject performed one or two passages from his/her repertoire which he/she considered to be the most difficult.[36] Taken as a whole, the results demonstrated: (1) that deltoid and biceps muscles showed low effort in comparison with other parts of the playing apparatus; (2) effort of lumbar erector and trapezius muscles as well as the muscles of the epitrochlea group was considerable, though within normal parameters; and (3) effort of trapezius muscles was generally asymmetric, with the left side putting forth more effort, in female subjects. In the males, both trapezius muscles were equally involved with respect to static and median loading while for peak loading there was much greater involvement on the right side.[37] Additional findings demonstrated that the smaller build and the lower muscle power of the females called for greater effort by the large muscles of the shoulder and trunk, especially the lumbar erector and trapezius muscles, in order to sustain finger motion. [38] Analysis of muscle involvement in executing the exercises shows excessive loading of several muscles and muscle groups, notably those of the forearm. Grieco concludes with suggestions for the prevention of injuries via ergonomic improvements of the piano bench. He suggests, at

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35 Ibid.

36 Ibid., 699.

37 Ibid., 705.

38 Ibid., 706.

least for practice if not for public performance, the use of seats with semi-rigid upholstery and shaped seating surface with a back rest for the occasional support of the spine.[39]

Control of Horizontal and Vertical Motion at the Piano

Michael Phelps wrote his doctoral dissertation on the two fundamental directions of motion at the piano.[40] He undertook a historical survey of methods of playing the piano, generalizing about specific trends throughout the history of piano technique. He points out that the importance of twentieth-century piano pedagogy lies in the idea that there is no one technique which is applicable to every player. Rather, there are generalities which apply to every player, including the laws of leverage and motion. This leads to efforts to establish and control body parts which move, stabilize other body parts, or transmit force.

The principal aim of this dissertation was to offer exercises for the student to use in exploring the control of horizontal and vertical motions at the piano. In these specific aesthetic contexts, basic movement principles were examined and discussed in relation to other aspects of piano technique. Specific skills or motions were not isolated; Phelps assumed that the students to which his work was addressed had already achieved a basic familiarity with the principles of motion at the piano.

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39 Ibid., 710.

40 Micheal T. Phelps, " An Approach for the Advanced Pianist Toward Developing Control of Vertical and Horizontal Motion, The Two Fundamental Directions of Movement In Piano Technique" (D.A. diss., Ball State University, 1981), 175-78.

Ergonomics of Virtuosity

Meinke conducted an ergonomic analysis of virtuoso piano playing.[41] The work of piano virtuosity falls into three areas which may occur simultaneously or intersect with one another: (1) the work of performance, (2) the work of learning, and (3) the work of interpretation. Meinke defines virtuosity as being characterized by speed, precision of movement, and control of musical tone. He criticizes studies which have investigated motions at the piano on the grounds that they examine what the pianist actually does when playing without addressing what motions are required to play. Meinke discusses the piano key mechanism and the relationship of force and speed as applied by the pianist. He hypothesizes that the amount of force and speed applied has a direct bearing on tone quality. A fast attack on the key will cause more and stronger restrikes of the hammer upon the string; a slower approach will reinforce the string fundamental.[42]

Meinke next overviewed basic principles of human anatomy. His position is that hand size does not prohibit virtuosity; that is, even the smallest hand and shortest fingers have virtuosic capacity. Meinke's next step was to approach the first three measures of Brahms's *Rhapsody* op. 79, no. 1. He noticed that for each hand, there was a repeating pattern of four phases: (1) reach, (2) unavoidable delay, (3) use (preparation and grasp), and (4) release (followed by either another cycle or an unavoidable delay). He points out that in connecting cycles, there is unavoidable delay, a concept generally ruled out by traditional ergonomics. He recognizes a Japanese adaptation of the ergonomic process, which holds that if delay cannot be eliminated, then the

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41 William B. Meinke, "The Work of Piano Virtuosity: An Ergonomic Analysis," *Medical Problems of Performing Artists* 10 (June 1995): 48-61.

42 Ibid., 51.

processes leading into a given cycle should be adjusted to produce only as much material as can be dealt with in the cycle. Meinke further noted that even though the time values of the notes were different, there was no apparent difference in the amounts of time required to complete the use and release portions of the cycle. He postulated that variations in cycle length were due to the amount of time needed to complete the reach portion of the cycle, or were caused by unavoidable delay. Fundamental motions of cycles are linked so that completion of movement often coincides with, and may overlap, the beginning of the next cycle. He also postulates that fundamental motions are linked between hands; motions occurring in one hand are temporally and physically dependent upon those occurring in the other hand.[43]

Meinke applied the laws of motion economy specifically to piano playing. Effortless acceleration of gravity using the weight of the arm should be capitalized on in order to deliver force to the keys. Meinke speculates that the small movement often seen preceding the actual downstroke is a movement used to impart added kinetic energy to the downstroke in order to produce the desired musical effect. The player should take advantage of the natural recoil of the key mechanism to assist in positioning for the next keystroke. There is a similar principle at work within the human body itself. There is an intrinsic elasticity of the tissues of the forearm which also recoil naturally after a keystroke. Since it is impossible to alter the tone after the point of sound has been reached, forces other than gravity should not be applied to the key after that point has been passed. Although the shortest distance between two points is a straight line, in the playing of wide leaps the

[43] Ibid., 53.

shortest, most efficient motion is a curve. This is because movements described naturally by all joints are arcs. Finally, the pianist should avoid sudden changes of direction in movement. It requires far more energy to stop a motion moving one direction and then generate momentum in another direction than it does to apply a small force obliquely to a movement to gradually change its direction.[44]

Summary of Literature

Biomechanical studies have been done with regard to the fingertip, hand, wrist, and upper arm. However, as may be seen from the studies reviewed, the scientifically structured studies have generally focused upon one isolated part of the anatomy, or upon one specific motion. Wagner, although he did not examine motions used while playing, took detailed measurements of pianists' hands and examined hand flexibility and joint mobility. Although a large amount of quantitative data has been gathered, the applicability of these studies is not clear.

Two studies, those by Upright and Meinke, are more qualitative in nature. Upright discusses the anatomic design of the wrist and explicates its function within piano repertoire. Meinke applies the basic precepts of ergonomics in making some general recommendations about how to produce a tone. Ong's dissertation was the only study which attempted to draw a correlation between anatomic characteristics and overuse; however, he did not discuss overuse injury in relation to piano technique.

None of the studies examines the entire playing apparatus from a biomechanical perspective. Likewise, none of these studies discusses the

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[44] Ibid., 56.

execution of a technical skill at the piano, such as the performance of a scale or arpeggio, in terms of the cooperative work done by all involved parts of the anatomy. Drawing upon established quantitative data, this study will take a qualitative approach in describing and analyzing the execution of selected technical skills. The execution of any skill requires the integrated functioning of several distinct motions. This study, using knowledge from functional anatomy and kinesiology, assessed various technical skills by resolving them into their constituent motions and will establish a theoretical norm for each skill by applying the principles of biomechanics.

Methodology

A background overview of twentieth-century pedagogy is offered and the question of whether technical exercises contribute to injury is considered. The types of overuse commonly suffered by keyboardists are discussed and causes of overuse are explored. Based upon medical, biomechanical, and ergonomic observations, advice is offered regarding the prevention of piano-related injuries. Specific technical motions are then isolated and investigated from a theoretical biomechanics perspective. This study did not attempt to measure or quantify motions made at the piano. Instead, the goal of this project was to examine some common technical elements used in playing the piano in a descriptive, qualitative manner. Therefore, the analyses were conducted on the basis of motions observable by the naked eye. For aid in describing the motions involved in the selected skills, two videotape recorders were used to record the skills as they were performed. The perspectives chosen from which to view the skills were: (1) from a top-view looking straight down on the keyboard and the player's hands, which allowed the observer to note lateral motions of the hand, wrist, and forearm occurring in the transverse plane, and (2) from a side-view, which allowed for observation of the vertical activity of the hand, wrist, forearm, elbow, and upper arm occurring in the sagittal, and to some extent, the frontal planes. The use of videotape offers the additional benefit of observation in slow motion replay. Force sensors, electromyography, and other quantitative measurement instrumentation were not used for this study.

Scales, arpeggios, double notes (3rds, 6ths, octaves, etc.), sustained notes with active finger(s) in the same hand, and trills were broken down into component motions and described in detail. For each skill analyzed, opinions of piano pedagogy experts were first reviewed. Then, the motions were described and evaluated in terms of anatomic functioning, with environmental, biomechanical, and morphological constraints considered. The next step was to develop a theoretical biomechanical norm for the motion. Finally, checklists were developed based on the biomechanical ideal which break down each skill by the involvement of component anatomical parts. These checklists will allow piano teachers to perform qualitative analyses on individual students by providing guidelines for where attention should be focused in evaluating a skill. These guidelines are intended to help teachers and students identify and modify potentially harmful technical habits and thus prevent injury occurrence.

CHAPTER II

TWENTIETH-CENTURY PEDAGOGICAL VIEWS OF THE PLAYING APPARATUS

Historical Survey of Twentieth-Century Piano Technique

Innumerable books have been written concerning piano technique in general by piano pedagogy experts. One of the earliest keyboard technique methods was François Couperin's *L'art de toucher le clavecin,* published in 1716. In addition to giving instructions for the realization of common embellishments, this treatise offered finger exercises for practice by the student. The first treatise concerned specifically with the pianoforte, *Introduction to the Art of Playing the Pianoforte,* was written by Muzio Clementi in 1801. However, neither treatise offered instructions for the physical production of these finger exercises. These early treatises were followed by many like them during the eighteenth and nineteenth centuries, mostly written by French and German pianists. The essential drawbacks of seventeenth- and eighteenth-century techniques were that there was no consideration given to biomechanical constraints and there was too much emphasis on the small motions of the fingers. Varied movements of other parts of the playing apparatus such as the hand, forearm, and upper arm were ignored.[1] Players could cultivate such a technique based primarily on motions by the fingers due to the lighter action of the eighteenth and nineteenth century pianos, which had no metal parts. With the innovation of the metal frame and the resulting heavier action in the late nineteenth and

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1 Elena Letnanova, *Piano Interpretation in the Seventeenth, Eighteenth, and Nineteenth Centuries: A Study of Theory and Practice Using Original Documents* (Jefferson, NC: McFarland & Co., 1991), 144-45.

early twentieth centuries, it became apparent that finger motion alone could not accomplish increasingly difficult repertoire. It was at this juncture that pedagogues began to concern themselves with the physiological and anatomical aspects of piano playing.[2] Even then, these writings, offered mostly by renowned concert artists and teachers were often idiosyncratic, based primarily upon their own playing techniques. Even so, their writings have remained widely influential, with many pianists modeling their techniques directly upon the recommendations of these famous performers and teachers. Moreover, these writings are typically studied in university piano pedagogy classes at present.

Ludwig Deppe (1828-1890)

Although Deppe did not belong to the twentieth century, his ideas laid the foundation for twentieth century pedagogy. Deppe was the first to describe coordinated arm action in piano technique. He believed in distributing the effort of piano playing over every anatomical part from the shoulders to the finger tips. Deppe left no written record; his teachings were propagated by his students.[3] Deppe recommended sitting very low, so that the elbow was one to two inches *below* the keyboard.[4] This recommendation, it should be noted, results increased tension in the muscles of the shoulder and neck (as discussed in Chapter IV). Deppe recommended playing with the tip of the fingers; the elbow gave the impetus for motion while the wrist and hand were to be kept "light."[5] He was completely opposed to the use of high

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2 Ibid., 12.
3 Ibid., 97.
4 Ibid., 98.
5 Ibid., 98-99.

finger motions. The finger muscles were to cooperate with those of the hand, arm, and upper body with the larger muscles used to provide strength.[6] Deppe believed in complete relaxation of the playing apparatus.

Deppe recommended using laterally rounded wrist movements, with the relaxed hand describing an arc; his goal in general was non-interrupted motions. Thus, he was vehemently opposed to exercises in which one or more keys were held down while other fingers played, claiming that the depressed keys allowed the muscles of the hand and arm to rest, which caused the shoulder muscles to "sag," which led to a stiffened wrist and prevented "free-fall" of the finger.[7] Even so, Deppe did seem to believe that strength conditioning was helpful in piano technique; he lifted dumbbells and worked with a horizontal weight bar.[8]

Deppe has been widely criticized, along with Leschetizky (discussed below), for his insistence upon relaxation of the playing apparatus. After all, if the body were completely relaxed at the piano, it would slide off the piano stool to the floor. In order to initiate and apply forces to the keys and control the motion of the arms and hands, the body must alternately contract and then relax sets of opposing muscles. Deppe's concept of relaxation has been replaced by the idea of a support, in which the body moves naturally in accordance with its skeletal structure and the laws of mechanics.

Theodore Leschetizky (1830-1915)

Another of the first pedagogues to consider the anatomical issues of piano playing was Theodore Leschetizky. Though, like Deppe, he left no

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6 Ibid., 100.
7 Ibid., 114.
8 Ibid., 115.

formal written method, some of his students later published his teachings. Leschetizky recommended pressing down the key until it sounded, then lessening the finger pressure on the key, using just enough to keep the key from rising. He also advised raising the fifth and relatively weak fourth finger high so the fifth finger was strengthened and the fourth finger gained the "power of motion." He recognized that the fourth finger might move when the third finger played and that the fifth finger might similarly move during the playing of the fourth finger due to the shared tendon of the fourth and fifth fingers. In fact, he believed it was dangerous to suppress this motion as it might lead to injury.[9] He believed any fingering could be used as long as it did not interfere with performance of a given passage. He recommended using finger exercises which involved holding down one or two keys with other notes repeated in the same hand (discussed later in this chapter). Where fast repeated action was required of the fingers, Leschetizky advised moving the finger from the metacarpophalangeal (MCP) joint while maintaining a "quiet" hand and a high, loose wrist.[10]

Josef Lhevinne (1874-1944)

Josef Lhevinne believed that in the production of a good tone, there should be no movement in the fingers except at the metacarpal joint.[11] Another vital element he identified in producing a "singing" tone is a flexible wrist.[12] Lhevinne recommended that in learning to produce a singing tone,

[9] Roger Crager Boardman, "A History of Theories of Teaching Piano Technique" (Ph.D. diss., New York University, 1954), 83.

[10] Ibid., 86.

[11] Josef Lhevinne, *Basic Principles in Pianoforte Playing* (Philadelphia: Theodore Presser Co., 1924; reprint, New York: Dover, 1972), 12 (page references are to the reprint edition).

[12] Ibid., 19.

that the player poise the hands about two inches above the keys. The hand should be held in a position as would be used on the keyboard, but poised above the keys. The hand should then be allowed to fall a little with the peripheral interphalangeal (PIP) joint leading the way. As the hand descends, the fingers are curved naturally, not held straight. The wrist should remain very flexible so the weight of the descending hand and arm carries the key down to the key bottom without making a blow upon it. In fact, Lhevinne stated that the wrist is so loose that it normally sinks below the level of the keyboard as the key is depressed.[13] According to Lhevinne, as the finger touches the key surface, it feels as though it is grasping the key with the largest surface of the fingertip possible, not hitting or striking it. It is this blow which prevents a singing tone.[14] Every key struck, whether white or black, must go all the way to the bottom of the key bed. The fingers should not be perceptibly raised away from the key surfaces.[15]

Lhevinne went on to say that the tone should be produced by a downward "swing" of the hand, which allows for loud playing without a "bangy" sound.[16] The upper arm and forearm must feel so light that the player has a sensation of floating in these parts. However, the arms are not completely relaxed; if this were the case they would "flop limply." Yet, the arms can be held over the keys with no sensation of tension or stiffening.[17]

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13 This motion is potentially hazardous, as discussed in Chapter IV.

14 Ibid., 21.

15 Ibid., 27.

16 Ibid., 22.

17 Ibid., 26.

Tobias Matthay (1858-1945)

Tobias Matthay's first book, *The Act of Touch,* was written in 1903. He wrote *The Visible and Invisible in Piano Technique* more than forty years later to correct what he believed were misperceptions of his earlier book. He was interested in the important changes in exertion and relaxation of the playing apparatus. However, he did not discuss the roles of specific muscles because he believed it was impossible to exert control over these individual muscles.[18] Moreover, Matthay believed that the movements which are associated with piano touch give either little or only an illusory indication of the hidden stresses of the playing apparatus.[19] Instead of learning the precise locality and names of muscles, we should learn what stresses and relaxations are required of various parts of the playing apparatus. Each segment of the playing apparatus has muscles to contract and relax it (antagonists and agonists). If both sets of muscles are activated at once, no movement occurs. Matthay believed that the player must have control of both sets of muscles for every segment of the playing apparatus. He claimed that this sort of knowledge could only be attained through analyzing the sensations experienced within the body. In regard to the implications of this statement upon the teaching of technique, Matthay wrote:

> Those few gifted ones, who instinctively stumble upon Right Doing, physically, are usually precisely the ones least fitted to help us by self-analysis. The greater their temperamental, emotional and musically-imaginative gifts, the more likely are they to be disinclined, opposed and even resentful towards any exercise of self-analysis, mechanically and physically. Hence we find that these usually prove to be quite bad teachers, technically, in spite of their own well-doing. Nevertheless, it

[18] Tobias Matthay, *The Visible and Invisible in Piano Technique* (London: Oxford University, 1932; reprint, 1947), vii (page references are to the reprint edition).

[19] Ibid., 14.

> is only a successfully musical player, who has really achieved technical mastery, and is *at the same time* gifted with powers of analytical and mechanical reasoning (a rare combination) who can possibly supply *the needed information*; that is, HOW IT FEELS, *physically*, to play *rightly*, and also how it feels to play *wrongly*.[20]

Matthay did, however, believe that we could learn and teach the greater muscular mechanics of the playing apparatus. He felt it was imperative that teachers make clear which limb stresses are necessary and which are to be avoided.[21]

Matthay pointed out that the greater the speed of the vibrating piano string, the louder its resultant sound. The player should never "hit" the key. Matthay cautioned against this use of sudden and uneven force, observing that depressing the piano key 3/8 of an inch results in a hammer movement of about five times that distance. Every movement made at the key is thus exaggerated by the hammer.[22]

According to Matthay, the tone-producing action is not applied until after either the arm, hand, or finger arrives at the key. He claimed exertion is required of the finger-tip at the moment of key depression.[23] He asserted that while the strong muscles of the hand, situated in the forearm, must invariably be used to depress a key, once the key is depressed, these strong muscles should promptly cease working. If necessary, the weaker intrinsic hand muscles should continue holding the note.[24] This will allow the long muscles of the hand to rest. Thus, once the key is depressed, the forearm and hand will feel free of any tension. Matthay also firmly refuted the fallacy of

20 Ibid., 16.

21 Ibid., ix.

22 Ibid., 6-7.

23 Ibid., 18.

24 Ibid., 31E.

the finger working alone; we must also use the hand and arm.[25] The hand serves as the basis for moving the finger and the arm provides the basis for the hand.[26]

Matthay gave specific instructions as to the use of the finger. As previously stated, he believed that the finger should not "hit" the key, but instead be exerted downwards with the key during descent. He identified two forms of finger movement: (1) a "folding-in" or grasping motion, which he claimed was the most commonly used, and (2) an "opening-out" or reaching motion. He made the additional observation that when the finger is raised, it is in a flattened position; the finger "folds in" or curves naturally when descending to the key. This is the opposite of the "thrusting finger action" where the finger is bent when raised and opens out when descending. This "finger thrusting" leads to the negative consequence of "hitting" the key and is thus to be avoided.[27] Not only will such a thrusting motion cause the finger to jar against the key, it is also ergonomically unsuited to the task of depressing the key. Since the key is a lever with its fulcrum just underneath the fallboard, the most appropriate direction for force to be applied is perpendicularly downward into the key. Thus force is more aptly applied by the finger moving in its natural curve down into the key than by the finger applying force obliquely in the direction of the fulcrum.

Matthay noted that the motions of the finger are produced by either the small "weak" intrinsic hand muscles, or by the longer stronger muscles which reach up into the forearm. According to Matthay, when using these

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25 Ibid., 19.
26 Ibid., 20-21.
27 Ibid., 22.

strong flexors, there is a momentary tension on the underside of the wrist. He went on to say that the strong muscles are used to sound the notes, the intrinsic muscles of the hand are used to hold notes down once they have been depressed.[28]

Matthay likewise offered directions for the use of the hand. In order to enable the hand to work efficiently, he claimed that the hand must be exerted momentarily downward with each finger stroke to form a stable basis for finger action. The hand cannot be brought to bear without the intervening exertion of the fingers, especially the fingertips.[29] It is possible, according to Matthay, for there to be movement of the finger with invisible hand exertion, or the converse, movement of the hand with invisible finger exertion. The first is analogous to the popularized term "finger touch," the second is known as "hand" or "wrist touch."[30]

Like the finger, the hand also needs a stable base of operations. The arm serves in this capacity. In his second book, Matthay identified six ways to use the arm:

1. Poised-arm
2. Forearm-rotation
3. Forearm weight
4. Whole arm weight
5. Forearm downward exertion plus weight
6. Upper arm forward motion with forearm downward exertion.

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28 Ibid., 23.
29 Ibid., 24.
30 Ibid., 25.

The first two uses of the arm, according to Matthay, are compulsory and absolutely integral to good technique. The last four uses identified may be used at the player's discretion. However, the last way of using the arm, pushing the upper arm forward along with a downward motion by the forearm, is a major cause of bad tone production and should be avoided.[31]

The poised arm, which is essential to good playing, balances the arm by means of its own muscles. It serves in between the sounding of tones as the basis for action of the fingers in holding down notes, as when producing key-connection legato.[32] Any continuously resting arm weight on the key beds compels the player to exert the hand continuously. Matthay equates this constant hand exertion to weight transfer.[33] Weight transfer, according to Matthay, has the inevitable drawback of interfering with the ability to choose a distinct tone for each individual note. Thus it is only good for "mass-production" effects like crescendo and decrescendo. Conversely, using "arm vibration" involves using individually timed exertions of the finger and hand for tone production while the arm vibrates sympathetically. This arm vibration is used for any rapid passage which must be controlled musically, whether legato or staccato.[34] Matthay favored this type of arm use over his conceptualization of weight transfer. However, it is important to note the difference between a "poised" arm, as referred to by Matthay, and an arm in which the deltoid muscle is unnecessarily tensed. In Matthay's view, a poised arm is the natural result of a torso which is maintained with maximum support.

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31 Ibid., 26.
32 Ibid., 27.
33 Ibid., 29.
34 Ibid., 27.

Matthay declared that there is no such thing as "free-fall" of the arm, stating that an ounce falls with the same speed as a ton. If the arm is "dropped" onto the key, the player cannot tell how much force is needed to produce the desired tone.[35] However, Matthay did acknowledge that inertia must be overcome before the actual act of tone production.[36] Whether movement is initiated by weight or by the muscles, in Matthay's view, was a purely psychological distinction, having little to do with the sound produced.[37] Yet, he later seemingly contradicted himself by advocating weight initiation, claiming that it led to a "rounder" tone.[38]

Matthay also addressed forearm rotation. He does not seem to be talking about large forearm rotary movements, but rather the smaller invisible adjustments made by the hand in order to lend strength to the individual fingers.[39] Matthay stated that the direction of rotation always proceeds from the last finger used toward the next finger being used.[40] He went so far to assert that the supposedly weak fourth and fifth fingers were actually stronger at the piano than the thumb, if rotation was properly applied.[41] He based this conclusion on his observation that the thumb moves obliquely up and down, while the fourth and fifth fingers move more vertically. However, he failed to take into account that if rotation is properly applied to the thumb, it too moves more or less vertically in relation to the keyboard.

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35 Ibid., 39.
36 Ibid., 41.
37 Ibid., 42.
38 Ibid., 43.
39 Ibid., 50.
40 Ibid., 56.
41 Ibid., 55.

Paul Pichier (1873-1955)

Pichier was a student of Leschetizky, and served as his teaching assistant for twelve years. His focus was attempting to understand the connection between the physical mechanics of making a tone and musical expression. Like Leschetizky, Pichier himself published no written record of his teachings; his views, in the form of discussions with one of his students and an anatomist, were later published by his students.[42] Pichier considered the functioning of the anatomy in detail. However, he substituted his own terms for anatomical terms, preferring to label body parts according to their primary function or appearance. For instance, he referred to the trapezius muscle of the neck as the "hood muscle." However, he is not consistent in his use of terminology; he refers to the biceps and deltoid muscles, for instance, by their anatomical designation.

Pichier purported that the playing apparatus is supported by a separate supporting apparatus. Moreover, some parts of the body are superfluous for piano playing.[43] He divided the playing apparatus into three parts: (1) the "adjusting" apparatus, (2) the "grasping" apparatus, and (3) the "weight" apparatus. The adjusting apparatus is responsible for adjusting the length of the playing lever. There is a need to attain a connection between the hand and the key; this is accomplished by the grasping apparatus. The key moves in the direction of gravity; the weight apparatus is responsible for controlling gravitational force. He pointed out that no one muscle or bone belongs

[42]*The Pianist's Touch: Method and Theory of Paul Pichier,* ed. by Walter Krause, trans. Martha Ideler and Peter R. Wilson (Graz, Austria: Perelen, 1972), 11-12.

[43] Ibid., 59-60.

exclusively to one of the three categories, but can function as part of several categories simultaneously.[44]

The adjusting apparatus as defined by Pichier involves muscles and bones functioning together to manipulate the length of the active playing lever. The shoulder girdle and arm are the primary length adjusters. The primary muscles used, according to Pichier, are the elbow-flexing muscles. No work should be done by the biceps.[45] Tension of the muscles on the underside of the arm must be just enough to transfer weight of the heavier parts of the apparatus closer to the torso to the key. Pichier likens this state to a chain and terms it "suspension." He pointed out that playing with more tension than is strictly necessary is counterproductive, destroying this suspended state. If there are mutually antagonistic tensions, that is if both the flexors and extensors of any given body segment are activated simultaneously, there can be no suspension.[46] This observation is similar to that of Matthay, who noted that if both agonists and antagonists (flexors and extensors controlling the same segment) were activated, no movement occurs. Pichier referred to the arm with antagonistic tension as a "light arm," and believed that it should never be used. Instead, the player should take advantage of the natural weight of the "heavy arm." He did concede that these concepts of "light" and "heavy" did not refer to actual weight, but were expressive of a subjective feeling by the player.[47]

According to Pichier, movements for length adjustment before the top of the key is reached are directed from the end point of the playing apparatus

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44 Ibid., 60-61.
45 Ibid., 60.
46 Ibid., 65-66.
47 Ibid., 67.

nearest the torso. The fingers themselves can also initiate motion; when bent at the MCP joints, the fingers pull the rest of the arm forward and raise the wrist. This action was termed "grasping" by Pichier. This grasping motion can also be accomplished through flexion at the wrist.[48] As long as the finger is not in contact with the key, every movement in the playing apparatus moves the more distant part (the finger) around the part nearer the torso (shoulder), i.e., the shoulder serves as the fulcrum of movement. As soon as the finger makes key contact, the parts of the playing apparatus closest to the torso can be moved around the finger, i.e., the finger serves as the fulcrum. Thus action by the adjusting apparatus gradually gives way to action by the grasping apparatus. Pichier claimed this change in the center of motion occurs gradually en route from key top to key bottom.[49] Motions of the grasping apparatus only take place at key bottom; the grasping motion does not directly cause key depression. Instead, it intercepts the weight apparatus (discussed below) and results in what Pichier terms an "after-motion" or "after-flexion." That is, the finger pulls on the key, causing the back of the hand to move slightly toward the fallboard and the wrist to rise in response. Pichier claims that the purpose of the after-motion is to bring the parts of the playing apparatus into position for the next note or chord.[50] Pichier admitted that it was difficult to distinguish a correct after-flexion with the finger pulling against the key against the weight of the arm and shoulder from an incorrect after-flexion in which the shoulder pushes the wrist upward.[51] It should be noted that a correct after-motion as described by Pichier has the

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48 Ibid., 73.
49 Ibid., 76.
50 Ibid., 77-78.
51 Ibid., 78.

potential to generate excessive tension in the flexors of the fingers, since it calls for the finger to continue pressing into the key after the key has already been depressed.

Though anatomy books place physiological limits on the degree of rotation of ball-and-socket joints, Pichier disagreed, claiming there was always some degree of "passive overextension" possible. He similarly believed that the hand can be stretched passively.[52] He taught that the finger joints should not collapse, nor should they be frozen into a "claw."[53] He advocated using a "vaulted hand" in which the finger bones were spread and the finger ligaments were taut for maximum firmness.[54] In this position, the hand describes a globe with the thumb and fifth finger rotating away from each other, aiming downwards.[55] This position, unfortunately, places an inordinate amount of tension on the flexors of the hand, and actually inhibits movement as readily apparent when assuming this position. Pichier claimed that when making grasping motions from this position, the target for grasping of the thumb is the hollow of the fourth finger, while the target for the other fingers is the wrist end of the thumb ball. Grasping motions are made in these directions indirectly, in motions which describe a cone.[56] Pichier claimed that an external indication of a correct grasping motion was the visible gliding of the long extensor tendons on the back of the hand away from the MCP joints. However, this visible tautness of the long extensor tendons would seem to indicate tension in the hand. Furthermore, he claimed that the finger was light as it rested on the key with the wrist hanging

52 Ibid., 81.
53 Ibid., 85.
54 Ibid., 92-93.
55 Ibid., 95.
56 Ibid., 96-97.

heavily below it. Therefore, when making the after-flexion, the relatively weak finger must push against the key to pull the wrist upward in order to prepare for the next stroke. The wrist must similarly work against the hanging elbow.[57] With the adoption of the after-flexion, Pichier seemed to be advocating a motion which directly produces tension.

The weight apparatus as defined by Pichier was made up of the clavicle, scapula, humerus, and ulna (which he referred to as the collar bone, shoulder blade, upper arm, and ulna).[58] Pichier noted that when totally relaxed on the keys, the hand was slightly supinated. Although the radius and ulna lie side-by-side in the forearm and are roughly the same weight, Pichier claimed that the ulna tends to sink with the heavy parts of the arm near the body while the radius is held higher by the hand on the key. Thus, he claimed the ulna was part of the weight apparatus while the radius, was part of the grasping apparatus.[59] The weight apparatus overlaps the adjusting apparatus, but not the grasping apparatus.[60] Pichier's observation is questionable. While the radius may be maintained in a slightly higher position when the hands are placed on the keyboard, both the radius and the ulna tend to "sink" downward due to gravity.

Pichier advocated pulling rather than pushing with weight at all times. Therefore, he claimed that the shoulder would sink backward with each keystroke. He taught that the student should actively pull the shoulder as far down and back on the rib cage as possible.[61] This assertion is questionable, as this movement seems to be superfluous and thus ergonomically

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57 Ibid., 98.

58 Ibid., 102.

59 Ibid., 68-69.

60 Ibid., 102.

61 Ibid., 103.

inappropriate. Pichier claimed that stretching of parts of the playing apparatus releases mutually antagonistic tension. This is accomplished when the wrist is flexed forward during the after-flexion; the elbow, upper arm, and shoulder are passively stretched.[62] When the weight apparatus was properly used, Pichier purported that there was a resulting feeling of carrying the weight of the arm low in the back.[63]

Like Matthay, Pichier refuted the notion of weight free-fall in depressing the keys. Actual free-fall, he claimed, accelerates weight to the bottom of the key, contacting the key with an end velocity of approximately 11 feet per second. Allowing this acceleration to proceed unimpeded would lead to a harsh, undesirable accent. The movement must instead be retarded before the key top is reached, and the arm-lifting muscles must be relaxed gradually as the key is depressed. Pichier termed this "controlled free fall."[64]

According to Pichier, weight of the arm does vary from tone to tone. Therefore, playing force for dynamic control must be increased or decreased by the muscles. He believed that the latissimus dorsi which runs obliquely along the length of the back was the single most important muscle in this regard. The elbow extensor transfers the force of the latissimus. He claimed that it was also the muscle primarily responsible for moving playing and supporting apparatuses in relation to each other.

The supporting apparatus must remain firm, yet pliable.[65] It consists of the anatomical parts which directly support the playing apparatus. The neck and spine are lengthened, and the ribs and breastbone sink in response to the

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[62] Ibid., 106-7.
[63] Ibid., 111.
[64] Ibid., 112.
[65] Ibid., 121.

sinking of the shoulders.[66] Backward rocking on the pelvis is limited by the need to maintain balance. The pelvis may be rocked backward without a corresponding alignment of the spine in order to maintain balance; however, the result is a slumped posture. Forward rocking can occur to a greater extent without loss of balance.[67] Excess forward positioning of the pelvis places undue strain on the lower back.

The pelvis should be raised to one side when reaching toward the extremes of the keyboard.[68] Pichier taught that constant equilibrium should be maintained in the sitting position. He cautioned against pulling against the floor with the feet, claiming that it could cause backward motion of the pelvis and disturb alignment of the spine.[69] With the feet in a naturally supporting position, the natural tendency is for the pedal to be depressed; the player must therefore exert muscular activity at the front of the shin to lift the pedal.[70] Interestingly, Pichier implies that the movements of the supporting apparatus are different when practicing versus performing in that the supporting apparatus can move continually in practice but must be restricted in performance. This raises the question of whether tension will therefore be automatically generated in performance due to the unfamiliar restriction of the supporting apparatus.

Abby Whiteside (1881-1956)

Whiteside advocated a "blended" playing action; that is, she believed that parts of the playing apparatus had to function cooperatively with the

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66 Ibid., 124-5.
67 Ibid., 130.
68 Ibid., 135.
69 Ibid., 144.
70 Ibid., 147.

fingers. She addressed the role of the torso in providing physical support for the arms and in projecting rhythm.[71] One of Whiteside's primary areas of interest was how the upper arm functions in piano technique. She asserted that the upper arm, which she referred to as the "top arm," initiates the action of the entire arm and acts as a fulcrum for fast articulation by the forearm.[72] She further defined the action of the upper arm as gauging distance and delivering power to the key; in fact, she claimed the upper arm was directly responsible for key-drop. She characterized the upper arm as "pulling" in order to produce a tone and claimed that in this way, speed and power can be achieved without overburdening smaller muscles of the playing apparatus. Additionally, the upper arm provides large motions to give continuity to phrases and other linear gestures, such as scales.[73]

Whiteside also discussed an action of the forearm which she called "alternating action." Alternating action is produced by the combination of leverage between the elbow and wrist. While the forearm lifts, the hand goes down. The hand then produces the tone while the forearm prepares to move downward. Whiteside likens this motion to the crack of a whip, citing the effectiveness of flinging the hand down or out through the wrist joint in order to produce much power with a small motion.[74] Rotary motion is the other forearm motion mentioned by Whiteside. She does not discuss this element of technique in any detail; she says only that rotary motion is

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[71] Abby Whiteside, *Indispensables of Piano Playing*, in *On Piano Playing*, ed. Joseph Prostakoff and Sophia Rosoff (New York: Charles Scribner's Sons, 1955; anthology reprint, Portland: Amadeus Press, 1997), 30-32.

[72] Ibid., 33.

[73] Ibid., 33-4.

[74] Ibid., 39-40.

essential to virtuosic technique and that it functions cooperatively with alternating action.[75]

Whiteside said little concerning the precise movements of the fingers. She believed that the action of the playing apparatus further up the arm was more critical than the action of the fingers. In response to the traditionally prescriptive advice concerning the exact movements of the fingers and thumbs, Whiteside stated:

> If I could blast these concepts right out of existence I would not hesitate to do so. That is how faulty and pernicious I think they are. They can literally cripple a pianist if they are put into actual operation. Virtuosity demands that this technique of passing the hand along the keyboard be a blended activity involving every possibility from shoulder to fingers. Certainly that can only mean that the action is initiated at the center of the radius of activity and not at the periphery. Thumb and fingers follow through with perfect timing, but they do not and should not initiate the control for either distance or power. When a movement is necessitated for the completion of an act, nature will supply one which is right in proportion.[76]

Whiteside was right about the larger muscles providing power, but she has seemingly taken an extreme position in response to the "finger schools" of the eighteenth and nineteenth centuries. While the fingers may not provide all the power needed for tone production, they do contribute some muscular effort for small and quick motions. For quick motions, the larger muscles of the arm and shoulder are slow and ineffective; attempting to use them in this way might result in tension in these muscles.

Otto Ortmann (1889-1979)

Ortmann was the first to undertake a scientific study of piano technique based on the principles of physics and human anatomy. Ortmann

[75] Ibid., 42.

[76] Ibid., 42-3.

described in great detail the skeletal and muscular components of the playing apparatus and how they are affected by the neural and circulatory systems. He also discussed the properties and various states of muscles. He stated "in piano-playing the mechanical aim of all movements is the production at the piano-key at the proper time and place of a force sufficient to produce the desired tonal intensity."[77] Like earlier writers, Ortmann viewed the playing apparatus as a leverage system. He pointed out that any extended movement of the hand or finger involves movements in all the other joints.[78] Many of Ortmann's views concerning the leverage system and anatomical constraints were echoed and expanded by other pedagogues, including Paul Pichier and William Newman.

Ortmann arrived at some conclusions regarding the most effective ranges of motion for parts of the playing apparatus. He noted that joint motion is most effective in the middle of the range of motion.[79] The upper arm abducts between a vertical and horizontal position and thus theoretically is at its most effective range at 45° from vertical. However, since abduction acts against gravity, the actual position of the humerus is more adjusted toward vertical. The elbow functions most effectively through an arc slightly less than 90° from vertical. Lateral wrist motion is restricted in range, and must depend upon cooperation of the forearm. Ortmann concluded that the long-standing advice of maintaining the wrist in a straight line with the back of the hand was justified, though the wrist could make vertical adjustments according to the demands of the musical passage. The most effective ranges

77 Otto Ortmann, *The Physiological Mechanics of Piano Technique* (New York: E.P. Dutton and Co., 1929; reprint, 1962), 99 (page references are to the reprint edition).

78 Ibid., 33.

79 Ibid., 31.

of motion for the finger joints are near 40° for the MCP joint, 45° for the proximal interphalangeal (PIP) joint, and 30° for the distal interphalangeal (DIP) joint. However, combining all these angles results in the fingers being curved to such a degree that the nail comes into contact with the key. Ortmann divided the excess curvature among all the joints of the playing apparatus so that the wrist was slightly depressed, the back of the hand ascended toward the MCP joint, and each finger joint was extended slightly beyond its theoretical ideal. In this adjusted position, the finger pad is in contact with the key and all joints still move through their median ranges of motion.[80] Even so, Ortmann did not advocate maintaining a single position, but instead emphasized the fluid nature of living tissue.

In regard to muscular activity, Ortmann derived several basic principles:

1. The simplest muscular movement involves coordinated muscular activity from a number of muscles.
2. Even the smallest movement involves some spread of muscular activity from one muscle group to another.
3. Equal and opposite spatial movements do not necessitate equal and opposite muscular movements. For example, forearm supination covers a wider force range than does forearm pronation.
4. The size and strength of a muscle depends upon its function. The most powerful muscles of the upper limb are accordingly in the back and chest, the next-most powerful in the shoulder, then the arm, and forearm. The weakest muscles are in the hand.
5. The more extended or forceful a movement is, the more necessary is the activity of the larger muscles.
6. Absence of motion does not necessarily mean absence of muscular activity.
7. No muscle is limited to the production of one single motion. Though a muscle might have a primary function, it always has secondary functions and works in coordination with other muscles.
8. Many horizontal and vertical movements are produced by rotation. For example, the hand may move across the keyboard due to

[80] Ibid., 31-32.

> rotation of the upper arm. The finger stroke may result from rotation (flexion) in the MCP joint combined with opposite rotation (extension) in the interphalangeal joints.[81]

Ortmann did not subscribe to the "relaxation" view, pointing out that any position of the forearm other than the vertical position at the side of the body demands fixation of the humerus, which is controlled by the shoulder muscles. The forearm is held in position by contraction of upper arm muscles, and the position of the hand is controlled by muscles of the forearm. Without this muscular contraction, the arm would hang limply. Thus Ortmann refuted "relaxation" in favor of controlled movement.[82] Muscular contraction is not continuous, but shifts from shoulder down to finger, depending upon which part is most active at any given moment.[83]

Ortmann derived three general principles of movement which have practical application to piano technique:

1. All movement generated by motion at a single joint is curvilinear.
2. Any motion of a part of the arm in a straight line results from simultaneous movement at more than one joint.
3. Simultaneous motion in two or more joints can generate both rectilinear and curvilinear movement.[84]

In general, Ortmann believed the majority of movements at the piano are curvilinear. He was moreover very concerned about the ways in which changes of direction, especially abrupt ones, are accomplished, claiming that this required a great expenditure of energy.[85]

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81 Ibid., 47-49.

82 Ibid., 124-25.

83 Ibid., 133.

84 Ibid., 76.

85 Ibid., 78.

George Kochevitsky (1903-1993)

Kochevitsky characterized piano technique as being both mental and physical work. He believed that "each muscle, tendon, joint, and ligament has its representatives in the motor area of the cortex" of the brain.[86] He stated that the sensations received by the brain from movements of parts of the body were proprioceptive. He claimed that proprioceptive sensations were imperative when acquiring motor skills. This assumption led him to assert that when practicing, the fingers should be raised enough to obtain distinct sensations for each motion, but "only as much as is needed for this purpose."[87] Unfortunately, he was not able to quantify exactly how much the fingers should be raised. Furthermore, this recommendation seemingly conflicts with his position concerning the "finger schools," which he regarded as "biomechanically constraining" and "unnatural."[88] In order to enhance proprioceptive sensations, Kochevitsky also claimed that pianists should practice slowly, imparting slight pressure into the key *after it is already depressed*.[89] This advice conflicts with currently recognized ergonomic guidelines which stipulate use of minimal energy. Once the key has been depressed, additional pushing is futile. One might also be skeptical about Kochevitsky's claim that proprioceptive senses from the left hand are weaker than those from the right.[90]

Kochevitsky acknowledged that to some degree, piano technique is unique to the player's personality and is tied to the musical ideas expressed in

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86 George Kochevitsky, *The Art of Piano Playing* (Evanston, IL: Summy-Birchard, 1967), 24.

87 Ibid., 24-5.

88 Ibid., 8.

89 Ibid., 25.

90 Ibid., 27.

a piece. He therefore asserted that technical perfection should be measured by how successfully the player's artistic intentions correspond with his/her means of realization, not by how well the player has mastered formal technical exercises.[91] He went on to say, however, that though technique is individual to some extent, the basic laws of technical development are the same for all since all humans are subject to the same skeletal, muscular, and neurological constraints.[92] In regard to the action of the fingers, Kochevitsky pointed out that participation of the upper arm muscles is required.[93] Like most of the other pedagogues already discussed, Kochevitsky looked upon the playing apparatus as a series of levers, which can be used to increase the radius of the arm action (to adjust the length of the lever).[94]

Kochevitsky was concerned about avoiding fatigue. He stated that by "contracting the proper muscle, as much as necessary, at the proper moment, for as long as necessary, a pianist would avoid fatigue if he approached any new motor problem properly."[95] He did not believe, however, that it is necessary to know the names and functions of individual muscles in order to develop piano technique.[96] He cautioned against making excessive demands on muscles, stating that this would cause muscular atrophy.[97] This belief is the exact reverse of the process as it is now understood, in which overused muscles swell and frequently build up scar tissue.

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91 Ibid., 37.
92 Ibid., 31.
93 Ibid., 38.
94 Ibid., 38.
95 Ibid., 39.
96 Ibid., 38.
97 Ibid., 39.

General Principles of Twentieth-Century Piano Pedagogy

As part of his dissertation, Michael Phelps summarized the general concepts put forth by twentieth-century piano pedagogues regarding how the body operates in piano playing. He pointed out the trend to view the body as an elaborate system of levers operating in accordance with the laws of physics. He noted, however, that this system is too complex and changes occur too rapidly when playing to allow the pianist to observe and apply all the principles of leverage. Instead, there are a few broad concepts which have been derived by piano pedagogues which can be observed and applied in broad terms.[98]

Phelps listed the necessary components of all leverage systems: (1) a movable lever to which force may be applied, (2) a resisting force, and (3) a fulcrum against which movement takes place. The movable lever is provided by the part of the skeletal structure which is moved during the production of sound. Resisting force is offered by the mechanics of the piano action and the weighted keys, and also by the player's body. The parts of the body against which movement takes place act as fulcrums. Phelps noted that fulcrums must be located behind the joints of motion in order for force to be imparted to the key.[99]

Phelps then turned his attention to the mechanics of both the keyboard and the player's body. He stated that the resistance of the key is fixed, while the resistance of the player's body is variable according to position of body parts. While the resistance offered by a given keyboard is constant, the

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98 Michael Phelps, "An Approach for the Advanced Pianist toward Developing Concepts and Control of Vertical and Horizontal Motion, The Two Fundamental Directions of Movement in Piano Technique" (D.A. diss., Ball State University, 1981), 3.

99 Ibid.

amount of resistance differs from keyboard to keyboard.[100] Slight variances aside, it takes approximately two ounces of force to overcome the resistance of the piano action.[101] As the point of contact of the fingertip with the key is moved closer to the fulcrum of the piano key, the control of force is inhibited as the distribution of application of force is decreased. Thus, moving the point of contact toward the fallboard is not desirable if the player wants to maintain a great amount of control over the applied force.[102] In the player's body, the size and location of the lever producing the force and the area which functions as the fulcrum vary according to the needs of the moment. The entire leverage system of movement, resistance, and fulcrum is used simultaneously at the moment of tone production. Phelps termed the state of the leverage system at this moment the "playing unit." The joints in the playing unit can function as any one of the three parts of the leverage system.[103] The length of the lever is adjusted according to how much force is required by adding or taking out of play bones in front of the fulcrum.[104]

The joints of motion used in piano playing identified by Phelps are the arch of the hand, wrist, elbow, and shoulder. These can also serve to stabilize levers (acting as a fulcrum) when not being used as moving joints. He also stated that the natural tendency is to produce movement in the middle of joints' ranges of motion.[105]

Phelps emphasized the twentieth-century concept of movement being comprised of two processes, that of actual movement, and that of inhibition

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100 Ibid., 4.
101 Ibid., 59.
102 Ibid., 57.
103 Ibid., 4.
104 Ibid., 4-5.
105 Ibid., 5.

of movement. To produce movement, the body uses two sets of muscles working in opposition to each other; one set contracts while the other relaxes. Thus as motion occurs at one point, it is restricted in range at other points. When preventing motion, both sets of opposing muscles contract equally, resulting in tension.[106]

According to Phelps, it is a prerequisite that some degree of tension must be present in the joints when movement is taking place. The amount of tension is dependent upon the amount of force and the speed of the movement. He claimed that when sudden dynamic (in the sense of loud and soft) changes are necessary, it may be desirable to actually add more tension to a joint in order to restrict the range of its movement and thus limit the amount of force it can produce.[107] Tension in the connecting joints distal to each joint of motion, which Phelps referred to as the "joints of transmission," is increased or decreased according to the length of the playing lever. When tension in the playing lever rises, there is a corresponding rise in tension in the joints of transmission; tension level in the joints of transmission is directly dependent upon that of the joints of motion. Overall, there is less tension when playing *p* versus playing *ff*.[108] Stabilization areas, or fulcrums, are produced by adding or subtracting tension in the joints located proximal to the joints of motion. Generally, he noted that rapid movement causes more tension in the entire leverage system.[109]

Phelps recommended that players experiment with increasing and decreasing the amount of tension necessary in order to produce horizontal

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106 Ibid, 4.

107 Ibid., 6.

108 Ibid.

109 Ibid., 7.

and vertical movement at the keyboard until a minimum is found which will produce the desired result. He cautioned that the pianist cannot rely solely upon the sound he or she hears as an indicator of physically correct tone production; a player may produce the exact desired tone quality while still having an extraordinary amount of tension.[110] He further stated that muscles, like joints, work most efficiently along the middle of their ranges of motions. After this mid-range is exceeded, other muscles are activated to relieve the over-stressed muscle. Phelps termed this the "spread of activity." He claimed that this spread normally takes place from smaller to larger muscles. This spread of activity is accompanied by tension, giving rise to stiffness.[111] The brain may not be consciously aware that muscle activity and tension have spread and may retain the use of a larger, more tense playing unit even after the need to use it has passed. The result is uncoordinated playing.

Views Concerning the Use of Technical Exercises

Use of Exercises Versus Isolation of Technical Problems Contained Within Repertoire

Piano pedagogues disagree about whether piano technique should be developed through practicing exercises or by isolating a musical passage which requires that a given technical motion be employed. Exercises are purely mechanical note patterns of varying length, usually only a few measures long. They are divorced from any musical content, and are devoted to only one technical skill. Like exercises, etudes usually concentrate upon developing one technical skill. However, etudes are fully developed pieces of

110 Ibid., 8.
111 Ibid., 9.

some length which allow the player to build skill within a musical context. The essential difference between the practice of exercises versus isolating and conquering technical passages from repertoire lies in the goal of the practice. When practicing an exercise, the goal is generally conditioning of the hand and fingers, while in isolation of a technical problem, the goal is generally to apply the learned motions within a musical context.

Nelita True, of the Eastman School of Music, believes that developing technique apart from repertoire is valuable. She found that as a young player, she was making musical decisions in her repertoire pieces based upon her physical capabilities. By developing her technique separately, she was able to learn repertoire faster. Based upon her personal experience, she recommends that students cultivate technique apart from repertoire. She holds the opinion that this approach helps prevent injury.[112]

Dorothy Taubman, a pianist currently instructing students in building injury preventative technique, strongly disagrees with this position. She believes that many of the motions used in piano playing are too small to be seen with the naked eye. Most technical training exercises are based on the visible, not taking into account invisible motions which cause visible results. This, she claims, has led to an overemphasis on training the fingers.[113]

Taubman further objects to the use of exercises on the assertion that they do not serve their alleged purpose. While practicing Czerny and other etudes may not do harm in and of themselves, Taubman claims they are a waste of time.[114] Singling out basic skills in an exercise will not solve a

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112 *Nelita True at Eastman*, "Technique Through Listening," vol. 3 (Kansas City, MO: SH Productions, 1991), videotape series.

113 *The Taubman Techniques*, tape 1, produced and directed by Enid Stettner, 2 hours (Medusa, NY: The Taubman Institute of Piano, 1994), videotape series, 1:09:09.

114 Ibid., 1:16:52.

problem in repertoire which is related; problems encountered in repertoire often are related to their context, that is, what comes before or after. Thus isolation will not fix the technical problem. Taubman purports that practicing exercises often only reinforces bad or incorrect habits.[115] In a similar statement, Kochevitsky condemned the practice of abstract exercises without practical musical application as one of the great deficiencies of the finger school. Though he believed that no exercise was good or harmful in and of itself, he felt that if teachers were to use them, the exercise material should be appropriate and carefully chosen.[116]

William Newman, like Taubman, had serious doubts as to whether technical exercises even served their supposed purpose. He stated that pianists practice these exercises on the "treacherous assumption" that somehow these exercises will apply. He stated that the belief in most fields other than music was that each person gets enough exercise for his/her chosen pursuit directly from the activities that pursuit requires.[117] This last claim may deserve some skepticism based upon what is now known about the role of conditioning. For example, distance runners employ weight training in order to strengthen their leg muscles in order to improve performance. He believed that while Czerny, Hanon, and similar exercises might not directly cause harm, they did no good either. He pointed out that their repetitive nature led to "psychological lethargy" and left the student's mind free to wander, yielding wasted practice time. He further asserted that these exercises had little direct applicability in actual repertoire, stating:

115 Ibid., 1:13:15.

116 Kochevitsky, 40.

117 William Newman, *The Pianist's Problems* (New York: Harper and Bros., 1956), 33.

> The practice of a Czerny study leads mainly to the perfection of that Czerny study rather than to Beethoven or Chopin or composers in general. The way to learn Beethoven is first of all to practice Beethoven. The practice of Czerny can help Beethoven only when an *identical* passage occurs in both, and such practice can mean the wasting of a lot of valuable time. (emphasis added)[118]

Newman believed that the reason for the traditional adherence to Czerny and similar studies is the assumption that piano practice entails developing the piano-playing muscles. Newman rejects this view as a fallacy, claiming that technique cannot be generalized in this way. Specific muscular coordinations must be developed for specific situations.[119] Newman did, however, admit that when a problem is encountered in repertoire, an exercise may be derived to address that particular problem which will help the player develop the coordinated motions he/she needs in that instance. Moreover, Newman approved of practicing trills, scales, arpeggios, octaves, and double notes separate from repertoire, claiming that these elements repeatedly occur in standard piano repertoire.[120]

Thomas Fielden, an English pedagogue of the mid-twentieth century, advocated the use of what he termed "gymnastics" in technical training rather than the use of traditional exercises. The gymnastics exercises offered by Fielden are to be performed away from the keyboard in order to acquaint the player with the muscles of the playing apparatus and to develop flexibility. He adopted the maxim that technique in the long run is more mental than it is physical. Fielden believed that the teacher can equip the student with the physical means to technique, but the student must develop the mental means him/herself. He stated that gymnastic exercises are the best

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118 Ibid., 34.
119 Ibid., 35.
120 Ibid., 36.

way to develop physical technical capacity, provided that the student relates them to the keyboard.[121] The player must use his/her acquaintance with the muscles to develop appropriate movement patterns at the piano. However, Fielden claimed the daily use of these exercises would give the player all the physical equipment necessary to play the piano, and asserted that they served greater purpose than "tedious" and "nerve-wracking" repetitive finger exercises.[122]

Matthay also disapproved of the use of exercises to develop technique, stating that it is "absurd and hopeless to try to acquire technique dissociated from its purpose to express music."[123] He further believed that while trying to gain technical facility, the player must give close attention to the musical concepts expressed by a piece of music. He based this opinion upon his view of music as time-dependent, i.e., movements made when playing pieces of music are related to the flow of the piece. He outlined four time principles:

1. Movement of the key must be timed toward the sound desired.
2. Notes fall into natural groupings. Each group of quick notes moves toward the pulse ahead.
3. Similarly, note groups fall into phrases which move to a climax point (by extension, phrases may in turn be grouped into larger phrases).
4. The sections of a piece function similarly in knitting the piece together as a whole.[124]

The skepticism raised by these piano pedagogues concerning the effectiveness of practicing technical exercises apart from repertoire are supported by evidence from the field of motor learning studies. One of the principal characteristics of theories of motor learning is their insistence upon

121 Thomas Fielden, *The Science of Pianoforte Technique* (New York: St. Martin's Press, 1927; reprint, 1961), 34-5 (page references are to the reprint edition).

122 Ibid., 44.

123 Matthay, 3.

124 Ibid., 3E-4E.

the value of practice variability in learning new motor skills.[125] Increased variability in practice is often associated with increased performance error. However, research evidence shows that more performance error can maximize skill learning when it occurs in the early stages of learning the skill. This observation suggests that, theoretically, practicing a new piano skill in multiple different forms, as opposed to practicing the same form repeatedly, might enhance learning. In an experiment conducted by Edwards and Lee (1985), subjects were asked to move their arms through a specified pattern within a certain period of time. Some of the participants were prompted by a "ready, one, two, three" count on tape. Other participants were informed of the time limit and then attempted to achieve the movement through a trial-and-error approach, receiving critical feedback about their timing errors after each attempt. Results showed that the two groups performed equally well in retaining the skill. However, the trial-and-error group performed the arm movement with greater accuracy. This is notable because the group who practiced with the prompting tape experienced much less error in practicing the arm movement skill than did the trial-and-error group. Yet experiencing less error during practice had no impact upon retention of the skill, and was actually shown to be detrimental in transferring the skill to a novel situation.[126] This finding seems to suggest that practicing technical exercises may have limited value in learning motions to apply to repertoire pieces.

Another observation from the area of motor learning studies which relates to the use of piano technique exercises concerns contextual

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125 Richard A. Magill, *Motor Learning: Concepts and Applications,* 5th ed. (Boston: McGraw-Hill, 1998), 226 .

126 Magill, 227.

interference. Contextual interference results from practicing a task within the context of the practice situation. A high degree of contextual interference may be present when a learner practices several different, but related, skills within a single practice session; low contextual interference exists when a learner practices the same skill repeatedly during a single practice session.[127] Many people view such interference as negative, and thus assume practicing the same skill repeatedly will lead to a superior performance. However, several experiments have shown that the opposite is true: practice which is high in contextual variability leads to much greater retention and ability to apply the skill in novel situations. One such study, undertaken by Shea and Morgan (1979), involved practicing three separate motor skills. Some participants practiced each skill separately, in blocked segments, while the other participants practiced the skills in a random arrangement. While the blocked practice group performed better during practice trials, the random practice group demonstrated superior performance during retention and transfer trials, where they encountered the same skills in a slightly different situation.[128] A later experiment by Hall, Dominguez, and Cavazos (1994) demonstrated that the contextual interference effect exists not only for beginners, but for already skilled individuals.[129] While researchers do not fully understand the underlying reasons for the positive contextual interference effect, two hypotheses have been advanced. The first is that higher levels of contextual interference may increase the complexity of the memory representation of the skill being practiced. The second purports that the effect may exist due to the need for the learner to more actively

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[127] Magill, 130.
[128] Magill, 231.
[129] Magill, 233-34.

reconstruct an action plan for a trial of skill when trials of different skills have intervened.[130] In either case, this observation about contextual interference suggests that both beginning and advanced pianists might theoretically benefit more from practicing multiple skills in one practice session rather than repeatedly practicing the same exercise.

Finger Independence Exercise

There are many variations upon this exercise, which has been practiced for as long as the pianoforte has existed as a distinct instrument. The merits of this particular type of exercise have recently been questioned, both by piano teachers, and performing arts medical specialists. Finger independence exercises typically involve one finger holding a note while the other fingers of the same hand alternately play in a pattern around the sustained note (Figure 2.1). A frequently encountered variation of this exercise involves articulating one note at a time while the other fingers sustain a chord, or voicing to various notes of a sustained chord (Figure 2.2). It is slightly easier when the sustained note is played with a digit at the extreme of the hand; in this case, wrist rotation can be used to help the other fingers play around the sustained note. In any case, whether the exercise involves sustaining one note or more than one note, the action of the long extensors running along the forearm are visible as they move at the back of the hand. The fingers must be lifted high to activate the key, a motion accomplished by using the intrinsic extensors in the hand. Thus, the long forearm extensors and the shorter, intrinsic finger extensors must be simultaneously activated. In many instances, this results in a visible stiffening of the wrist and forearm.

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130 Magill, 237.

Figure 2.1. Finger Independence Exercise around One Sustained Note

Figure 2.2. Finger Independence Exercise around a Sustained Chord

Taubman especially disapproves of practicing these exercises which supposedly strengthen the fingers, believing that they are actually responsible for many injuries.[131] She warns that practicing these exercises may lead to tendinitis, tension, and pain. This is because of the antagonistic motion which inevitably results from such exercises. All the fingers are held down, and one at a time is lifted as high and fast as possible. The weight of the hand is down, yet the fingers must pull upward against this weight. Taubman claims that this motion is especially hazardous with the fourth finger. Lifting this finger just a little immediately moves it to its extreme range of motion since it does not have tendon independence from the fifth finger. Hence, instead of true finger independence, which is the aim of the exercise, feelings of inequality are created.[132] Taubman purports that it is the weight of the forearm lined up exactly behind each finger as it plays that lends a feeling of finger independence, not actions by the muscles of the fingers themselves.[133]

Kochevitsky agreed with Taubman in this regard, claiming that strengthening the fingers does not improve their agility. He stated that the fingers already have sufficient strength for the work of piano playing at birth.[134] He referred to finger strengthening exercises as "unnatural" and "harmful."[135] He further claimed that true finger independence was achieved with the ability to press any key and produce a tone without calling forth muscular tension in nonparticipating fingers. In order for this to be achieved, the entire playing apparatus should be free from tension.[136]

131 Ibid., 1:11:40.
132 Ibid., 1:18:08.
133 Ibid., 1:20:03.
134 Kochevitsky, 40.
135 Ibid., 45.
136 Ibid., 38.

Gyorgy Sandor claimed that practicing to achieve independence of the fingers is only useful if it is undertaken within the concept of interdependence. He pointed out that traditional finger independence exercises are practiced due to the perceived unequal strength of the fingers. He claimed that much of this perceived inequality was a result of uncoordinated use of the playing apparatus. Lining up the fingers with their respective forearm tendons so that the tendon runs in a straight line into the finger and using the upper arm to position the forearm can ameliorate some finger inequality. He stated that use of finger exercises might possibly be helpful in enhancing coordinated movement, but only if the position and participation of the arm is considered. He based this belief upon his conclusion that we cannot really strengthen the finger muscles, because it is the forearm muscles which actually move the fingers.[137] His assumption was partially correct; it is almost impossible to strengthen the intrinsic muscles of the finger. However, his assertion that only the forearm muscles act to move the fingers is incorrect. As will be detailed in Chapter III, the fingers are controlled both by extrinsic (forearm) muscles and intrinsic (hand/finger) muscles.

Due to the design of the hand, some fingers are stronger than others. Each finger is equipped with flexor tendons (refer to Figure 2.3), which allow for the finger to be flexed at the joints and pulled toward the palm. The flexor pollicis longus controls flexion of the thumb into the palm. The flexor digitorum superficialis emerges from the wrist and divides into four separate strands which connect to each finger. Since the flexors are attached in the same way to each of the four fingers of the hand, they have little impact upon

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137 Gyorgy Sandor, *On Piano Playing* (New York: Schirmer, 1981), 155-56.

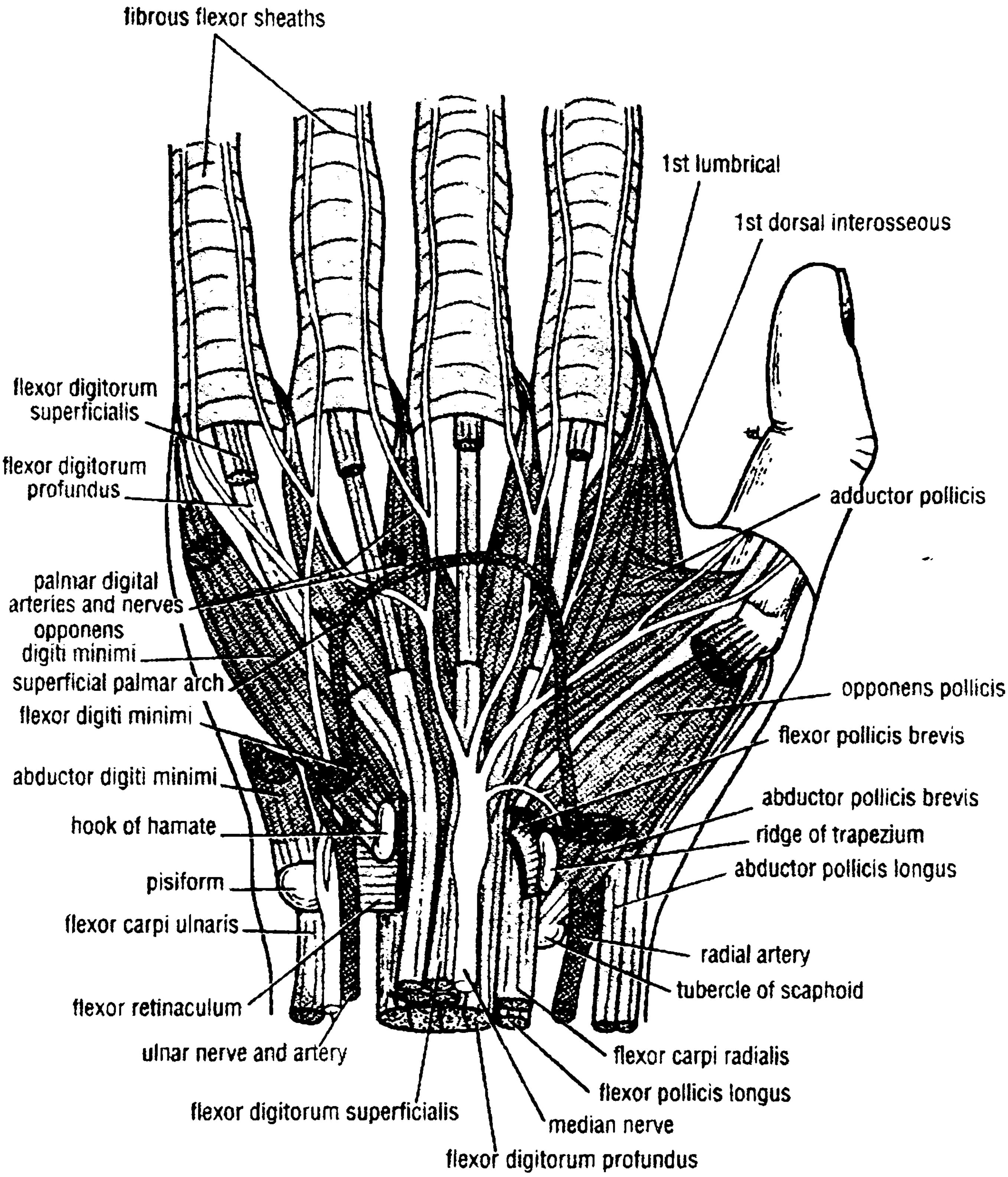

Figure 2.3. Finger Flexors

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the relative strength of the fingers. It is instead the extensor tendons which are the cause of strength and flexibility limitations of the various digits.

The extensor digitorum tendon (refer to Figure 2.4), which is ultimately responsible for extending the fingers, is situated along the forearm. As it passes through the wrist, it divides into three main tendinous strands. On the radial side, the first strand is tied exclusively to the second finger. The second strand directly lines up with and ties to the third finger. The third strand connects to the fourth finger, with a small tendinous slip branching off at the base of the fourth finger to connect to the fifth finger at its base. In addition to this branch off the third tendon connecting the fifth finger, there is also a branch which connects the third tendon to the second.[138] Therefore, the extensor tendons of the third, fourth, and fifth fingers are interconnected. Though the fifth finger has no independent extensor digitorum tendon, it has its own extensor tendon (the extensor digiti minimi) which contributes to its ability to be raised back up while the other fingers remain in a flexed position.[139] Moreover, the fifth finger gains strength due to its position on the end of the hand where it may be supplemented by forearm rotation. Though also connected to the fourth finger, the third finger has its own strand of the extensor digitorum and can thus still function relatively independently. However, as may be appreciated from the above description, the fourth finger is restricted in its independence. From a mechanical perspective, the fourth finger is inherently weaker than the other digits. This observation is readily appreciated by making a loose fist and attempting to fully extend the fourth finger without extending the other digits. The lack of

138 Richard S. Snell, *Clinical Anatomy for Medical Students*, 5th ed. (Boston: Little, Brown and Co., 1995), 434.

139 Ibid., 450.

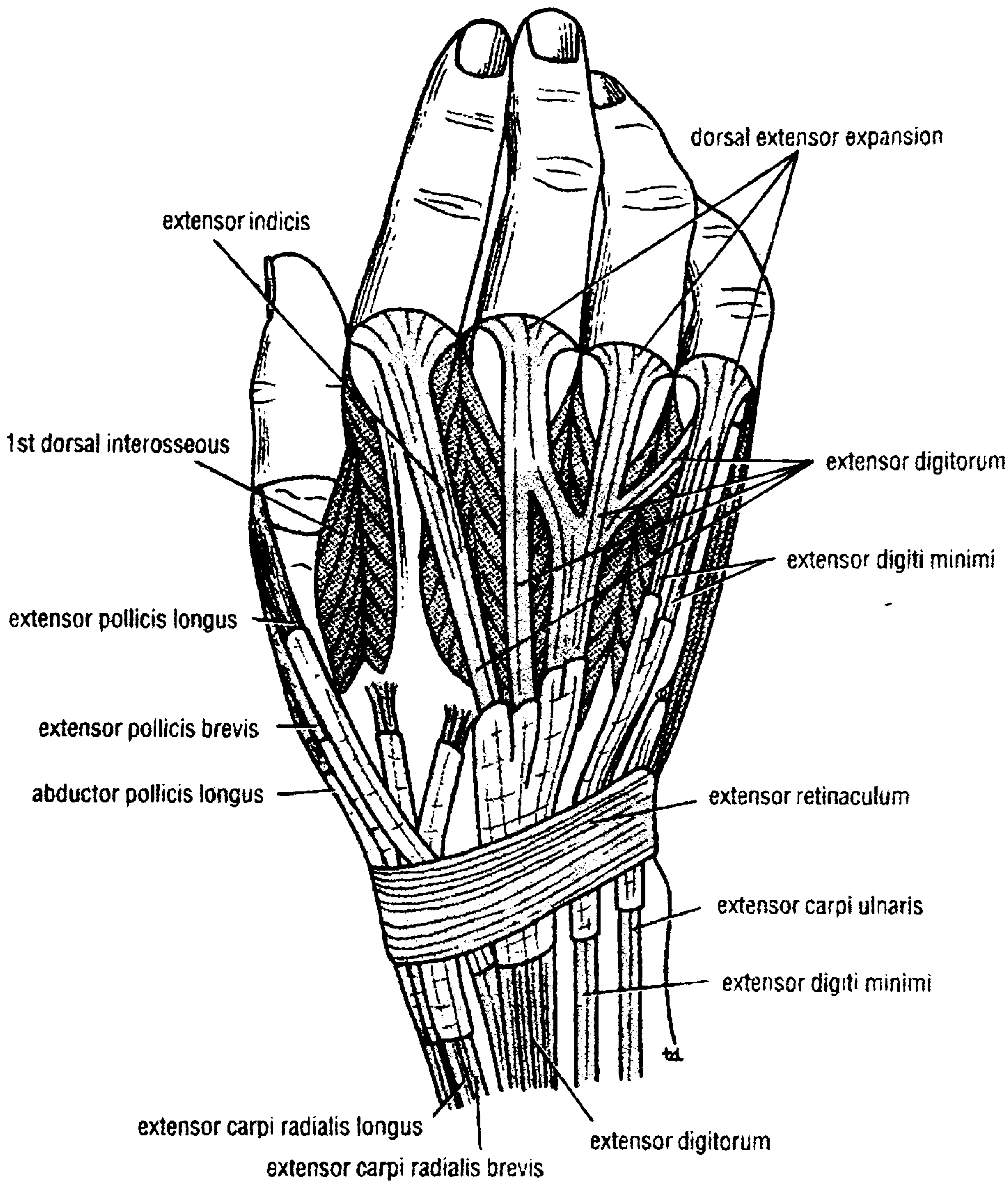

Figure 2.4. Finger Extensors

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ability to independently extend the fourth finger has direct bearing upon the finger independence exercise. After all of the fingers have descended onto the keys, the fourth finger lacks the ability to raise itself for the next keystroke as long as the other fingers are held down. The thumb and fifth finger have the greatest ability to apply force because they may be supplemented by forearm rotation. The second finger is the next-strongest finger due to the independence of its primary extensor tendon, which allows it to be raised for the keystroke. The third finger is next in terms of relative strength, followed by the fourth finger. These observations concerning anatomy lend support to the views of Taubman, Kochevitsky, and Sandor. The fingers are inherently unequal in strength, and attempting to strengthen intrinsic muscles might actually be potentially harmful.

The debate over the appropriateness of using exercises in developing piano technique is ongoing. Despite the concerns about the potential for physical damage and questions about applicability of exercises raised by many pedagogues, the use of technical exercises is still commonplace and widespread. Definitive medical studies investigating whether a correlation exists between practicing technical exercises and developing injuries have yet to be done. However, according to many performance arts medical specialists, empirical evidence suggests that repeated execution of the same passage within a short period can lead to overuse injuries.[140] It seems apparent that overuse may result from using the same muscles over and over.[141]

140Alice G. Brandfonbrener, "Harmful Practices That Cause Injuries," *Clavier* 33 (Feb. 1994): 15; Hunter J.H. Fry, "Overuse Syndromes in Instrumental Musicians," *Seminars in Neurology* 9 (June 1989): 139.

141 Alice G. Brandfonbrener, "Medical Help For Musicians," *The Instrumentalist*, 41 (May 1987): 29.

CHAPTER III

BIOMECHANICAL DESCRIPTIONS OF SELECTED SKILLS

Constraints Upon Movement

According to Joseph Higgins, an organization of movement is a purposive, systematic arrangement of constituent structural elements which make up the movement. Organization of movement is the systematic manner in which the organism produces goal-directed movement.[1] Movements are both a process and a product; the goal may be either the movement itself, or enacting a change in the environment.[2]

In order to accomplish an organized movement, the individual must effectively control sources of variation. Variation arises from three different types of constraints: environmental, biomechanical, and morphological.[3] When analyzing any physical performance, it is critical that the constraints upon movement be considered because they dictate the conditions under which movement must be performed. Careful examination of constraints upon movement allows for a movement to be adapted for maximal performance and additionally yields observations about how the constraints themselves may be utilized.

Environmental Constraints

Environmental constraints relate to the spatial and temporal organization of events external to the individual and account for one source

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1 Joseph R. Higgins, *Human Movement: An Integrated Approach* (St. Louis: Mosby, 1977), 42.

2 Ibid., 43.

3 Ibid., 43-4.

of variation. If control of the movement is to be maintained, variations in the environment must be accounted for by the movement.[4] The design of the task itself is an environmental constraint. Some skills, such as hitting a moving baseball, demonstrate a high degree of environmental uncertainty; these skills are called "open skills." Other skills have a high degree of spatial and temporal certainty and are therefore termed "closed skills."[5] Any given technical skill executed at the piano may be considered a closed skill; the player has complete control over the spatial and temporal elements. Environmental constraints affect each task differently. For instance, the environmental constraint of distance between keys necessitates the use of different motions in arpeggios versus scales. Though the spaces between keys remain unchanged, the nature of the two tasks involves coping with different distances. In this way, environmental constraints are intricately interwoven with the parameters of the task. It is the demands of the environment, specifically of the designs of the task, that most affect human performance.[6]

In addition to the constraints of the task, the overall design of the piano is an environmental constraint. While the limbs of the body are designed to move in arcs centered around the trunk, the piano keyboard is on a straight horizontal plane. Therefore, the hand must make various adjustments in order to conform to the piano. Playing a combination of white and black keys, in a scale for instance, requires the upper arm to move slightly backward and forward. In order to reach a maximum number of notes with a minimum of physical adjustments, the player usually sits so that the forearm lies on a plane parallel with the keyboard. Proper seating is

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[4] Ibid., 45.
[5] Ibid., 45.
[6] Ibid., 47-48.

crucial; an artist's bench allows the pianist to adjust the height of the bench to suit the individual player.

Biomechanical Constraints

Biomechanical constraints relate to physical laws and principles which can dictate an optimal way in which any given task should be accomplished. These constraints relate to the individual's ability to deal with factors such as gravity, mass, inertia, and force. In principle, the laws of physics dictate these properties which the performer must accommodate in his or her movement.[7]..Thus, biomechanical constraints may provide some similarity between the performances of different individuals due to the predictability of physical laws imposing themselves upon similar movements.[8]

At the piano, the player is constantly confronted with generation of force necessary to depress the keys. The optimal way to generate this necessary force is to use a combination of physical motions and gravity. In addition to helping provide acceleration for key depression, gravity can also oppose the player. Once the key is depressed, the player must find some efficient way for lifting the combined mass of the finger, hand, and arm out of the key.

Morphological Constraints

Morphological factors relate to the overall structure and form of the individual organism. These constraints include anatomic factors such as skeletal structure and function, joint articulation and range of motion, and

7 Ibid., 45.

8 Ibid., 47.

muscle and tendon structure and function.[9] Thus, in the sense of general anatomic design, morphological constraints may be considered to apply universally to all human beings. However, individual anatomic variations such as differences in hand shape and size are also morphological constraints. Other individual variables may include sex, weight, height, age, and level of experience. Of all the components of anatomy, the musculoskeletal system is the least pliable; each individual's biological constitution is largely dependent upon heredity, although training and adaptation may also play a role.[10] Morphology is the source of considerable variation from person to person. Assuming that environmental and biomechanical variations are constant, patterns of movement will be, to some degree, unique to any given performer.[11]

Regardless of individual morphological variations, some morphological constraints apply to all players. The elbows are generally slightly in front of the torso to allow the arms to move laterally unimpeded by the rib cage. The forearms and hands must be held away from the body. They are partially supported by the keyboard, but the deltoid, rhomboid, and trapezius muscles experience some static loading. The varying lengths of the digits of the hand are a major morphological constraint. Since the piano keys are all the same length, adjustments must be made by the upper arm, forearm, wrist, and hand to allow the shorter fingers to play. Ulnar deviation of the wrist is necessary when playing in the center of the keyboard in order to keep the thumb on the keys, while radial deviation is required at the

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9 Ibid., 46.

10 C. Roger James and Barry T. Bates, "Experimental and Statistical Design Issues in Human Movement Research," *Measurement in Physical Education and Exercise Science* 1 (1997): 57.

11 Higgins, 47.

extremes of the keyboard. Anytime the arm is held across the torso while playing, ulnar deviation is required; ulnar deviation increases the farther across the torso the arm is drawn.

Interactions of Constraints

There is constant interaction among these three categories of constraints. For instance, the width of the piano key may influence environmental, biomechanical, or morphological constraints depending on the context. Because the width of the keys does not vary, the player must make adaptations in order to place the fingers over their designated keys. In this case, key width might interact with environmental constraints. Key width might also be a biomechanical constraint with regard to how it affects the application of force. Key width might also factor into morphological constraints; a person with a relatively fat finger might have more difficulty depressing a white key between two black keys than a person with a thinner finger. In this instance, it can be seen that key width creates an interaction among the three constraint categories. If the key width is a factor in determining how much force is necessary to depress the key, then it could also be considered a biomechanical constraint.

For each individual performer, these constraints become increasingly predictable as skill improves. However, constraints still produce some variation from player to player due to morphological differences.[12] As was noted in the discussion of morphological constraints, some observations will apply regardless of morphological differences. In the analyses which follow,

[12] Ibid., 48.

the observations will be broad enough to apply regardless of individual anatomical differences.

The Playing Apparatus: A Kinesiological Description

Most of the work necessary for piano playing is accomplished by the upper extremity, which includes the anatomical parts between the shoulders and the fingertip. The lower extremity, which includes the legs and feet, also plays a role; for instance, the feet actively participate in pedaling. However, with the exception of pedaling, the role of the lower extremity is more supportive than active. In playing the piano, the legs work along with the spine and other parts of the torso to help the player maintain balance and manipulate the center of gravity. Since the biomechanical descriptions contained within this chapter focus primarily upon the various parts of the upper extremity, it is necessary to define all possible movements of these parts in order to understand their function. A glossary of terms is provided in Appendix A for reference.

Structure of the Shoulder

Joints of the Shoulder

The shoulder has four separate articulations: the glenohumeral joint, the sternoclavicular joint, the acromioclavicular joint, and the coracoclavicular joint.[13]

The glenohumeral joint (Figure 3.1) is a ball and socket joint connecting the head of the humerus, which is the bone of the upper arm,

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[13]Susan J. Hall, *Basic Biomechanics* (St. Louis: Mosby Year Book, 1991), 145.

with the glenoid fossa of the scapula. The glenohumeral joint is the shoulder joint and is also the most freely moving joint in the body.

The shoulder girdle articulations include the sternoclavicular joint, the acromioclavicular joint, and the coracoclavicular joint. The sternoclavicular joint is formed by the clavicle, the sternum, and the cartilage of the first rib. This joint serves as the major axis of rotation for movements of the scapula and clavicle. This joint is a modified ball and socket type which permits free frontal and transverse plane motion as well as limited forward and backward sagittal plane rotation. Rotation occurs in the sternoclavicular joint during shoulder shrugging motions, as well as when elevating the arms above the head.[14]

The acromioclavicular joint connects the acromion process of the scapula, located at the top back edge of the scapula, with the clavicle. This joint allows limited motion in all three planes. Rotation occurs at the acromioclavicular joint during arm elevation.[15]

The fourth and final articulation of the shoulder is the coracoclavicular joint, formed where the coracoid process of the scapula, located at the top forward edge of the scapula, is connected to the underside of the clavicle by the coracoclavicular ligament. Very little motion is permitted at this joint; it remains fairly immobile.[16]

Movements of the Shoulder

Movements made by the shoulder include extension, hyperextension, flexion, abduction, adduction, medial rotation, lateral rotation, and

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14 Ibid., 145.
15 Ibid., 146.
16 Ibid., 146.

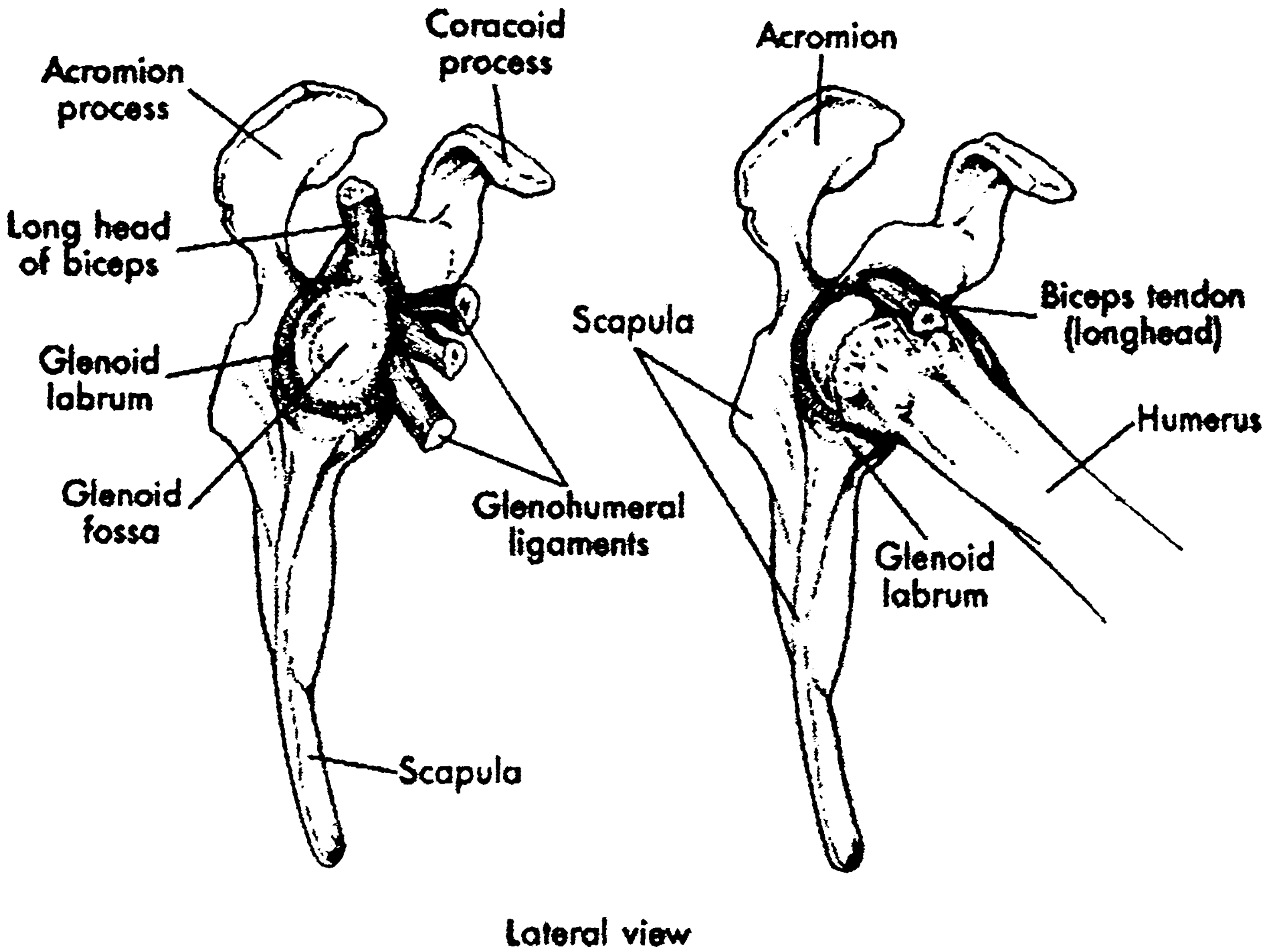

Figure 3.1. Glenohumeral Joint

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circumduction (Figure 3.2). The muscles which control the scapula (refer to Appendix B) stabilize the scapula so that it forms a stable base for muscles of the shoulder as they are exerted, and also facilitate movements of the upper extremity by positioning the glenohumeral joint properly.[17] The muscles of the scapula additionally contribute to movement of the shoulders, including elevation and upward and downward rotation.

Many muscles control the glenohumeral joint; some contribute to more than one action of the humerus. The action produced as muscles are exerted may change as the humerus is oriented in various positions due to the shoulder's large range of motion. The glenohumeral joint is stabilized largely by the muscles and tendons which cross it. Muscles work in opposing groups. When one of the muscles of the glenohumeral joint is tensed, tension may be required from that muscle's antagonist in order to prevent joint dislocation.[18]

The muscles which cross the glenohumeral joint anteriorly contribute to concentric flexion. When the humerus is extended unimpeded by resistance, gravity is the primary activator. Eccentric contraction of the flexor muscles, which causes these muscles to lengthen, controls or arrests extension. If resistance is offered, contraction of the muscles posterior to the glenohumeral joint, especially the pectoralis major, latissimus dorsi, and teres major, extend the humerus. The posterior deltoid assists with extension in instances where the humerus is externally rotated. The long head of the biceps brachii muscle also assists; since this muscle crosses the elbow, it makes

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17 Ibid., 150.
18 Hall., 152.

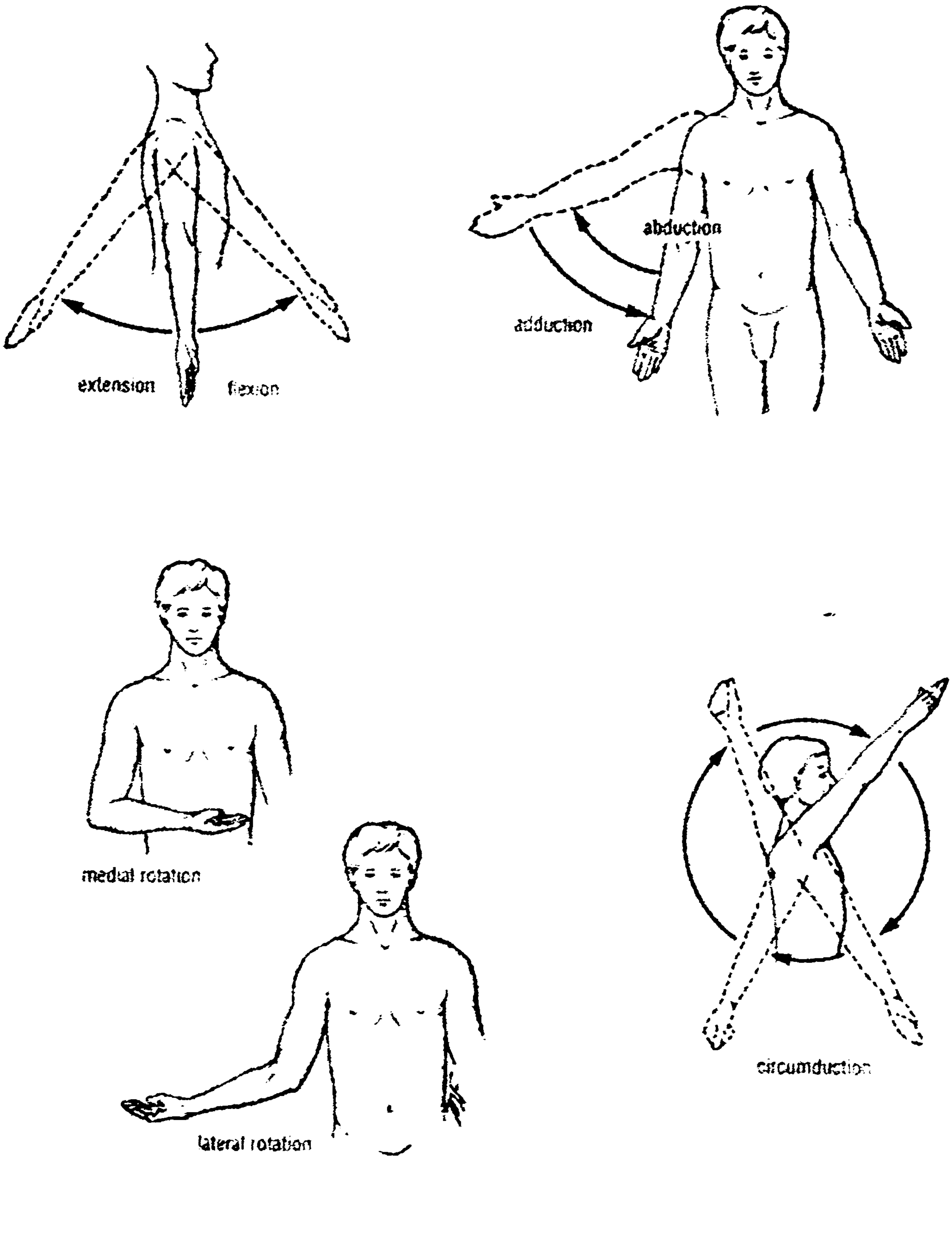

Figure 3.2. Possible Movements of the Shoulder

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a more significant contribution when the forearm is extended, as it is when playing the piano.[19]

Muscles crossing the shoulder above the glenohumeral joint are responsible for concentrically abducting, or raising the arms laterally. As with shoulder extension, adduction of the humerus in the absence of resistance is accomplished mostly by gravity with the abductors acting eccentrically to control the speed of the motion. When resistance is added, the muscles on the inferior side of the joint, including the latissimus dorsi and the sternal pectoralis major, are used to adduct the humerus.[20]

Inward rotation of the humerus is primarily enacted by the muscles attached on the anterior side of the humerus. Muscles attached to the back side of the humerus produce outward rotation with some assistance from the posterior deltoid.[21] The muscles on the anterior side of the joint produce horizontal adduction, moving the arm anteriorly in the transverse plane. Muscles posterior to the joint affect horizontal abduction.[22]

In addition to the movements of the glenohumeral joint, which positions the humerus in space, the scapulothoracic girdle plays a vital role in piano playing. The scapulothoracic girdle is suspended from the spine, rib cage and pelvis by powerful muscles and through a bony chain extending from the clavicle to the thorax. The scapulothoracic girdle is the major muscular support for suspension of the arm over the keys. It provides

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19 Ibid., 152-54.

20 Ibid., 154.

21 Ibid.

22 Ibid.

stability and greater freedom of movement of the arm at the glenohumeral joint through lateral gliding and posterior rotation of the scapula.[23]

The scapulothoracic girdle is composed of many muscles; the primary ones are the trapezius, the rhomboids, the levator scapulae, and the deltoid. The trapezius muscle is a large triangular muscle that extends on both sides over the back of the neck and across the top of the shoulders. It suspends the shoulder girdle from the skull and the vertebrae of the spine. The upper part of the muscle elevates the scapula, the middle section pulls the scapula medially, and the lower part pulls the medial border of the scapula downward.[24] The rhomboid major and the rhomboid minor run diagonally upward from the medial edge of the scapula to the thoracic vertebrae of the spine and work with the levator scapulae to elevate the medial edge of the scapula. The levator scapulae, which runs diagonally from the upper edge of the scapula to the upper thoracic vertebrae, works in conjunction with the middle fibers of the trapezius and with the rhomboids to pull the scapula medially and upward, bracing the shoulder backward.[25] The deltoid muscle is triangular in shape and covers the shoulder joint, forming the rounded shape of the shoulder. The deltoid is responsible for abducting the upper limb at the shoulder, also stabilizing the arm to prevent it from swaying forward or backward as it is abducted. For every 3° of abduction of the arm, a 2° abduction occurs at the glenohumeral joint and 1° occurs by rotating the scapula.[26] Pure glenohumeral abduction is only possible as much as

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23 Raoul Tubiana, "Fundamental Positions for Instrumental Musicians," *Medical Problems of Performing Artists* 4 (June 1989): 74.

24 Richard S. Snell, *Clinical Anatomy for Medical Students*, 5th ed. (Boston: Little, Brown and Co., 1995),400-1.

25 Ibid., 402.

26 Ibid., 402-3.

approximately 120°. Further movement of the upper limb above shoulder level requires rotation of the scapula itself.[27]

Structure of the Elbow

Joints of the Elbow

The elbow has three articulations: the humeroulnar, the humeroradial, and the proximal radioulnar joints. All are enclosed in the same joint capsule and are reinforced by ligaments. The humeroulnar joint is considered to be the major joint of the elbow. This is a classic hinge joint connecting the humerus and the ulna which permits flexion, extension, and a small degree of hyperextension. The humeroradial joint is adjacent to the humeroulnar joint and is an articulation of the humerus and the radius. The articulation between the head of the radius and the radial notch of the ulna is the radioulnar joint. This is a pivot joint which allows for forearm pronation and supination.[28]

Movements of the Elbow

Many muscles cross the elbow, some of which also cross the shoulder joint or move the hands and fingers. The motions possible at the elbow are flexion/extension and pronation/supination (effected by muscles of forearm).

The strongest elbow flexor is the brachialis. This muscle is attached to the ulna in a position which makes it equally effective whether the forearm is in a position of pronation or supination. The long and short heads of the biceps brachii are joined into a single tendon which attaches to the radius.

[27] Ibid., 410.
[28] Hall, 159.

This muscle contributes most to elbow flexion when the forearm is supinated. When pronated, the radius' position is changed in such a way that the biceps is slackened, so its effectiveness is limited. The third muscle which contributes to elbow flexion is the brachioradialis. Since this muscle attaches to the radius just above the wrist on the thumb side, it is most effective when the forearm is in a neutral position halfway between pronation and supination. The major extensor of the elbow is the triceps brachii, which crosses posterior to the joint. Although this muscle is divided into three heads with different points of proximal attachment further up the arm, these heads join into a common tendon which attaches to the ulna relatively close to the axis of rotation at the elbow.[29]

The other major motion which occurs at the elbow is pronation and supination (Figure 3.3), which involves rotation of the radius around the ulna.[30] This motion is accomplished by muscles located in the forearm. When in a position of supination, the radius and ulna lie alongside each other; when the forearm is pronated, the distal radius crosses over the ulna while the ulna remains stationary. There are three radioulnar joints which provide for this motion. The first is the proximal radioulnar joint of the elbow, already discussed, which acts as a pivot. There is another pivoting radioulnar joint close to the wrist (distal) end of these bones. The middle radioulnar joint is a stabilizing joint consisting of an elastic membrane which prevents longitudinal displacement of the radius and ulna. The major pronating muscle is the pronator quadratus (Figure 3.4), which attaches to the distal ulna and radius. The supinator muscle (Figure 3.5), attached to the

[29] Ibid., 160-62.
[30] Ibid., 159-64.

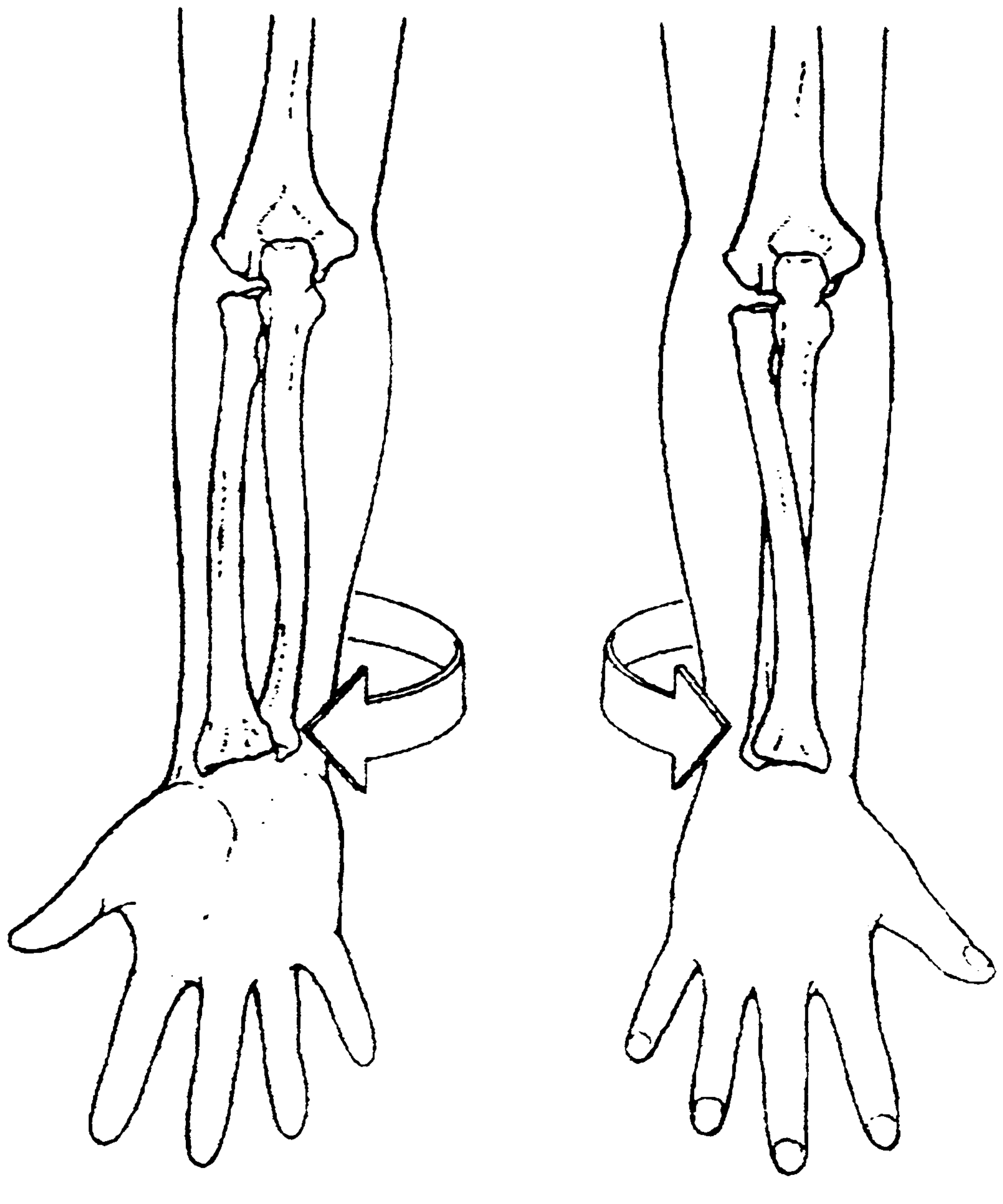

Figure 3.3. Pronation and Supination

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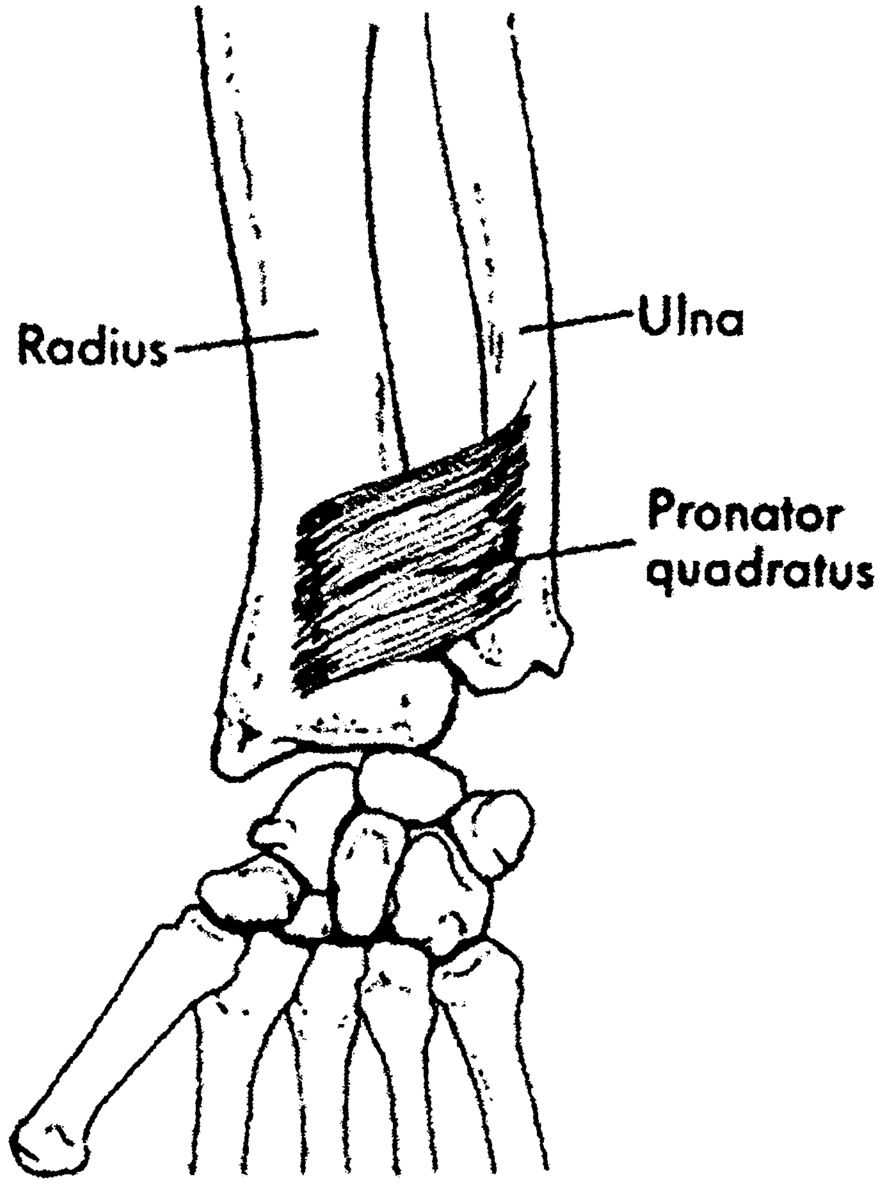

Figure 3.4. Pronator Quadratus

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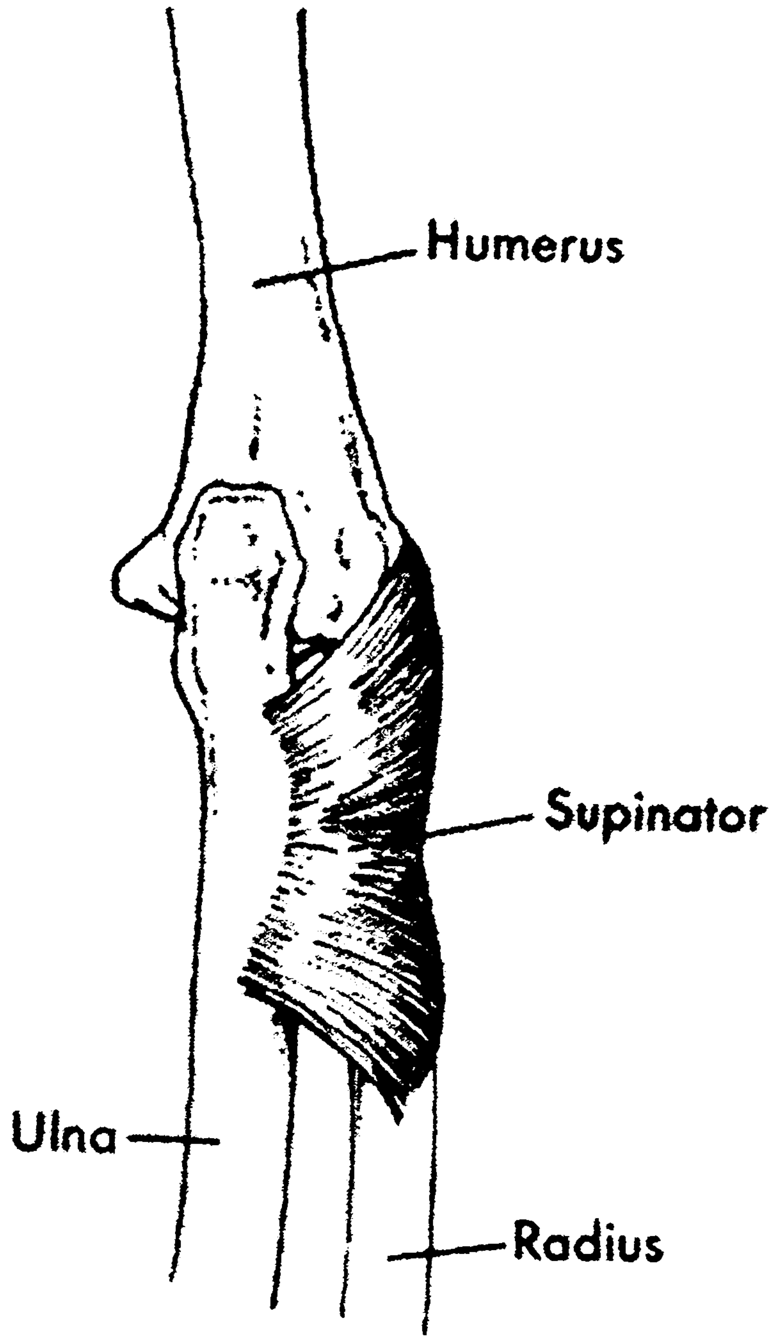

Figure 3.5. Supinator

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outside lower end of the humerus and the outside upper third of the radius, is primarily responsible for supination. However, when the elbow is flexed, the supinator is slackened somewhat, and must be assisted in its motion by the biceps.[31]

Structure of the Wrist

Joints of the Wrist

The wrist is composed of numerous joints between the radius, the ulna, and the bones of the wrist themselves. The intersection of the radius with three of the wrist (carpal) bones is considered to be the major articulation of the wrist. Sagittal and frontal plane motions, as well as circumduction, are permitted at this joint, known as the radiocarpal joint. A cartilaginous disc separates the distal head of the ulna from the radius and the bones of the wrist. This disc is common to both the radiocarpal joint and the distal radioulnar joint; however, these joints have separate joint capsules. The radiocarpal joint is reinforced by ligaments. The intercarpal joints, formed by articulations among bones of the wrist, are of the gliding type and add only slightly to wrist motion.[32]

Movements of the Wrist

The motions made by the wrist include flexion, extension, hyperextension, radial deviation, and ulnar deviation (Figure 3.6). Flexion of the wrist defines the motion made when the palmar surface of the hand approaches the inside of the forearm. The muscles responsible for wrist

31 Ibid., 164-65.
32 Ibid., 167.

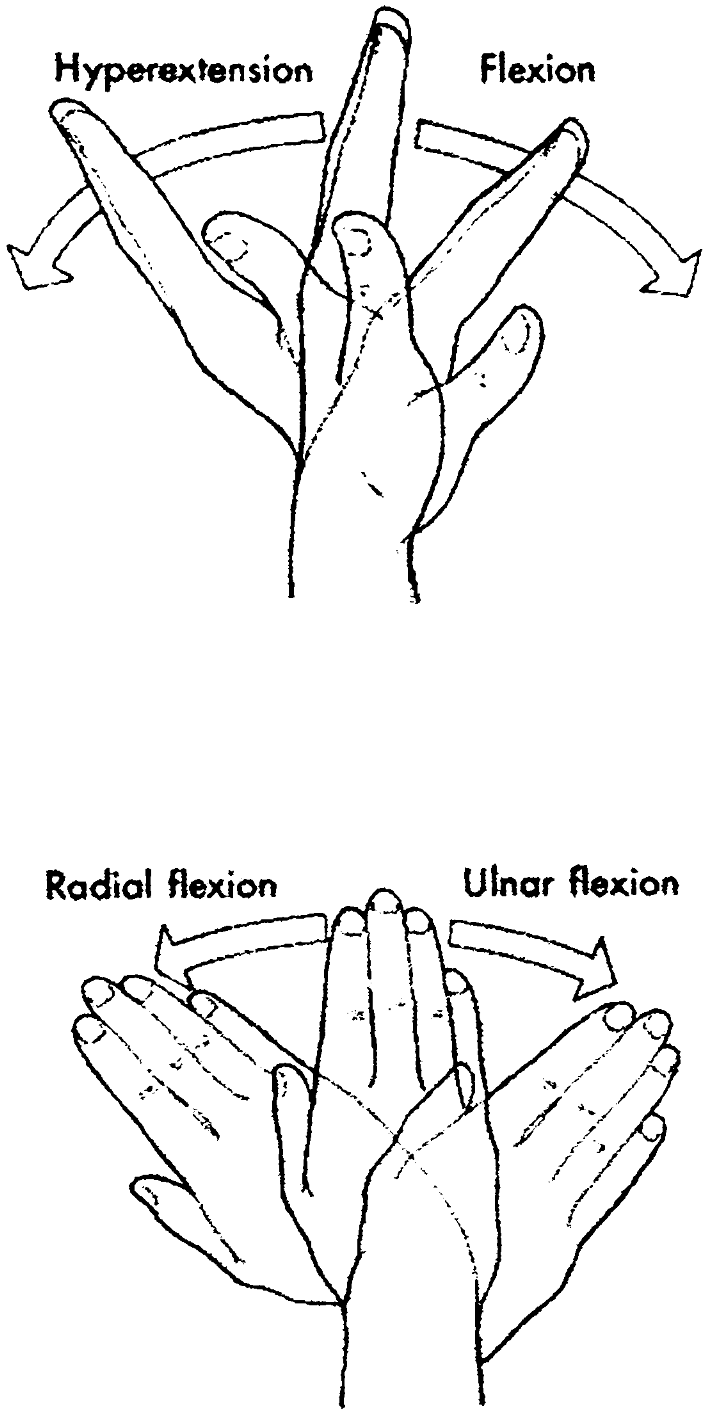

Figure 3.6. Movements of the Wrist

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flexion are located on the anterior side of the forearm and include the flexor carpi radialis and flexor carpi ulnaris. The palmaris longus, a muscle which is actually absent in many people, also contributes to flexion. All three muscles have proximal attachments on the medial epicondyle of the humerus. The flexor digitorum superficialis and the flexor digitorum profundus assist with wrist flexion if the fingers are completely extended.

Extension, the return to neutral anatomical wrist position, and hyperextension, in which the back of the hand approaches the back of the forearm, is accomplished by muscles running across the top of the posterior forearm– the extensor carpi radialis longus, extensor carpi radialis brevis, and extensor carpi ulnaris. These muscles originate on the lateral epicondyle of the humerus. Other muscles crossing the posterior side of the wrist, including the extensor pollicis longus, extensor indicis, extensor digiti minimi, and extensor digitorum also help with extension, especially when the fingers are in a flexed position.[33]

Radial and ulnar deviation (refer to Appendix A: Glossary of Terms) are lateral motions of the wrist made possible through cooperative action of both flexor and extensor muscles. The flexor carpi radialis and extensor carpi radialis contract in order to produce radial flexion; contracting the flexor carpi ulnaris and extensor carpi ulnaris results in ulnar flexion.[34]

Structure of the Hand and Fingers

Joints of the Hand and Fingers

Joints of the hand and fingers include the carpometacarpal (CM), intermetacarpal (IM), metacarpophalangeal (MP), and proximal and distal

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33 Ibid., 168.
34 Ibid., 170.

interphalangeal joints (PIP and DIP) (Figure 3.7). The carpometacarpal joints connect the bones of the wrist to the metacarpal bones of the hand. The first carpometacarpal joint, which connects the trapezium bone of the wrist and the metacarpal of the thumb, is a classic saddle joint. The other carpometacarpal joints are gliding joints; some researchers have described them as modified saddle joints. All carpometacarpal joints are surrounded by joint capsules which are reinforced by ligaments. The metacarpal joints connect the rounded distal heads of the metacarpals (hand bones) to the concave ends of the phalanges (finger bones). These joints form the knuckles of the hand. Each MCP joint is enclosed in its own capsule supported by strong ligaments. A ligament on the dorsal side of the hand strengthens the MCP joint of the thumb. The proximal and distal interphalangeal joints (PIP and DIP) are hinge joints joining the three segments of the phalanges.[35]

Movements of the Hand and Fingers

The carpometacarpal joint of the thumb permits a wide range of motion similar to that provided by a ball and socket joint (Figure 3.8). Motion at the other carpometacarpal joints is very limited due to constraining ligaments; slightly more motion is possible at the carpometacarpal joint of the fifth finger.

The metacarpophalangeal joints provide for flexion, extension, hyperextension, adduction, abduction, and circumduction in the second through fifth fingers (Figure 3.9). Abduction of the fingers describes any movement away from the middle finger; adduction applies to movement

[35] Ibid., 170-71.

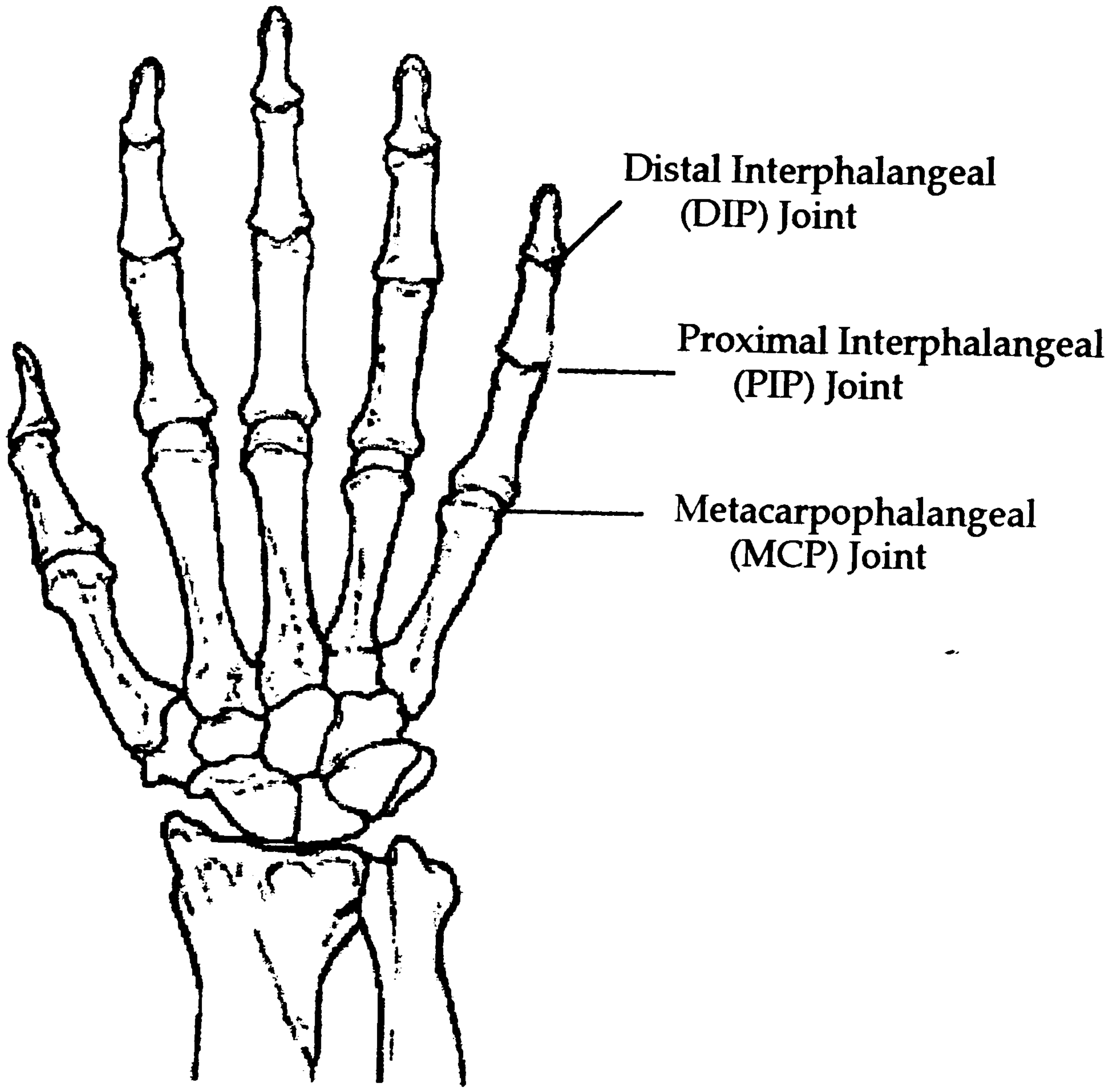

Figure 3.7. Joints of the Fingers

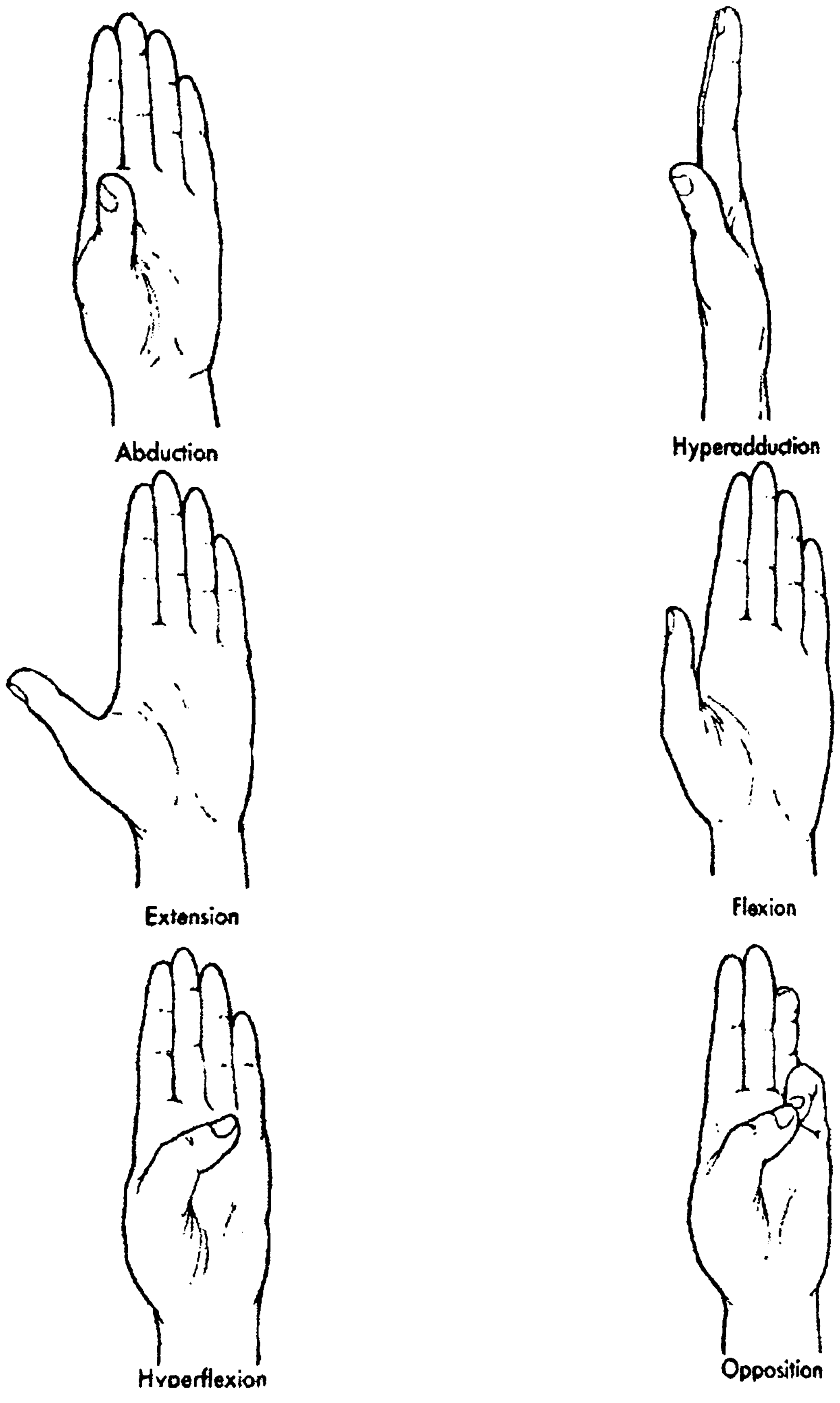

Figure 3.8. Possible Movements of the Thumb

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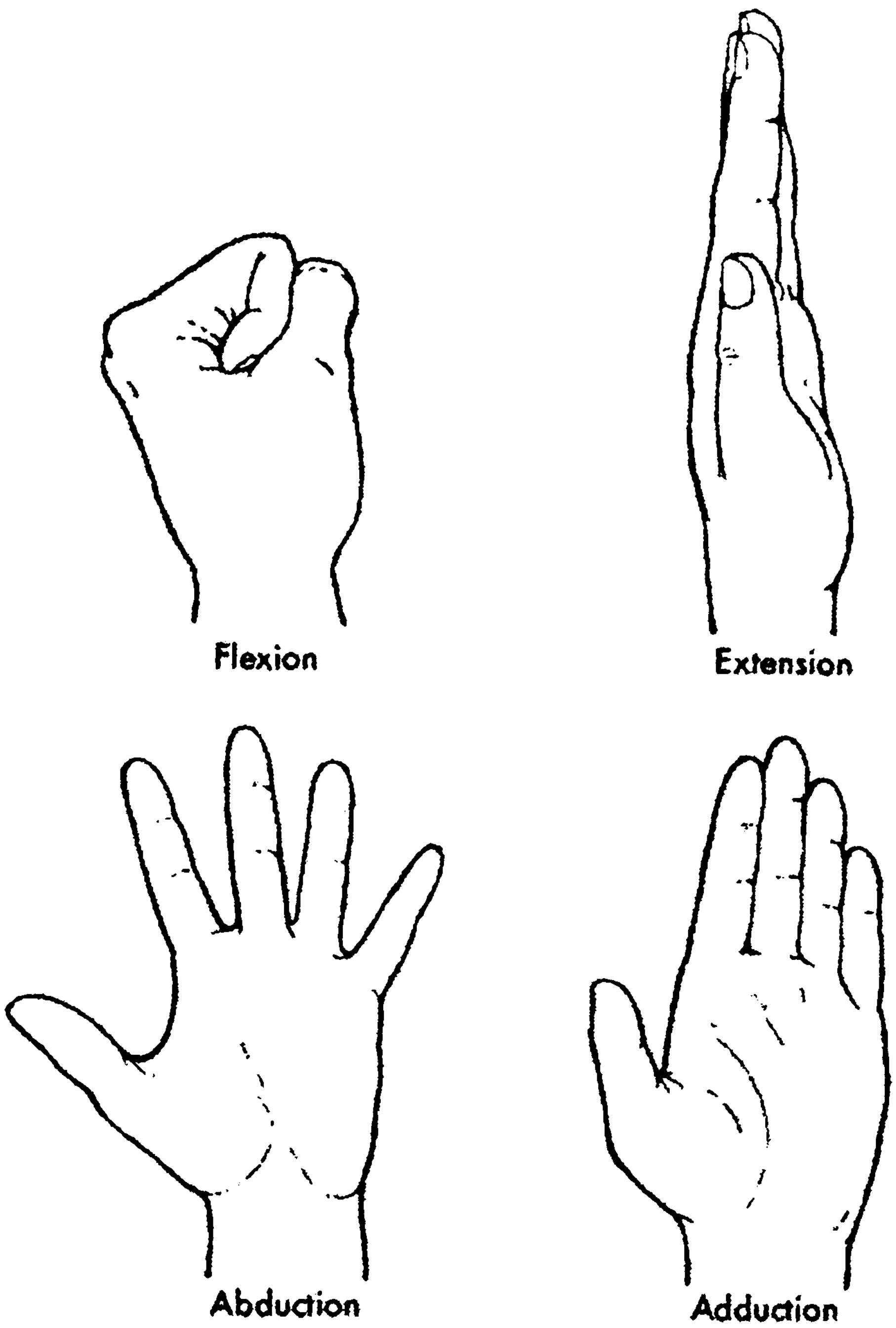

Figure 3.9. Possible Movements of the Fingers

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toward the middle finger. The bone surfaces at the MCP joint of the thumb are somewhat flat, so this joint functions more as a hinge joint with its primary movements being flexion and extension. The interphalangeal joints only allow for flexion and extension, and in some individuals, hyperextension.[36]

There are a large number of muscles which cause movement of the hand and fingers. The nine muscles which cross the wrist are known as the extrinsic muscles. There are ten muscles which have both their attachments distal to the wrist, known as the intrinsic muscles.[37] The extrinsic muscles are longer and therefore stronger muscles than the intrinsic muscles. Both intrinsic and extrinsic muscles of the hand and wrist are summarized in Tables 3.1 and 3.2.

Biomechanical Descriptions of Selected Piano Skills

In the descriptions of skills offered in this chapter, it is important to note that only visible motions are described. Very often, it is the small, invisible adjustments which take place as a skill is executed which determine its success and comfort for the player. Not only are these minute adjustments patently unobservable, they may vary from player to player. This compounds the challenge of describing piano technique in general enough terms to apply to all players. As an additional consideration, not all the visible motions detailed are produced by direct muscular exertion from the player. In a healthy technique, the upper arm, elbow, forearm, wrist, and hand are connected and function cooperatively to produce the desired result.

36 Ibid., 171-73.

37 Ibid., 173.

Table 3.1. Major Extrinsic Muscles of the Hand and Fingers

MUSCLE	PROXIMAL ATTACHMENT	DISTAL ATTACHMENT	PRIMARY ACTIONS
Extensor pollicis longus	Middle dorsal ulna	Dorsal distal phalanx of thumb	Extension at MP and IP joints of thumb
Extensor pollicis brevis	Middle dorsal radius	Dorsal proximal phalanx of thumb	Extension at MP and CM joints of thumb
Flexor pollicis longus	Middle palmar radius	Palmar distal phalanx of thumb	Flexion at IP and MP joints of thumb
Abductor pollicis longus	Middle dorsal ulna and radius	Radial base of first metacarpal	Abduction of CM joint of the thumb
Extensor indicis	Distal dorsal ulna	Ulnar side of extensor digitorum tendon	Extension at MP joint of second digit
Extensor digitorum	Lateral epicondyle of humerus	Base of second and third phalanges, digits two through five	Extension at MP, proximal and distal IP joints, digits two through five
Extensor digiti minimi	Proximal tendon of extensor digitorum	Tendon of extensor digitorum distal to fifth MP joint	Extension at fifth MP joint
Flexor digitorum profundus	Proximal three-fourths of ulna	Base of distal phalanx, digits two through five	Flexion at distal and proximal IP joints and MP joints, digits two through five
Flexor digitorum superficialis	Medial epicondyle of humerus	Base of middle phalanx, digits two through five	Flexion at proximal IP and MP joints, digits two through five

Reprinted, by permission, from Susan J. Hall, *Basic Biomechanics* (St. Louis: Mosby-Year Book), 174.

Table 3.2. Intrinsic Muscles of the Hand and Fingers

MUSCLE	PROXIMAL ATTACHMENT	DISTAL ATTACHMENT	PRIMARY ACTIONS
Flexor pollicis brevis	Ulnar side, first metacarpal	Ulnar, palmar base of proximal phalanx of thumb	Flexion at MP joint of thumb
Abductor pollicis brevis	Multangulus major and navicular bones	Radial base of first phalanx of thumb	Abduction at first CM joint
Opponens pollicis	Multangulus major	Radial side of first metacarpal	Opposition at CM joint of the thumb
Adductor pollicis	Capitate, distal second and third metacarpals	Ulnar proximal phalanx of thumb	Adduction and flexion at CM joint of thumb
Abductor digiti minimi	Pisiform bone	Ulnar base of proximal phalanx, fifth digit	Abduction and flexion at fifth MP joint
Flexor digiti minimi brevis	Hamate bone	Ulnar base of proximal phalanx, fifth digit	Abduction and flexion at fifth MP joint
Opponens digiti minimi	Hamate bone	Ulnar metacarpal of fifth metacarpal	Opposition at fifth CM joint
Dorsal interossei (four muscles)	Sides of metacarpals, all digits	Base of proximal phalanx, all digits	Abduction at second and fourth MP joints, radial and ulnar deviation of third MP joint, flexion of second, third, and fourth MP joints
Palmar interossei (three muscles)	Second, fourth ,and fifth metacarpals	Base of proximal phalanx, digits two, four, and five	Adduction and flexion at MP joints, digits two, four, and five
Lumbricales (four muscles)	Tendons of flexor digitorum produndus, digits two through five	Tendons of extensor digitorum, digits two through five	Flexion at MP joints of digits two through five

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Therefore, some of the motions which are visible when executing a skill should be thought of as secondary, or resultant, motions. Though these secondary motions are not actively functioning to produce the desired result, they appear as a consequence of the initiating muscular impulses. The information which is included in the following descriptions of skills is intended to aid the piano teacher and student in focusing on the relevant parts of the anatomy when developing technique to accomplish a given skill. If some secondary motions are absent upon observation, it may indicate that there is tension in some part of the playing apparatus, or that the primary (active) motions of the skill are being incorrectly produced.

Scales

Observations and Recommendations of Noted Pedagogues

One of the most frequently encountered technical skills in piano playing is the scale. The advice offered by piano pedagogues in regard to scale execution could fill several volumes.

Alfred Cortot points out that until the seventeenth century, the use of the thumb in scale playing was completely neglected, if not actually forbidden. The thumb came to be employed twice in one octave during the time of Clementi. Thus the thumb came to be used as a pivot to enable the hand to travel over several octaves, an innovation which contributed greatly to velocity.[38] Cortot purports that the use of the thumb should not cause modification in tone or in the position of the other fingers, nor should it

38 Alfred Cortot, *Rational Principles of Pianoforte Technique* (New York: Éditions Salabert, 1930), 23.

lessen speed.[39] Due to the construction of the anatomy, passing the thumb is different when ascending and descending. Cortot claimed that scale execution was more difficult in the ascent of the right hand and descent of the left hand, in which cases the thumb must pass under the third finger. He believed perfect "smoothness" could be obtained by preparation of the thumb's attack along with rapid lateral displacement of the hand to aid in the thumb crossing. Specifically, he recommended sliding the thumb close to the keyboard, approaching the note it is to play while reducing participation of the hand to a minimum. In order to learn where the thumb crossings take place, Cortot advised blocking the notes of the scale, isolating the thumb. For example, in the right hand ascending C scale, the thumb would play alone on C, then fingers 2 and 3 would play simultaneously on D and E. The thumb would next depress F and be followed by fingers 2, 3, and 4 playing G, A, and B.[40]

Otto Ortmann pointed out that scales, chromatic passagework, and diatonic passagework are similar in the movements they demand. Moreover, the octave diatonic scale differs from a 5-finger pattern only in the passing over of the thumb and hand.[41] Ortmann, like Cortot, focused upon the role in the thumb in scale playing. Ortmann believed that the thumb is passed underneath the hand by the rolling of the thumb on its longitudinal axis along with movement in the thumb joints. He observed that when crossing the thumb under, the third finger must be lifted off the key to allow the second finger to play immediately following the thumb. This lift is

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39 Ibid., 25.

40 Ibid., 26.

41 Otto Ortmann, *The Physiological Mechanics of Piano Technique* (Toronto: E.P. Dutton and Co, 1929; reprint, 1962), 251 (page references are to the reprint ed.).

accomplished by a lateral shifting of the hand to bring the fingers over the proper keys. The finger lift and hand shift occur almost simultaneously. Ortmann claimed that as the shift occurs, the third finger describes an approximately straight line until it descends vertically upon its proper key.[42]

In regard to the teaching of scales, Ortmann believed it was the mastery of the vertical thumb motion which occurs "under the hand" which was the problem, not passing the thumb under the hand. He claimed that any student could make the "passing under" gesture by simply touching the thumb to the tip of the fifth finger. It was sounding a note with thumb while the third finger was still holding the previous note which was troublesome.[43] Thus Ortmann advocated a true connection with the fingers between the third finger and the thumb. He seemed to recognize that this motion was very uncomfortable and not naturally suited to the hand. Unfortunately, instead of stopping to examine the supposition that notes should be actually physically connected within the thumb crossing, Ortmann recommended that students practice exercises requiring the thumb to play while under the hand and separated from any horizontal scalar motion.[44]

Addressing the height of the back of the hand over the keyboard, Ortmann pointed out that greater hand height is required when the thumb is in a position of normal flexion at the side of the hand than when the thumb is flexed under the hand. Consequently, in an ascending scale, the greatest hand height was observed toward the end of the lateral shift as the hand rises to facilitate placement of the thumb on its key after the third finger plays. In

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42 Ibid.
43 Ibid., 253-4.
44 Ibid., 254.

the descending scale, the greatest height was noted near the beginning of the shift.[45]

Ortmann was the first pedagogue to attempt to scientifically study the motions employed at the piano. With this aim, he attached a light source to the first phalanx of the third finger immediately behind the middle joint of the finger. He then used photosensitive paper to record the motions described by the third finger in the execution of a scale. He chose to examine the movements of the third finger because he believed that the movements of this finger in relation to the thumb are similar in both ascending and descending scales, while the movements of the other fingers are not symmetrical.[46] He eventually determined that the movements of the third finger were not symmetrical, as he supposed.[47]

When first learning to play scales, Ortmann recommended that students practice in slow motion. Each finger was to be lifted high enough to enable passage of a pencil over the finger depressing the key and under the lifted adjoining fingers.[48] This recommendation is potentially dangerous; it places an inordinate amount of tension on the intrinsic flexors of the hand. Ortmann also advised that as each finger struck its proper key, there was to be a slight rise in the "hand knuckle" which would pull the hand slightly forward on the key.[49] This motion requires the additional participation of the longer extrinsic flexors which run up the forearm. This tension in the long flexors in combination with the tension in the intrinsic flexors is ergonomically disadvantageous and could lead to injury. Ortmann believed

45 Ibid, 251.
46 Ibid., 252.
47 Ibid., 253.
48 Ibid., 254-55.
49 Ibid., 256.

that both elbow extension and humerus abduction were involved in the execution of the scale. The elbow straightened as the hand advanced along the keyboard and the upper arm was lifted slightly away from the side of the body. He noted no appreciable backward or forward motion of the upper arm.[50]

However, when the scale was played rapidly, Ortmann believed that the motions changed. He claimed that the straight line disappeared and was replaced by a series of forward and backward movements of the upper arm, perhaps better referred to as flexion and extension. The overall motion became curvilinear and continuous instead of describing a straighter line. He also claimed that since the muscles causing arm shifts were different from those controlling finger action, a slow scale would differ from a rapid scale in muscular requirements.[51] Ortmann's photographs of motions found that some hand shift occurs regardless of the speed of the scale. He pointed out that this finding is intriguing with regard to traditional pedagogy's insistence upon a "quiet" (motionless) hand in executing a scale. It was his opinion that moving the hand probably did not cause uneven accents in the scale. He also noted that some other experts had therefore concluded that the thumb should not be passed at all in a rapid scale, a conclusion which Ortmann felt to be an exaggeration of facts. He asserted that the passing of the thumb motion is present in a scale regardless of the tempo; the moment of actual passing merely decreases as tempo increases.[52]

Ortmann believed it impossible to transfer weight smoothly from one finger to the next when there was rapid repetition of the strokes of individual

50 Ibid.
51 Ibid., 257.
52 Ibid., 258.

fingers, in this case the thumb.[53] He claimed that the speed of finger-lifting motions was an essential determinant of weight-transfer. In playing rapid scales, it is impossible to get the third finger out of the way so the thumb may pass under (in the ascending right hand) unless it is lifted very quickly. This results in a break of weight-transfer.[54] Weight transfer proceeds smoothly up until the point where the thumb passes under; however, at that point, the smooth transfer is interrupted by the lifting of the third finger and the vertical dropping of the thumb onto the key after it is passed under. However, if one observes the scale carefully, it can be seen that there is actually no rapid repetition of finger motion. Each finger is called upon to play, at maximum, twice within one octave. It is unfortunate that Ortmann termed this phenomenon "rapid repetition of finger motion." Perhaps a better description would be "interruption of weight-transfer," since it is possible for weight to be transferred from finger to finger between thumb passings. Moreover, the arm applies a constant degree of weight even during thumb passings.

Paul Pichier, like both Cortot and Ortmann, advocated the use of exercises to promote the acquisition of the thumb-crossing motion. He recommended holding the second finger down while alternately playing the upper and lower neighboring keys with the thumb. While the thumb is moving, the second finger makes an "after-flexion" (discussed in Chapter II), pulling on the depressed key in order to lift the thumb for its next descent.[55] This "after-flexion" must not cause the back of the hand to change position.

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53 Ibid.

54 Ibid., 143.

55 Paul Pichier, *The Pianist's Touch*, ed. Walter Kraus, trans. Martha Ideler and Peter R. Wilson (Graz, Austria: Leykam Pädagogischer Verlag, 1972), 255.

After this exercise is mastered, the next exercise described by Pichier involves holding down the third and fourth fingers while the thumb plays neighbor notes. The thumb always moves ahead in the direction of playing. The final exercise recommended by Pichier was the blocking of the scale into finger groups, isolating the thumb as earlier described by Cortot.[56]

Ortmann, as mentioned above, pointed out that some experts have adopted the radical position that the thumb is not passed at all during the execution of a scale. Just such a belief is held by Gyorgy Sandor and was put forth in his book *On Piano Playing*. He contended that the thumb should never pass under the other fingers, or into the palm at all.[57] Instead, the thumb should remain alongside the hand with the wrist lowered to accommodate it, allowing the thumb freedom to fall vertically. As the third finger plays, the thumb is to be raised alongside the hand while turning the elbow outward; then the wrist is immediately lowered to position the thumb for its descent upon the key.[58] The thumb is to be raised slightly both before and after it plays.[59]

Sandor also described other movements used in executing a scale. He stated that the fingers require continuous adjusting motions by the wrist, forearm, and upper arm in order to move freely.[60] He distinguished between the vertical motion of the fingers, which originates where the first phalanx hinges on the metacarpal bone, and the motion of the thumb, which originates where the metacarpal bone attaches to the wrist. This observation has led Sandor to conclude that playing with the thumb requires a different

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56 Ibid., 256.

57 Gyorgy Sandor, *On Piano Playing* (New York: Schirmer, 1981), 57.

58 Ibid., 61.

59 Ibid., 64.

60 Ibid., 52-3.

wrist position than playing with the fingers.[61] According to Sandor, when the thumb plays, the wrist should be lowered slightly. When proceeding from the thumb to the second finger, the wrist must raise slightly because the second finger's first phalanx and metacarpal bone connect at the higher point than where the thumb's metacarpal bone meets the wrist. Thus the fingers should be aligned with respective higher or lower wrist positions, with the fifth finger being the highest and the thumb, the lowest.[62] In scale playing, the wrist moves in both the horizontal and vertical plane. These movements are to be continuous and precise, never sudden.[63]

Concerning the other fingers, Sandor pointed out that each finger should be placed to form as straight a line as possible with its respective forearm muscles and tendons. Therefore, the necessary adjusting motions of the wrist should not be excessive, but slight and continuous.[64] The wrist will make a slight upward motion to compensate for the use of the fifth finger as the upper arm is moved away from the body. Sandor also believes it is imperative that when fingers are not in use that they be raised slightly from the keys, so that the force of gravity can aid in striking the keys. The fingers should not be raised so high that strain results.[65] Though functioning in cooperation with the hand each finger should, however, work independently from the other fingers.[66]

Sandor has also made assertions about the contribution of other parts of the playing apparatus. The body moves slightly in the direction of the

61 Ibid., 53.
62 Ibid., 57.
63 Ibid., 53-4.
64 Ibid., 59.
65 Ibid., 60.
66 Ibid., 72.

scale, and the upper arm and elbow must reach away from the body.[67] Concerning contrary motion scales, Sandor stated that when moving outward toward the extreme ranges of the keyboard, the upper arm, wrist, and forearm go down when the thumb is used and up when the other fingers are used. The upper arm uses small pendulum-like motions while the body moves forward to prevent over-stretching of the arms. When moving toward the center of the keyboard, the upper arm stays out at all times while the body leans backward.[68] He believes that there is no fundamental difference in motions used to play fast and slow scales. At a faster tempo, the fingers are simply "thrown" instead of "placed."[69] At any speed, according to Sandor, piano technique must be economical and purposeful, with no wasted motion. He also advised that each component of the anatomy should be used within the central area of its range of motion to avoid strain, though he does not cite scientific support for this viewpoint.[70]

Unfortunately, Sandor's own recommendations conflict with these final statements concerning ranges of motion and economy of motion. Sandor vigorously maintained that the thumb should never be passed into the palm to any degree. If this advice is followed, one of two consequences will result. If Sandor is to be understood as stating that the thumb should not pass underneath the other *fingers* at all, then the scale will have an audible break in legato immediately before the thumb plays each time and there will be an audible accent when the thumb plays due to the need to lift the entire hand in order to effect the shift. Moreover, the overall scalar motion will be

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67 Ibid., 64.
68 Ibid., 65.
69 Ibid., 64.
70 Ibid., 65.

disrupted, resulting in a jerky motion. The other undesirable alternative, which preserves legato, is to raise the elbow until the upper arm is nearly 90° in relation to the torso. However, if Sandor merely meant that the thumb should not contact the thumb, then the thumb may be adducted behind the second and third finger and both difficulties can be avoided.

Sandor's view in general is that any change of position is helpful because it eliminates any fixed tension in the joints and muscles and enables the hand and arm to transmit "throw," or momentum, to the fingers.[71] Caution should be exercised to avoid using superfluous motions. While slight adjustments certainly take place during scale execution, excessive motions are inefficient, requiring the body tissues to work more, not less.

In her book *Indispensables of Piano Playing,* Abby Whiteside also offered some advice regarding scales. Her position is that scales should never be used as the basis of developing technique due to their complexity. Her concern is that traditional pedagogy has overemphasized the role of the fingers. She points out that fingers are only the periphery of the total playing mechanism, and emphasis on their use does not necessarily develop a "blended action of all the levers needed for fluent playing."[72] Instead of being played mainly by using the fingers, the scale should be produced by a follow-through action of the top arm with all the other levers assisting.[73] The scale should be the result of previously established coordination. Whiteside believed that the scale should be treated as music for a long period of time before attempts are made to refine all the movements involved; the scale

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71 Ibid., 61.

72 Abby Whiteside, *Indespensibles of Piano Playing*, in *On Piano Playing,* ed. Joseph Prostakoff and Sophia Rosoff (New York: Charles Scribner's Sons, 1955; anthology reprint, Portland: Amadeus Press, 1997), 123.

73 Ibid., 123-24.

should be the last technical skill to be perfected.[74] This opinion is shared by Seymour Fink, who holds that the scale is not the best vehicle for establishing primary mental and physical orientation to the piano.[75]

Scales are treated extensively in Dorothy Taubman's videotape series, in which her ideas are presented by her assistant Edna Golandsky.[76] Her primary concern is that in traditional teaching, there has been so much insistence upon passing the thumb into the palm. This motion results in what Taubman terms "dual muscular pulls," which refers to the simultaneous use of two opposing muscles.[77] In this case, the thumb is flexed into the palm by means of its flexor muscle, impeding the flexor muscles of the fingers. Instead of passing into and being held against the palm, the thumb is "hidden" behind the second and third finger. After playing, the thumb gradually moves so as to form a straight line behind the second finger, and then the third finger. The thumb is in a natural, relaxed position; it is not curled, which would necessitate undue exertion by the thumb flexor.[78]

The thumb is aided in its passage by the use of forearm rotation. According to Taubman, rotation is one of the most important if not the most important motion utilized in achieving comfortable piano playing. Forearm rotation is the only other motion in the playing apparatus which can match the fingers in speed. [79] Rotation occurs as one unit from the fingertip to the elbow; if the upper arm is rotating, the player has rotated too far.[80] The scale

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74 Ibid., 124.

75 Seymour Fink, *Mastering Piano Technique* (Portland: Amadeus, 1992), 59.

76 *The Taubman Techniques* tape 2, produced and directed by Enid Stettner, 2 hours (Medusa, NY: The Taubman Institute of Piano, 1994), videocassette.

77 Ibid., 1:43:10.

78 Ibid., 1:46:30.

79 Ibid., 1:10:30.

80 Ibid., 1:24:03.

is played using single and double rotations. A double rotation is really two motions, a preparatory swing in the opposite direction of the note being played, and the swing to the note itself; these two motions will be experienced as one continuous motion.[81] A single rotation eliminates the preparatory swing; in this type of rotation, two fingers move opposite to each other.[82] Moving from the thumb to any other finger, or from the fifth finger to any other, always uses a single rotation due to the thumb's and fifth finger's position at either extreme of the hand.[83]

Taubman has pointed out that when the thumb moves downward by itself, it uses the same abductor muscle which functions in the other fingers to move them side to side. The sluggishness of the thumb in its downward motion can be overcome by using rotation.[84] Taubman describes two types of rotation: single rotation and double rotation. In the right hand ascending scale as described by Taubman, after the thumb plays there is preparatory motion to the left followed by a swing to the right which causes the second finger to land on its key. This swing from left to right occurs as one motion which Taubman terms a "double rotation." As the second finger plays, the thumb lines up behind it and there is another double rotation from the second to the third finger. Taubman describes the movement from the third finger to the thumb as a single rotation. This is because the thumb can only be used in the direction of pronation (to the left). The movement of the thumb as it lands on its key provides a preparatory swing for the movement from the thumb to the second finger.[85] Taubman claims that the range of

81 Ibid., 1:17:54.
82 Ibid., 1:25:50.
83 Ibid., 1:31:15.
84 Ibid., 1:43:10.
85 Ibid., 1:46:30.

motion of the thumb is exceeded if it passes beyond the third finger; this is true if the fingers are flexed. Since in the second half of the white-key scale, the fingering is 1 2 3 4, the thumb does line up behind the second and then the third finger, according to Taubman. In this second half of the scale, the thumb merely hovers next to the second finger.[86] In order to cross from the fourth finger to the thumb in order to begin the next octave of the scale, Taubman recommends the use of the "walking arm" motion. In this motion, the hand and forearm stay aligned as the upper arm moves outward.[87] This motion, when combined with the rotation already described, provides the needed lateral adjustment to cover the distance between the fourth finger and the thumb. By combining the "walking arm" motion with rotation, Taubman provided for an actual key connection between all notes of the scale, even at thumb-crossings. The rotations as each individual finger plays, which are visible at a slow tempo, become less noticeable as tempo is increased. As the forearm rotation motion is perfected, it is the fingers which initiate movement; the forearm responds invisibly to the fingers' needs.[88] The weight of the forearm is centered behind the finger which is playing; the hand is not "tilted."[89] Eventually, the motions of the fingers appear to be straight up and down into key. Even so, Taubman has cautioned against using one finger to "push off" the key into the next preparatory swing. She has also pointed out that stretching or reaching with the fingers to gain speed will destroy the momentum of rotation and hence will slow the scale down.[90]

86 Ibid., 1:49:35.
87 Ibid., tape 4, 1:28:00.
88 Ibid., 1:32:58.
89 Ibid., tape 4, 2:29:20.
90 Ibid., tape 2, 2:04:15.

In the right hand descent as described by Taubman, there is no need for large, twisting motions as the third finger passes over the thumb. Instead, the forearm is rotated, causing the thumb to actually roll over onto its nail bed as it sits at the bottom of the key. This rolling of the thumb is accompanied by wrist pronation. One does not have to be concerned with lifting the thumb off of the key; the playing of the third finger using rotation causes the thumb to release the key.[91]

Thomas Fielden's views regarding the overemphasis of the fingers are similar to Whiteside's. He found that scales are of little use as finger exercises. Instead, their purpose is to teach the logic and method of fingering along with fostering an acquaintance with the cycle of keys.[92] Having practiced with this goal, the pianist should be able to derive a solution to almost any problem of scale fingering which may arise within a repertoire piece.[93] William Newman also believed the purpose of scales is to teach fingering.[94] His views differ with those of Whiteside and Fielden, however, in that he believed that scales do have value as finger exercises. He advised practicing them in a rotating cycle, playing in certain keys on different days so that all keys have been practiced within a fairly brief period.[95] Like Cortot, Newman recommended mastering each hand separately as well as blocking the scale, isolating the thumb to train the fingers in passing the thumb under.[96]

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91 Ibid., 1:55:45.

92 Thomas Fielden, *The Science of Pianoforte Technique* (New York: St. Martin's Press, 1927; reprint, 1961), 156 (page references are to the reprint edition).

93 Ibid., 159.

94 William Newman, *The Pianist's Problems: A Modern Approach to Efficient Practice and Musicianly Performance* (New York: Harper and Bros., 1956), 38.

95 Ibid., 38.

96 Ibid., 41

In summary, the thumb and the crossing of the thumb is the primary concern of these experts. However, if the scale is broken apart into its constituent motions, it is apparent that the thumb is not the only part of the body which participates in this skill. In some cases, these experts seem to be describing idiosyncratic patterns of movements, ones they have adopted as individuals. Ortmann described in detail many extraneous and wasteful motions: lifting the fingers high, pulling with the proximal joint. Ortmann, along with Cortot and Pichier, recommended isolating and practicing a vertical stroke of the thumb while held under the palm, though Ortmann himself recognized the biomechanical difficulty of this motion. Because of its anatomical awkwardness, this motion might hypothetically contribute to overuse or strain of body tissues if practiced repetitively within a short period of time. Pichier spoke of practicing thumb-crossing by using an "after-flexion," which calls for the finger to pull against the key after it is already depressed. Since the key is already depressed, adding more downward force is ergonomically impractical; the hand and arm are required to overcome this applied force in addition to gravity in order to play the next note of the scale. Sandor also seems to have recommended the use of unneeded motions. For instance, in the crossing of the thumb, he maintains that the thumb is not to be passed under at all; instead, the elbow is to be raised to an extreme position to allow the thumb to fall upon its proper key while connecting the tones of the scale. Dorothy Taubman's belief that the thumb is playing in the direction of pronation as it lands on its new key after passing is also questionable because it requires that the forearm first pronate and then immediately supinate as the other fingers are played. Adding this extra motion will likely disrupt the flow of the scale as it ascends and descends. Taubman did point out that small motions tend to become invisible at faster tempos; however, one might question whether or not this extra pronation is even present at a fast speed. If this is the case, why include the motion at slower tempos? If the thumb is simply passed aided by the lowering of the forearm, this extra unneeded motion is eliminated.

However, some of the advice offered by piano experts seems to be both justifiable and practical. Both Whiteside and Fink recognized the inherent complexity of motions employed within the scale and contend that the scale should only be learned and practiced after the student acquires a thorough familiarity with the basic motions used in piano playing. Likewise, Fielden and Whiteside point out the value of scales, not as finger training drills, but as the vehicle for developing mental strategies to solve complex fingering difficulties encountered within repertoire and the ability to play in all keys. Taubman has pointed out the physical dangers of curling the thumb up against the palm. Sandor has recognized the appropriateness of keeping joint and muscle motions centered within anatomical ranges of motion. Ortmann discovered that traditional pedagogy's insistence upon a "quiet" hand in scale playing was not justified. He discovered that there is some movement of the hand in any scale, and that this movement did not necessarily lead to rhythmic unevenness or misplaced accents.

Biomechanical Description of A Scale

The following is a description of the movements involved in executing a scale beginning on a white note. It is assumed for the purposes of this analysis that the scale is executed four octaves by both hands simultaneously.

The goal in scale playing is a smooth, linear projection of tones. The notes of the scale should be rhythmically even, with no sudden accents or rushing of tempo. In order to achieve this goal, the scale must be executed by smoothly transferring weight from one finger to the next.

Since the hands are symmetrical, the right hand ascent is similar to the left hand descent in the passing under of the thumb while the left hand ascent is similar to the right hand descent in the passing over of the third finger. It is readily apparent that the playing of hands-together scales in parallel motion is no easy feat; the right hand ascent requires different motions than the left hand ascent, and the same is true of the descent in each hand. For this reason, it is probably best to teach the scale hands-separately first. Playing the scales in contrary motion will likely prove a helpful intermediary step between hands practiced separately and hands played together in parallel motion. In many scales, the thumb (or the hand) is passed simultaneously in both hands when playing in contrary motion.

Right Hand Ascent/Left Hand Descent

The general pattern of fingering for most scales beginning on white keys (except for B major, left hand and F major, right hand) is: 123 1234 123 1234 continuing to the top (right hand)/bottom (left hand) of the scale and ending on the fifth finger (note that spaces in the fingering pattern mark hand shifts). Other scales use a similar fingering pattern, but begin with a finger other than the thumb. For instance, when playing the A-flat major scale, the pattern is: 34 123 1234 123, etc.

In the typical white-key scale, after the thumb plays the first note of the scale, it is gradually adducted to line up behind the second and third fingers.

This motion is accompanied by slight radial deviation (refer to Appendix A: Glossary of Terms). The hand also rises slightly so that the second and third fingers play progressively farther back on the key; the most visible aspect of this motion (though not the initiating factor) is a slight rise in the wrist's position.

While behind the second and third, the thumb hangs loosely; it is not pressed onto the surface of the palm. If the thumb were to be actually held against the palm, the thumb's flexor would be overexerting itself; the motions of the other fingers would be impeded. Allowing the thumb to line up naturally behind the second and third finger allows for maximum flexibility in these fingers. Even though the thumb will lose contact with the surface of the keys, it should not be allowed to drop below the level of the keys since this will necessitate extra motion to bring the thumb back up to key level. As the third finger plays, the thumb gradually approaches the next key. As the third finger releases the key, the thumb is dropped onto the next key, facilitated by the dropping and slight supinating of the forearm. The thumb will play more forward on the key (toward the player) than does the third finger. The thumb lands on the side of the nail and rolls very slightly toward its fleshy pad (note that the thumb never plays on its fleshy pad). There is a moment of slight ulnar deviation as the hand resets itself; this moment of ulnar deviation diminishes as the right hand moves toward the upper registers and as the left hand descends to the lower extremity of the keyboard. After the thumb lands on its proper key, the second, third, and fourth fingers play accompanied by slight radial deviation of the hand, which grows increasingly less pronounced as the extremes of the keyboards are approached. After the fourth finger plays, the thumb is passed under once again to continue to the next octave of the scale. However, as Taubman pointed out, it is not possible for the thumb to hand naturally behind the fourth finger while the fingers are flexed. After it plays, it adducts behind the second and then the third finger. As was noted in the first passing of the thumb above, as the crossing is approached, the hand and wrist rise slightly. As the fourth finger plays, the hand deviates toward the radius and the forearm lifts and pronates slightly, raising the hand. This slight adjustment provided by the lifting and pronation of the forearm allows for the thumb to land on its key as the fourth finger is released, aided by the natural tendency of the hand to correct the radial deviation by enacting the opposite motion of ulnar deviation in order to return to a more neutral position. Thus, legato is preserved. The hand is now in position to continue the scale into the next octave.

Left Hand Ascent/Right Hand Descent

The general pattern of fingering for most scales beginning on white keys is: 54321 321 4321 321 continuing to the top (left)/bottom (right) of the scale and ending with the thumb. After the fifth finger plays, weight is transferred smoothly from one finger to the next until the thumb is reached. This transfer of weight is largely accomplished by subtle and invisible pronation. As the thumb plays, it rolls onto the thumbnail and the hand is quickly pronated, throwing the third finger over the thumb. Although the amount of pronation is small, it takes place very rapidly. As the third finger plays, the hand resets itself through ulnar deviation of the wrist. As the thumb is arrived at again, hand pronation is repeated, this time throwing the fourth finger over the thumb. As was noted above, since the thumb cannot pass beyond the third finger, there must be an additional adjustment made to complete the passing of the fourth finger. In this case, the hand makes a slight ulnar deviation to allow the fourth finger to land on its key. The fourth finger will land on the key farther back (toward the black keys) than does the thumb; this helps span the distance between the thumb and fourth finger.

The left hand ascent/right hand descent requires less wrist motion than does the right hand ascent/left hand descent. This is due to the relative shortness of the thumb. When the thumb is passed under the hand, the wrist must lift to allow passage of the thumb and then immediately lower to allow the thumb to play its key. More radial deviation is required for the same reason. Moreover, while invisible pronation aids in the transfer of weight from one finger to another between hand shifts in the left hand ascent, there is no corresponding motion of supination to assist transfer of weight between hand shifts in the right hand ascent. Instead, in the right hand ascent, transfer of weight is accomplished by slight radial deviation motions as the thumb is approached. The left hand ascent requires far less lateral and vertical wrist motion, relying primarily upon pronation.

Coordinated Movements of the Scale

As may be noticed from the general patterns of fingering laid out above, the ideal in scale playing is for the longer fingers to fall on black keys while avoiding using the thumb or fifth finger on the black keys. This fingering is due to both the environmental constraint of the black keys being positioned farther back on the keyboard than the white keys and the morphological constraint of the shortness of the thumb and fifth finger. In general, the hands begin their ascent the same way. With the player seated, the hands are lifted from the lap and placed over the first note of the scale. After a slight upward motion of the wrist, the weight of the hand and arm is dropped onto the first note of the scale. Some players choose to omit the initial placement of the hand and from the lap, drop the hands directly onto the first note of the scale. As the scale ascends, the torso and arms direct weight into the fingers. Weight is smoothly transferred from finger to finger as each note is played, with each finger contributing some independent mechanical motion. After each finger plays, it is released as the next finger descends. Thus, there is no overlapping or "blurring" of tones.

When playing the scale hands-together for four octaves, the center of gravity at the beginning of the scale is centered toward and slightly above the left hip. During the scale ascent, the center of gravity gradually shifts to the right as evidenced by the movement of the torso in that direction and shifting of weight from the left hip to the right. As the scale descends, the center of gravity shifts back to the left. This movement of the upper arm in combination with the shift of the center of gravity helps provide momentum. The moment when the center of gravity is centered exactly between and slightly above the hips occurs when each hand is approximately the same distance from middle "C." Thus, the torso describes an arc in the frontal plane, with the fulcrum centered between the hips. The upper arms also describe an arc centered around the torso (Figure 3.10). The torso and upper arms move in the same direction along their respective arcs. Interestingly, the arc of the torso is shorter than that of the upper arms. Therefore, the torso moves slightly ahead of the arms in the middle registers of the keyboard, but as the scale ascends, the movement of the arms gradually overtakes that of the torso and continues upward, even as the center of

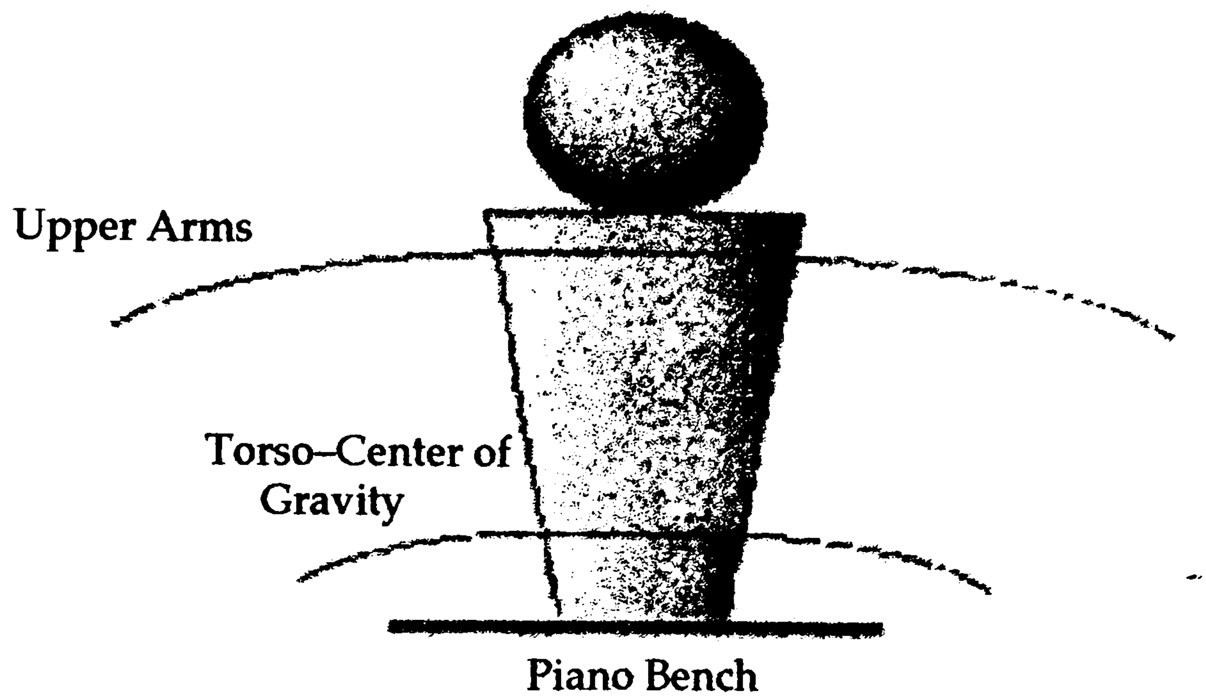

Figure 3.10. Arcs Described in the Frontal Plane by the Upper Arms andTorso in the Playing of a Scale

gravity begins a shift back to the center. The same phenomenon is observable in the descent. Thus, the velocity of the movement of the center of gravity is slower than that of the upper arms.

Since the hands are symmetrical, some generalizations may be made. The movements made in the ascending right hand scale are similar to those of the descending left hand. Likewise, the descending right hand and ascending left hand use the same motions. In general, longer fingers play progressively farther back on the key. The thumb plays forward on the key due to its relative shortness. It should be noted that these variations of individual fingers in positioning on the key are very minute. It is more ideal to play forward of the black keys because the keys weigh less and are easier to depress when force is applied farther away from the key fulcrum (just behind the fallboard). When playing in the center of the keyboard, the hand is deviated toward the ulnar side. As the extremes of the keyboard are approached, the upper arm is gradually abducted away from the torso and the hand is in a position of radial deviation. As the upper arm is adducted toward the body, the hand undergoes ulnar deviation. This general movement of the upper arm, as has already been described, delineates an arc. When the end of the arc is reached, there is a gradual change in the direction of momentum. This gradual shift in momentum at either end of the scale causes the motion outlined by the elbow to be rather like a flattened circle around the arc described by the upper arms (Figures 3.11 and 3.12). This path described by the elbow is a direct result of the pendulum-like flow of weight in the upper arms. It is accompanied by a corresponding motion of the wrist, which describes the same shape albeit smaller. It may therefore be observed that the wrist and elbow are in a lower position during the ascent of the right

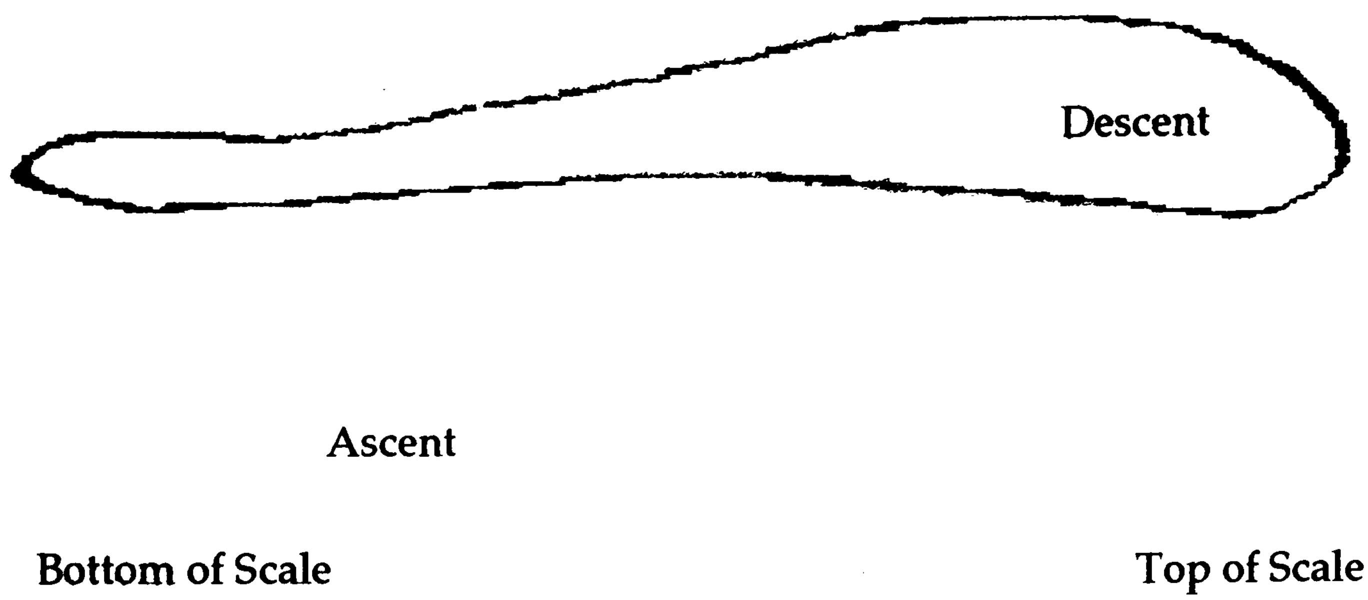

Figure 3.11. Flattened Circle Described in the Frontal Plane by the Right Elbow in Playing a Scale

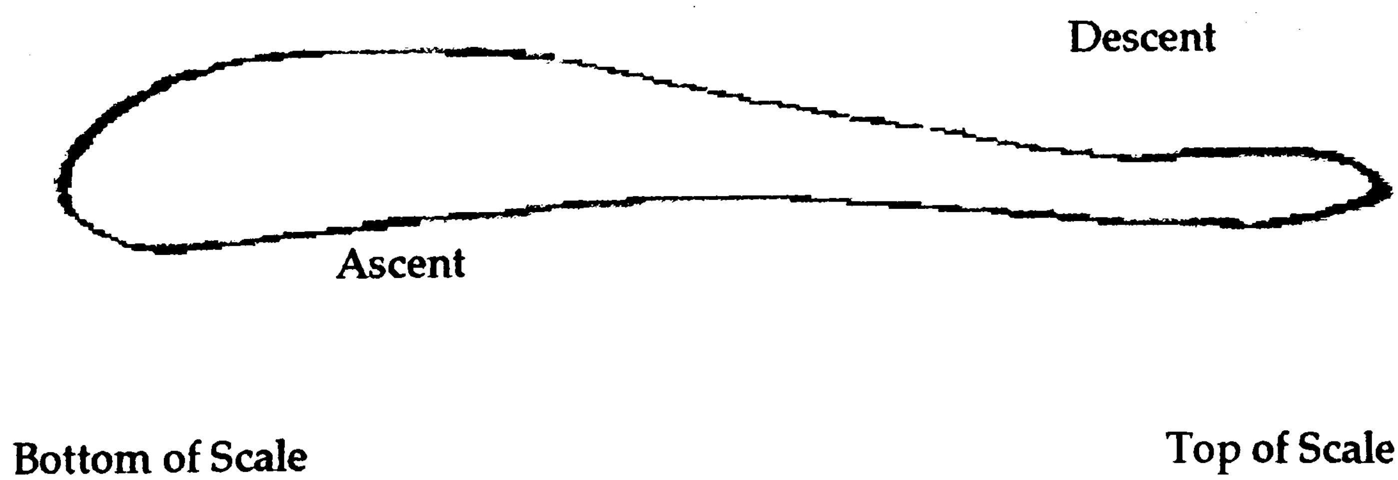

Figure 3.12. Flattened Circle Described in the Frontal Plane by the Left Elbow in Playing a Scale

hand, and are generally higher during the descent. This observation applies oppositely in regard to the left hand, since it is the mirror-image of the right hand. Muscles controlling the elbow itself should remain relaxed as they are not required to exert any effort in the playing of the scale.

Arpeggios

Observations and Recommendations of Noted Pedagogues

Most piano pedagogy experts seem to hold the opinion that arpeggios use the same basic motions as scales. However, though the basic motions of crossing the thumb under and the hand over are the same for both scales and arpeggios, the added element of distance in the arpeggio creates special difficulties for the pianist. It is readily noticed, even by the untrained observer, that the motions used in executing arpeggios are magnified and exaggerated in comparison with a scale.

Cortot noted that the mechanism for passing the thumb under in the execution of arpeggios requires "more accentuated flexion of the wrist than for scales" due to the stretching of the fingers in an arpeggio.[97] Sandor has noted that the technique for executing both scales and arpeggios basically involves connecting and adjusting motions between notes and fingers; these motions are larger and wider in arpeggios.[98] Ortmann referred to arpeggios as "large scale[s]," in terms of muscle movement.[99] Joan Last pointed out that in arpeggio-playing, the fingers cannot be curved as much as in scale-playing; they flatten naturally due to the greater distances involved.[100] She also noted

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97 Cortot, 27.

98 Sandor, 62.

99 Ortmann, 262.

100 Joan Last, *Freedom in Piano Technique* (New York: Oxford, 1980), 40.

that while arpeggios and scales share the same basic movement patterns, arpeggios at slow to moderate tempos require a more pronounced "lateral swing" at thumb-crossings than do scales because of the distance traversed by the thumb.[101]

Last pointed out that different motions are used in executing a fast arpeggio than when playing at slow to moderate tempos. Increase in speed, combined with the increased distance requirements of the thumb, results in greater problems maintaining physical comfort and accuracy. This is especially true for the right hand ascent/left hand descent, when the thumb must pass underneath the hand. Due to this increased distance at thumb-crossings, many pedagogues, including Last and Seymour Fink, recommend quickly lifting the entire arm to place the hand in each new position rather than reaching under the hand with the thumb.[102] When the hand is lifted in this fashion, lateral wrist motions at thumb-crossings virtually disappear; an actual key connection is not made by the fingers. Instead, momentum is provided by the arm traveling outward; the wrist is less active laterally. No audible break will result from the lifting of the hand; the shift occurs very quickly, and the actual break is slight.[103] When playing hands-together arpeggios, this slight break is disguised by the other hand, which can be played with more key connection. Other experts disagree with this recommendation, claiming that lifting the hand completely for each hand shift will result in undesirable accents.

Abby Whiteside discussed arpeggios extensively. Whiteside believed we have complicated the already difficult task of arpeggio playing by over-

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101 Joan Last, 39.
102 Fink, 115.
103 Last, 40.

analyzing movements instead of concentrating on the desired sound and using the ear. She claims that a "natural" talent has this ear control.[104] Ironically, the bulk of her comments on arpeggios describe physical movements.

Whiteside defined the ideal arpeggio as having no "bumps in dynamics" and "fluency with accuracy."[105] She believed that inaccuracy in playing correct notes, in at least 90% of instances, is the result of a faulty adjustment in controlling distances, not the result of insufficient practice. Moreover, she claimed that maintaining key legato by actually connecting the notes with the fingers does "inestimable damage" in playing arpeggios.[106] This type of connection will hinder progression from one octave to the next.

Whiteside stated that the crucial ingredient for "beautiful" arpeggios is power in sound production, evenly applied to successive keys. Even application of power gives rise to two problems: (1) how to find the correct key each time, and (2) how to produce tones smoothly.[107] She pointed out that in finding each key, continuous in and out adjusting motions are required due to the shortness of the thumb. Similar adjustments must be made in order to play black keys. The "top arm" (upper arm) and the forearm are the predominant means of covering distance on the keyboard; the hand and fingers act as secondary levers.[108] The top arm controls horizontal motion, and the other levers conform to the top arm. Whiteside compared the motion of the top arm in an arpeggio with that used in a glissando; there

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[104]Whiteside, 107-8.
[105] Whiteside, 103.
[106] Ibid., 103-4.
[107] Ibid., 105.
[108] Ibid., 105.

is a smooth transfer of momentum.[109] The action of the upper arm in playing arpeggios is distinguished from that used in executing glissandos by the control of distance, and evenness of tone and rate of progression from note to note. In order to stimulate this use of the upper arm in students, Whiteside has them close the keyboard lid and rest the elbows on the lid, imitating a tiny back and forth motion which is sufficient to shake the hands.[110] This exercise allows the student to gain a feel for how the top arm functions in an arpeggio; the student feels how the top arm gives momentum to the hand and fingers and controls backward and forward motions necessary to play black keys. Since the hand and fingers only extend this action of the top arm, Whiteside eschewed training of the fingers of independent digits, claiming that overemphasis on the fingers in an arpeggio will disrupt the momentum of the upper arm. However, Whiteside did concede that the larger the size of the hand, the less need there is for exaggerated action elsewhere to cover the distance.[111] Instead of independent fingers, the ideal should be cooperation of the hand, fingers, forearm, and upper arm.

The timing of the body levers in producing a tone is crucial.[112] Vertical key control must be timed and coordinated with horizontal control by the upper arm.[113] The upper arm activates the fingers, which transmit the action of the upper arm into the keys.[114] In the right hand ascent/left hand descent, the upper arm also propels the hand into each new position with the help of the forearm and the use of rotary motion. According to Whiteside, this shift

[109] Ibid., 106.
[110] Ibid., 109.
[111] Ibid., 106.
[112] Ibid., 107.
[113] Ibid., 108-9.
[114] Ibid., 114.

in position will result in slight breaks in key connection.[115] While the hand is thrown into each new position, the upper arm is finding each proper key and is maintaining the level of tone production. The action of the wrist is the result of action occurring farther up in the arm.[116] Although the primary motion occurs in the top arm, the action of the forearm is more visible because it describes a wider arc of distance than does the upper arm.[117]

Whiteside further clarified the problems of arpeggios playing as (1) finding the correct key without reaching with the finger, and (2) achieving articulation with dynamic control. She offered solutions which detail the role of each part of the anatomy. The upper arm should be used:

1. to gauge distance,
2. to provide continuity in action,
3. to gauge the level at which power must be released to maintain tone production,
4. to provide momentum, with the help of gravity, for vertical key drop,
5. as the fulcrum for the activity of the forearm,
6. to provide the initial activity between tones. Finger articulation, should take place only at the instant of tone production.[118]

The forearm should be used:

1. for rotary action in order to propel the hand into position,
2. to initiate control of vertical key action (except when the top arm is providing key-drop momentum),
3. to provide rotary action for sharing key-drop and horizontal distance control.[119]

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115 Ibid., 115.

116 Ibid., 111.

117 Ibid., 112.

118 Ibid., 117.

119 Ibid., 117.

The hand should be used:

1. as an extension of the upper arm,
2. to maintain chord formation. This control of hand shape takes place between the metacarpophalangeal (MCP) joint of the fifth finger and the second joint of the thumb, never at the finger tips.[120]

The fingers should be used:

1. as a bony structure to transmit the power of the arm into the keys. They should never produce power independently of the arm.
2. to share, in coordination with the leverage of the arm and hand, in the vertical distance of key-drop,
3. as the last link completing the bony structure between the shoulder and the keyboard. The bony structure of the finger easily transmits the power of the arm into the keys, but the independent muscle power of the finger is totally inadequate for producing a full range of dynamics.[121]

Dorothy Taubman has taken a position different from that of Whiteside in regard to the upper arm. Her position is that the upper arm does not initiate movement; it is carried along by the forearm.[122] She has stated that accuracy and freedom from fatigue in executing large leaps at top speed are achieved when distances are made to feel as small and as close as possible. The parts of the playing apparatus which are chosen to execute leaps must be capable of great speed. Traditionally, and as advocated by Whiteside, the upper arm has been used to initiate the jump, carrying the forearm up and sideways to its destination. However, Taubman has determined that the upper arm is too slow and is therefore inefficient; using the upper arm contributes to the sensation of great distance. Instead of using the upper arm, Taubman has recommended using the forearm, which carries the upper arm along with it. In other words, the upper arm does move, but is not

120 Ibid., 117.
121 Ibid., 117-118.
122 Taubman, tape 1, 2:49:45.

responsible for initiating movement. Strict use of the forearm alone can lead to a feeling of note disconnection. This lack of connection may be remedied by adding the element of forearm rotation.[123] Taubman believes that initiating motion with the upper arm is a major cause of neck, shoulder, and back pain.[124]

However, Taubman does agree with the other pedagogues that crossing the thumb in arpeggios presents a challenge due to the distances involved. Typically, at the moment of thumb-crossing the player will either twist the arm or release the note just prior to the playing of the thumb. According to Taubman, the notes of an arpeggio can be connected by using the "walking hand and arm" in combination with forearm rotation, as described in reference to the scale.[125] Though the impetus for key depression is coming from the finger, the upper arm does make adjustment to make the work of the fingers easier. Even if the fingers are not able to provide an actual key connection, the upper arm offers a feeling of one continuous motion; the arpeggio feels "as if connected."[126]

Ortmann, like other pedagogy experts, was also concerned about the demands of crossing the thumb under the other fingers in arpeggio playing. He compared the angle of the thumb during its crossing in a scale to that demanded in an arpeggio. Motions of the thumb were recorded using two horizontal aluminum rods with writing points which marked on revolving drums. He attached one rod to the first phalanx of the thumb and the other rod to the forearm at the wrist. He found that in a scale the thumb stretches

123 Ibid., tape 2, 2:38:48.
124 Ibid., 2:42:06.
125 Ibid., tape 4, 1:31:00.
126 Ibid., 1:37:00.

about 40° to cover the interval of a 4th; this flexion of the thumb is within normal range of motion. Therefore, he claims that the scale may be played without shifting the arm to allow for thumb-crossing. On the other hand, in an arpeggio, the thumb covers the distance of an octave and the angle of flexion demanded in order to pass the thumb is beyond the normal range of motion. Therefore, the passing of the thumb must be accompanied by an arm shift, which occurs primarily in a horizontal plane; thumb action is parallel to arm shift.[127] However, Ortmann believed that using arm shift alone to accomplish the crossing of the thumb results in an undesirable accent every time the thumb plays and stated that actual thumb passage and arm shift must be combined in an arpeggio.[128]

Ortmann believed that the difficulty of thumb-crossing in arpeggios, as in scales, lies in the vertical motion of the thumb after it is passed. In arpeggios, the thumb is stretched out and the arch of the hand relatively flat in comparison with its shape in playing a scale, where the arch is more rounded. In order to gain momentum for the dropping of the thumb, Ortmann recommended that the hand be lifted somewhat by raising the wrist slightly. This lift should be accompanied by a slight forward arm motion to compensate for the shortness of the thumb. Thus by combining lift of the wrist with forward movement of the arm and some thumb flexion, the thumb-tip is brought over its key without reaching outside its range of motion. Similar to his recommendation for scales, Ortmann rejected the use of a "quiet" hand. Using a fixed hand would cause the thumb to act outside its normal range of motion, seriously impairing freedom of movement.[129]

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127 Ortmann, 263.
128 Ibid., 267-8.
129 Ibid., 266.

Rapid exercises which require a quiet hand with the passing of the thumb, according to Ortmann, do not teach movement patterns which actually occur in a scale. In preparation for arpeggio study, Ortmann recommended assigning various broken chord figures within a single octave, to which the thumb-shift may be added.[130]

Taking a top view of the hand, Ortmann noted forward/backward displacement during the ascent of the right hand. These forward/backward movements result in corresponding lifting and lowering of the wrist. As the thumb plays, the wrist draws away from the keyboard. It is then pushed forward and raised as the thumb passes under. During the moment of crossing, the hand pulls back "a trifle" as the thumb reaches for the next key and the hand resets itself. Ortmann also noticed that the descent of the right hand was simplified due to the forward position of the hand in activating the vertical thumb stroke.[131]

From a view facing the player, Ortmann noticed considerable vertical displacement of the wrist during the ascent of the right hand. According to Ortmann, the wrist drops as the thumb plays, is lifted to accommodate the passing of the thumb, and drops when the thumb plays again. This is consistent with his belief that arpeggios are essentially "large scales."[132] In the right hand descent as observed from the front, Ortmann noted the absence of the vertical displacement of the wrist. Instead, the back of the hand traverses an almost straight horizontal line. The overall position of the wrist, and hence of the elbow, was noticeably raised in the descent and lowered in the

130 Ibid., 276.
131 Ibid., 266.
132 Ibid., 262.

ascent.[133] This observation applies to scales as well (Figures 3.11 and 3.12) though it was not noted by Ortmann in his discussion of scales.

Like Last, Ortmann believed that the pattern of movement varied with tempo. In slow arpeggios, he claimed that periods of movement alternate with periods of rest while in rapid arpeggios, arm movement is continuous though the thumb action remains periodic. In a slow arpeggio, the actual shifts are made just as quickly as in a rapid arpeggio; however, the slow arpeggio has rest periods added, prolonging the duration.[134]

Mirroring his statements concerning weight transfer in scales, Ortmann maintained the same position with regard to arpeggios. Weight transfer, he claimed, is dependent upon the speed at which the fingers are lifted from the keys, speed and loudness of the skill being executed, and the keyboard distances involved. There are increased distances involved in arpeggio playing, which requires greater speed in finger-lift and greater speed in the lateral transfer of the arm.[135] He claimed that the necessity for the third finger to lift very quickly to allow for thumb passage precluded the possibility of weight transfer. As was pointed out in the section regarding scales, Ortmann's position on the impossibility of weight transfer in a scale is not supported by empirical evidence. It is still possible for weight to be transferred smoothly from finger to finger *in between* shifts; moreover, the application of weight by the upper arm remains constant, even during hand shifts. Ortmann overemphasized the contributions of each individual finger, pointing out that vertical finger strokes are needed to depress each key. While this is certainly true to a degree, it is also true that the fingers do not act

133 Ibid., 269.
134 Ibid., 265.
135 Ibid., 262-63.

independently from the hand and arm, which supply the main force. Ortmann further opined that only independent finger strength can supply enough force for producing loud arpeggios.[136] This assumption is contradicted by our knowledge of anatomical structure and mechanical principles; greater force is applied through the larger leverage of the arm in combination with gravity, not by the short, relatively weak fingers. Furthermore, power (tone volume) is a product of both force *and* velocity of the piano key. In producing forte arpeggios, the fingers need not supply force, only transmit the force of the larger units (torso, upper arm, and forearm) with greater velocity into the key bed.

Biomechanical Description of An Arpeggio

As previously described for scales, the following description applies to a hands-together arpeggio beginning on a white note which traverses four octaves. As in scale playing, the goal in arpeggio playing is a smooth, linear projection of tones with rhythmic accuracy and no misplaced accents. In contrast to the views of Ortmann, weight transfer from finger to finger between hand shifts is required in order to accomplish this uninterrupted flow of sound. As in a scale, the motions of the right hand ascent may be considered analogous to the left hand descent, and the left hand ascent analogous to the right hand descent due to the symmetry of the hands.

Right Hand Ascent/Left Hand Descent

The fingering pattern for all major and minor arpeggios beginning on white keys in the right hand is: 123 123, etc., ending on the fifth finger (note

136 Ibid., 275.

that spaces in the fingering pattern indicate a hand shift). The descending left hand fingering pattern may vary according to the position of black keys within the arpeggio and the shape of the individual player's hand: 123 123, etc., ending on the fifth finger, or 124 124, etc., ending on the fifth finger.

After the thumb plays the initial note, it is gradually adducted to line up behind the second and third fingers, but to a lesser degree than in a scale. This is because the lowered arch of the hand in combination with the need to cover a larger distance at the thumb-crossing, demands that the arm play a greater role at the moment of crossing. If a true key connection were to be preserved, the player would be forced to lift the upper arm at almost a right angle to the torso, raising the third finger nearly vertical in relation to the key. Use of this motion would require a large correcting motion after the thumb-crossing to allow the thumb to drop onto its proper key. Instead, the more efficient motion for thumb-crossing is to slightly adduct the thumb to line up behind the second and then the third finger gradually as the crossing is approached. As was the case for scales, the thumbs should not be allowed to drop below key level. As was mentioned in regard to the scale, the thumb will lose contact with the key surfaces but should never be allowed to drop below the level of the keys. This gradual thumb adduction is accompanied by very slight radial deviation. The hand also raises to prepare for the passing under of the thumb accompanied by a slight pronation. This slight lifting of the hand and pronation minimizes the break between notes at the crossing. Both motions will be more pronounced at slower tempos.

At the actual moment of crossing, the entire hand is lifted and placed into position in the next octave. Ideally, the hand should not be lifted high over the keys, but should make a short, shallow arc to allow the thumb to land on its key. In rapid arpeggios, there is not an actual key connection between the third finger and the thumb. The continuous momentum of the upper arm and forearm helps provide some sound connection. The break in sound is so slight that it is scarcely perceptible; the faster the tempo, the less the actual break in sound. Furthermore, since crossings occur at different points in the right and left hands when playing hands-together, any slight break which occurs will be concealed by the other hand. Unwanted accents by the thumb are prevented by the slight vertical and lateral adjustments of the wrist.

Left Hand Ascent/Right Hand Descent

The fingering pattern for all major and minor arpeggios in the left hand ascent is: 5321 321 321, etc., or 5421 421 421, etc., depending upon the arrangement of black keys in the arpeggio and the shape of the individual player's hand. The fingering pattern for the right hand descent is: 5321 321 321, etc. At the outset, the wrist is in a straight line with the arm and hand. This position contrasts with the outset of the left hand ascent/right hand descent of the scale, in which the hand is in a position of greater radial deviation. This is due to the greater distance of the elbow from the torso, which will be considered in the coordinated movements section. A pattern of very slight ulnar deviation is present within each octave, accompanied by forearm pronation. After the fifth finger plays, the hand is gradually deviated toward the ulna (ulnar deviation) as the thumb is approached. The degree of ulnar deviation will vary according to hand size (small hands require more lateral wrist motions). As the thumb plays, the forearm enacts a pronation, adducting the thumb behind the fingers which helps to lift the hand. During the brief moment in which the hand is airborne, the third finger is directly over the thumb, with the thumb hanging down loosely. The pronation of the forearm along with the momentum of the upper arm helps control the positioning of the hand so that the third finger descends onto its proper key aided by gravity. After the third finger falls onto its key, the hand resets itself with the thumb emerging from beneath the hand accompanied by ulnar deviation.

Coordinated Movements of the Arpeggio

As has already been discussed, the motions of the arpeggio are similar to those of a scale. This is especially true of the motions observable in the large levers. The entire arm is shifted in toward the piano or out toward the body in order to reach black keys. This in/out movement is perhaps the most important means of achieving comfort and accuracy in arpeggios. The shift of the center of gravity from left to right when playing hands-together in parallel motion is observable in the arc described by the torso in the frontal plane. Likewise, the weight of the upper arms outlines an arc in the frontal plane (Figure 3.10). The elbow and wrist describe flattened circles as a result of the arcing of the upper arms and torso. As in a scale, the circle of the wrist is smaller than that of the elbow. However, in arpeggio playing, the elbow is held consistently farther from the torso, keeping the forearm and wrist in a straight line in order to keep each finger aligned with its respective extensor tendons. This is due to the greater distances traversed between the notes of an arpeggio in comparison with a scale. In fact, this traveling over greater distances accounts for the unique motions observed in an arpeggio. In comparison to a scale, the hand is more opened out; as a result, the arch of the hand collapses somewhat, giving greater potential for fatigue. If the hand is kept open but is not held rigidly, the potential for injury may be minimized. As was noted in the right hand ascent/left hand descent description, it also requires that the arm and hand play a greater role in shifting from octave to octave. The slight adjusting motions of the wrist allow for the smooth projection of evenly accented notes to proceed without interruption.

As was the case in the scale, the ideal arpeggio fingering allows the longer fingers to fall on black keys while use of the fifth finger and thumb on black keys is avoided. The hand is in a position of ulnar deviation when playing in the middle of the keyboard. As was seen in the motions of the scale, there is increasingly less ulnar deviation and thus more radial deviation as the extremes of the keyboard are approached. It is always the case that the farther the arm is reached across the body at the keyboard, the more ulnar deviation is required. The right hand ascent/left hand descent requires more radial/ulnar motion as well as supination/pronation rotation by the forearm and hand than the right hand descent/left hand ascent. This is due to the varied lengths of the fingers. Because the thumb's reach is shorter, especially when adducted, more slight vertical and lateral hand adjustments are required to achieve note accuracy.

Trills

Observations and Recommendations of Noted Pedagogues

Executing trills is one of the most challenging skills faced by the pianist. It is a delicate task; if too much forearm rotation is used, the fingers will not be able to move effectively, the keys will not be able to return to a position sufficient for them to be depressed again, and the trill will "get stuck." On the other hand, if too little rotary motion is used, the fingers will be more uncoordinated and slow in the depression of the key and the trill will sound sluggish.

Ortmann discussed trills as a specialization of the tremolo. In his view, both trills and tremolos require a rotary motion around an axis which is approximately parallel to the long axis of the forearm, that is, pronation and supination. Ortmann made an analogy between the type of rotary motion used in trills and tremolos and the motions used to turn a doorknob or screwdriver. If during this rotation the thumb and fifth finger are fully extended (as when playing an octave), Ortmann claimed that the thumb and tip of the fifth finger will each describe arcs belonging to the same circle on the frontal plane. Using the thumb and fifth finger to play intervals of decreasing size, the circle becomes correspondingly smaller; the thumb and fifth finger still describe arcs belonging to the same circle. He also stated that if the length of the arcs described by the thumb and fifth finger remains the same while the size of the circle is decreased, the direction and curvature of the finger stroke will be altered, making the finger stroke less effective. The nearer together two notes are, the less effective the tremolo rotary motion. Thus octaves, 6ths, and 5ths lend themselves to rotary motion; using rotary motion when playing 3rds and 2nds (trills) is mechanically disadvantageous.[137]

With regard to rotary motion in tremolo playing, Ortmann pointed out that the hand must be shifted at the wrist so that the axis of rotation falls midway between the two notes of the tremolo. Ortmann claimed that when

[137] Ortmann, 186.

the hand is in its neutral alignment with the wrist, the axis of rotation runs through the fourth finger, not the third finger. He therefore concluded that in order for the third finger to become the axis of rotation, the hand must be slightly abducted toward the fifth finger (ulna).[138] If one simply allows the arm to hang down at the side of the torso naturally, it is apparent that this statement does not hold true. With the hand in its neutral position, the third finger does in fact line up with the axis of forearm rotation, which runs through the proximal and distal radio-ulnar joints. With the arm hanging and the fingers naturally curved and resting lightly on a flat surface (such as the closed lid of the piano) if the forearm is pronated and supinated, it is observed that the fingertip of the curved third finger remains in constant contact with the surface, while the other fingers alternately contact and withdraw from the surface as the forearm is rotated.

It is not necessary, according to Ortmann, that adjacent fingers be used to execute trills. The hand may be cupped so that the tips of the second and fourth, or even the second and fifth fingers are brought close enough to cover adjacent keys.[139] In fact, many other finger combinations are possible which Ortmann did not mention. Using non-adjacent fingers is helpful when using a tremolo motion. Ortmann did point out, however, that trills do not use true tremolo motion; he stated that trills should be executed by independent finger motion. The chief advantage of using the fingers in this way is a reduction in the factors of inertia and momentum. Executing a trill requires repeatedly and rapidly effecting a complete reversal in direction. Any rapid movement requiring a quick change in direction is most economically made

138 Ibid., 187.
139 Ibid., 188.

by a lighter mass, and the fingers weigh much less than the arm.[140] Assuming the time rate of the finger descent remains the same in using a tremolo versus finger movement, it will take much more force to reverse the momentum of the arm than of the fingers. Ortmann did acknowledge that occasionally rotary motion must be added to the finger motions of a trill. This is true in cases where the intensity demanded of the trill is more than the fingers alone can supply. However, Ortmann claimed that in most trills, "finger-tremolo" motion is much more effective than rotary motion because it permits better tone control and is more economical. Ortmann went on to claim that this need for finger motion in trills supports the need for finger drills "in order to strengthen the finger flexors lying in the hand," though he did not describe exactly the type of drill to use. He further claimed that stiffness which often accompanies students' first attempts at finger trills results from insufficient strength in finger muscles.[141] This assertion has potentially dangerous implications. The intrinsic finger muscles and the tendons of the hand are relatively small and weak in comparison with the muscles of the rest of the arm. Speculatively, the player could exceed the tissue tolerances of the finger muscles while attempting to build strength, resulting in a greater potential for acute or chronic overuse injury.

Ortmann also considered the effects of velocity on trills. He was aware of the inverse relationship between acceleration, force and mass expressed by the formula: acceleration = force/mass. Therefore, he concluded that to increase velocity, the mass of the active anatomical parts must be lowered.[142] Strictly speaking, Ortmann has made an erroneous assumption since

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140 Ibid., 188.

141 Ibid., 189.

142 Ibid., 191.

acceleration and velocity are not the same. Acceleration represents rate of increase while velocity refers to constant speed.

Ortmann claimed that the arm weight should be "carried" by the shoulders and the keys should be depressed by finger motion unaided by gravity. This, he claims, is an example of a "non-relaxed" touch form. He further stated that instead of being supported by the keys, the arm must be suspended above them.[143] Ortmann has described a potentially dangerous use of the anatomy. Ortmann's description would place the arms and shoulders in a position which could contribute to excessive tension in the shoulder girdle musculature as the hand and forearm are suspended above the keys. Conversely, it is possible to maintain a light arm and hand without unduly tensing the trapezius and deltoid muscles of the shoulders.

Ortmann likewise considered the effects of volume. He notes that force is a product of both acceleration and mass. Therefore, force can be increased by increasing either the mass or the acceleration of the active playing components. He claimed, however, that by increasing arm weight we also increase inertia. The principal of inertia is that bodies in motion tend to stay in motion, while bodies at rest tend to stay at rest. Therefore, he concluded that it is mechanically preferable to increase velocity instead of mass.[144] After conducting experiments to measure the effects of dynamic and tempo variations and on the transfer of weight in trills, Ortmann found that at the softest volume, finger speed was at its greatest and fluctuations of weight transfer from finger to finger were least, that is, weight transfer was relatively constant. As both speed and volume were increased, the number of

143 Ibid., 192.
144 Ibid., 192.

finger strokes in a given time period decreased and there was more fluctuation in weight transfer.[145] Ortmann concluded that all loud rapid tremolo motions are, from a muscular standpoint, non-legato.[146] Although weight-transfer at the fastest speeds and loudest volumes may approach zero, Ortmann concluded that in all cases, there was still some weight transfer present. He concluded that "at a given speed only a certain amount of weight can be transferred from one finger to another."[147]

The recommendations of Newman and Last agree with the advice offered by Ortmann. Newman stated that unlike tremolos, trills are best played by the fingers alone.[148] He suggests using simple fingerings, stating that 3-2 or 3-1 is often the best solution; complicated fingerings can cause difficulties in concentration and memorization.[149] Newman also believed that the notes of a continuous trill should never be forced into an exact meter.[150] Last believes it impossible to lay out an exact method for fingering trills, claiming that fingering choices are dependent upon the shape of the hand, especially finger length. The fingers must be unhampered from the weight of the hand and arm; furthermore, they should not be lifted higher than the striking point of the key. Last believed the earliest attempts at trill-playing should be modest in speed, and fingerings should be mastered in order from simplest to most complex: 1-3, 2-4, and finally, 3-5. Last believed that using adjacent fingers was not the most flexible fingering solution and therefore advocated learning these fingerings in addition to the most

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145 Ibid., 136.
146 Ibid., 192.
147 Ibid., 137.
148 Newman, 65.
149 Ibid., 74.
150 Ibid., 141.

commonly used 2-3 fingering.[151] Unlike Ortmann, Last spoke of the height of the wrist, stating that trills can be played successfully either with a high wrist or a low wrist. Last recommended using the wrist in a position which is slightly lower than normal. In order to achieve the brilliance of virtuoso trills, extra energy must be imparted from the hand muscles, and even from the arm.[152]

Whiteside's approach to trill playing is different from that of Ortmann. She pointed out that an octave trill can only be accomplished with brilliance and speed when the top arm is used along with alternating action.[153] She defined alternating action as the combination of flexion and extension between the hand and forearm which allows the hand to go up while the forearm goes down and vice versa.[154] According to Whiteside, a trilling on adjacent notes should involve the same motions as trilling octaves; there is just more free play of motion. The trill is actually produced by the repeated action of the forearm which in turn produces repeated action in the hand. The source of power is the repeated action of the elbow, which is transmitted to the keyboard via the repeated action of the wrist and the bones of the fingers.[155] The repeated action of the elbow throws the hand in such a way that the repeated action of the hand is highly visible. The hand should move easily in response to the quick action at the elbow; the hand represents only the periphery of the playing apparatus.[156] Whiteside's statements with regard

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151 Last, 57.
152 Ibid., 58.
153 Whiteside, 88.
154 Ibid., 28.
155 Ibid., 92.
156 Ibid., 90.

to this "action of the elbow" are vague at best. The elbow is a joint; it cannot itself initiate motion.

In learning to execute trills, Whiteside stated that "perhaps the most efficient manner of achieving a single trill with the same repeated action which is demanded by the octave trill is to slip up on it unawares by doing something else which is closely related."[157] She suggested practicing fast repeated double-thirds, then gradually opening up the thirds until only two notes are sounding. Then the trill may be practiced as a blocked second; rotary motion can be used to gradually open the second up into a trill.[158] In the first efforts at producing a trill, legato should be avoided because the fingers can take over the trill too easily. She cited two habits which should be avoided: (1) allowing the fingers to take over the key-drop and produce power for tone (in direct contradiction to Ortmann on this point), and (2) using rotary motion which is too wide. Whiteside lists habits which should be cultivated:

1. Take the key-drop with the top arm on rhythmically important tones.
2. Use alternating action for fast articulation.
3. Coordinate finger action with alternating action.
4. Use rotary motion in a small compact arc.
5. Provide power entirely with the top arm along with alternating action, not with the fingers and rotary motion.[159]

Whiteside acknowledged that this last statement may not be entirely true, but it offers imagery for the desired result of a blended action.[160]

No easy blend of necessary movements will take place until the power produced by the upper arm is balanced against the key action at the dynamic

157 Ibid., 89.
158 Ibid., 93.
159 Ibid., 91.
160 Ibid., 91.

level at which the tone is produced. According to Whiteside, this feel of balance must be ever-present. Moreover, the key should never be allowed to come all the way back up to its top level; it should be allowed to rise only just enough to make another depression possible. In this way, the vertical arcs of the fingers (which were described by Ortmann) are smallest and most efficient.

The views of Sandor conflict even more sharply with those of Ortmann. He stated that in executing trills, not only is rotation required, it is the prevailing motion.[161] He believed that most trills use this motion, especially those with 1-3, 2-4, and 3-5 fingerings. Forearm rotation must be transmitted to the fingers, which should be slightly raised above the key to anticipate the "axial throw" of the forearm. However, he qualified his view on rotation by stating that one must be careful to use an appropriate amount of forearm rotation; too much immobilizes the fingers, while too little strains the fingers as they are forced to do most of the work of trilling.[162]

Sandor believes that trills are nearly impossible to teach.[163] The best one can do is create conditions which are conducive to the production of good trills. He stated that almost any combination of fingers can produce a good trill. It is the teacher's job to ensure the free mobilization of the fingers, wrist, and forearm. Sandor has pointed out that it is often easier to begin a trill at a moderated tempo with slightly articulated finger and arm motions. The trill may then be gradually accelerated. If excessive speed is attempted, coordination is lost, the trill is forced and eventually "freezes." Fingers may be either curved or extended, and the wrist may be in a high or low position.

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161 Sandor, 128.
162 Ibid., 128.
163 Ibid., 136.

It is important to place the arm in a comfortable position, aligning the fingers with their respective forearm muscles. One should also use the usual adjusting motions of the wrist and arm; these motions diminish as the speed of the trill increases.[164]

Taubman has advised that when trilling, the wrist must often be at a slightly lower than normal position to accommodate the thumb. However, the wrist fulcrum should not be broken.[165] She has further recommended that trills be executed using single rotations from one note to the other. In this way, the momentum for the next note is provided by the first. The rotation goes a little beyond the finger playing one note and then swings back in the other direction.[166]

After reading the conflicting advice concerning how trills should be executed, it is perhaps helpful to view the execution of trills as a continuum from finger execution at one extreme and execution using forearm rotation at the other extreme. Each extreme has its corresponding potentially hazardous anatomical ramifications. Solely using the fingers may lead to hand injuries such as tendinitis. Using the forearm alone may cause the trill to "get stuck" in the keybed due to the excessive weight applied to the fingers; moreover, there is the potential for tension in the shoulder musculature.

Biomechanical Description of Trills

Since by far the majority of trills are executed by the right hand, the trill combinations are described as performed by this hand. However, the muscles, tendons, and skeletal structure are symmetrical in the left hand, so it

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164 Ibid., 136.

165 Taubman, tape 1, 2:04:50.

166 Ibid., tape 2, 1:25:50.

is conceivable that the process would be similar in this hand. There might be some minor inconsistencies in comparing left hand trills to those of the right hand due to strength, coordination, and experiential differences.

In executing a trill, the arm should be kept light. Although weight is suspended, the muscles of the shoulder and upper back should not be strained at all. The upper arm should be loose. Although Last seems to prefer keeping the wrist in a low position, it is mechanically more advantageous to keep the wrist higher, so that the bones and joints of the trilling fingers are aligned in a position for maximum stability and leverage. Playing with the wrist in a lower position requires considerable exertion by the extensor tendons of the hand. The fingers should be allowed to curve naturally and the hand should be free of tension. As previously noted for other skills, when the hand plays in the middle of the keyboard, ulnar deviation is required. There is more corresponding radial deviation at the extremes of the keyboard. Additional radial/ulnar deviation is required depending upon which fingers are used to trill. The forearm should form a straight line with the midpoint in between the two trilling fingers. Unused fingers are kept from contacting the keys so that unwanted notes will not enter into the trill. These unused fingers describe arcs in the frontal plane. The exception to this generalization is the third finger. Since it is in the center of the hand, it makes minute vertical motions in the sagittal plane.

The distance of the fingers from the black keys will vary according to whether the trill is a white key to white key trill, a black to white key trill, or a white to black key trill. In general, when playing white key to white key, it is advantageous to play closer to the edge of the keys because this is the point of least resistance along the key. However, if black keys must be played in the trill, the entire hand will be positioned at the edge of, or in some cases, in between the black keys. In any case, the hand should be aligned as discussed above with the midpoint of the trill forming a straight line with the forearm. As the trill is executed, the player may find it helpful to make slight in and out adjustments with the hand or forearm. This motion causes the fingers to fall in a slightly different position on the keys with each stroke, preventing fatigue in the fingers and helping maintain trilling momentum.

Ortmann, Whiteside, and Sandor were each partially correct about the roles of the arm and the fingers in producing trills. However, both the arm and the fingers are involved in trilling. The visible arcs made by unused fingers confirm that the fingers do not act alone in producing a trill; arcs are the product of rotation. Even so, the fingers supply the impetus for trilling. If one attempts to add too much weight from the arm, finger velocity is hindered and the fingers get stuck at the bottom of the key bed.

White Key To Adjacent Black Key

The following description applies to a trill executed in the first octave above middle C on the notes B and C with the right hand. When fingering trills with the second and third fingers, the thumb, fourth, and fifth fingers are lifted away from the surface of the keys. The fifth finger and the thumb are slightly abducted. As Ortmann suggested, as the active fingers trill, the thumb and fifth finger describe arcs. However, these arcs *do not fall in the same circle,* at least not on the frontal plane. The thumb is connected to the wrist closer to the forearm than the fifth finger. Furthermore, the thumb is in a lower position in the sagittal plane than the fifth finger. Thus, the arc described by the thumb is of a greater angle than the arc described by the fifth finger. However, if the thumb is extended enough, it is possible that the thumb and fifth finger might describe arcs belonging to the same circle falling in a transverse plane. The arcs described by the thumb and fifth finger will vary according to the hand shape and hand position during trilling used by individual players. Very slight forearm rotation is visible. When the thumb and the third finger are used to trill, the fourth and fifth fingers describe arcs. When fingering with 2-4 or 3-5, the thumb describes a larger arc than it does when trilling with 2-3. In all these positions, the wrist remains relatively high and stable. However, when trilling with a 1-3-2 finger combination, more vertical adjustments are required of the wrist. These adjustments are necessary because of the shortness of thumb; this lifting/lowering of the wrist allows the thumb to move forward onto the key.

White Key to Non-Adjacent Black Key

This trill is described as executed one octave above middle C with the right hand. In this case, since the trilling notes are non-adjacent keys, the fingerings 2-4 and 1-3 are most effective. Interestingly, when the 2-4 fingering is used, there is marked radial deviation. This is not the case when trilling with 2-4 on adjacent white keys. The radial deviation here is due to the principle that the wrist must be turned so that the axis of rotation is in between the two trilling fingers. In this case, since the trill contains a black key, the fourth finger is in a higher position than the second finger, necessitating radial deviation in order to place the rotational axis between the second and third finger. The fingering 3-5 and 2-3 are more awkward; using 2-3 does not require any wrist deviation since the third finger is longer than the second finger.

Black Key to Adjacent White Key

The last trill is described as executed in the second octave above middle C by the right hand. In this case, since there is no key in between the two trilled notes, 2-3 fingering works well and requires little to no wrist deviation. The fingering 3-1 with the thumb under the third finger also requires little wrist deviation and produces more velocity. This surprising result is likely made possible by the grasping motion of the thumb. The fingerings 2-4 and 3-5 are more awkward, requiring significant ulnar deviation. The arcs described by the unused fingers in this trill are much smaller than in either the white key to white key trill or the white key to black key trill.

Double Notes

Observations and Recommendations of Noted Pedagogues

Passages of double notes which must be executed with one hand, such as thirds, sixths, or octaves, are regarded as among the most difficult pianistic challenges. Double notes may be encountered as scales, as repeated intervals or chords, or as melodic passages which use different combinations of intervals. In addition to the possible diatonic combinations, double notes can also be employed chromatically. For this reason, practicing double-third scales, octave scales, and other similar exercises has traditionally been recommended as an integral step in building piano technique. Many pedagogues offer advice on how to overcome the difficulties of executing double notes.

Alfred Cortot pointed out that the execution of double notes is a more complex issue even than polyphonic playing. He stated that in polyphonic playing, it is a question of which of two or more melodic lines should be made to predominate while in playing double notes, maintaining evenness in tone and equal intensity of the two parts is the goal. According to Cortot, the slight predominance often given to the upper note when playing double notes is used only to create a sense of clarity and precision.[167] However, he recognized that in most cases, the upper part outlines the melody with the lower voice following in contrary or parallel motion.[168] This observation suggests that the slight emphasis usually given to the upper voice might have as much to do with melodic projection as it does precision. Cortot believed that practicing double-note combinations was very important as an end in itself and further stated that it was the best technical preparation for polyphonic playing.[169]

In *Rational Principles of Pianoforte Technique,* Cortot offered numerous exercises for developing double-note playing in diatonic passages. The player is first introduced to double-note playing in scalar passages and is then given practice in performing double notes in arpeggios and broken chords. These exercises give the player practice in fingering passages in doublings of every interval from a second to a seventh, giving systematic fingerings for each interval. Some of these exercises focus upon the role of the thumb in displacing the hand as well as the positioning of fingers when they are not actively engaged in producing tones; others emphasize finger exchange.

Having dealt with diatonic double notes, Cortot then offered advice about chromatic double notes, which he believed to be more easily executed

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167 Cortot, 37.

168 Ibid.

169 Ibid.

than diatonic doublings. He stated that "in diatonic scales, owing to the laws of modality, chords of the same kind become major or minor according to the degrees on which they occur. This entails the use of a slightly different technique in each of these cases."[170] Simply stated, when playing passages of diatonic double notes, the player must make adjustments in order to play the black keys dictated by the key signature; chromatic-double-note fingering is more uniform because all black and white keys are used. Cortot pointed out that executing chromatic double notes presents some special challenges to the player, including sliding a finger other than the thumb from a black key to the adjacent white key, crossing of the upper fingers of the right hand and the lower fingers of the left hand, and substitution of fingers according to whether the interval is major, minor, augmented, perfect, or diminished.[171] Use of these strategies will vary according to the fingering chosen by the player.

Since he stated that chromatic-double-note fingering is more straightforward than diatonic-double-note fingering, Cortot's approach to teaching this skill is surprising. He offered three different sets of fingering for every chromatic double interval, two solely for the purposes of study and one for execution. The first, according to Cortot, is "systematic" and is to be practiced for "gymnastic independence of the fingers and suppleness in the displacements of the hand."[172] The second fingering is to be used to promote the sliding of a finger from black keys to white keys. Finally, Cortot offered a third fingering, the only one which was intended for use in actual execution

170 Ibid., 47.
171 Ibid.
172 Ibid.

of chromatic-double-note passages.[173] Cortot's approach to chromatic doublings is surprisingly complex.

Whiteside pointed out the difficulties of executing double notes by comparing the skill to the execution of a single-note scale. She claimed that a good finger scale is of practically no help when playing double-thirds, an argument she uses to support her previous conclusion that practicing single-note scales is of little use in acquiring overall technical facility.[174] As was her belief with regard to single note scales, Whiteside believed that the only practical way to execute scales of double thirds, fourths, and sixths was through the active involvement of the upper arm. She suggested that before attempting double scales, the student play rapid repeated double thirds to get the feel of the action of the upper arm.[175]

Whiteside identified potential problems in executing double-note passages in thirds, fourths, and sixths:

1. Movement from note to note is difficult.
2. Reaching for notes with the fingers should be avoided because it will necessitate articulatory movements in between tones.
3. Two active fingers must function together as a unit.
4. More power is needed to produce two notes than one note.
5. Rotary action is not available.
6. Hands shifts are made more difficult because the shift to the new position is slower and has to be made all at once instead of gradually.[176]

As remedies for the problems she recognized, Whiteside offers the following recommendations:

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173 Ibid.

174 Whiteside, 51.

175 Ibid., 80.

176 Ibid., 96.

1. Do not separate the execution of double notes from the basic rhythm of the musical idea. Do not focus on the individual initiations of power.
2. Locate position by using the "top arm", not by reaching with the fingers. If the upper arm is used to gauge distance, it will also fill in the time between tones and by doing so it can implement the basic rhythm.
3. Do not relax the adjustment of one set of fingers while another set is functioning. Two sets of finger bones should always be ready to receive the power from stronger levers.
4. Extra power needed for producing two tones should be provided by the upper arm and forearm, never by the fingers. Whiteside emphasized this point strongly.
5. Make up for the lack of rotary motion by having very active "alternating action", i.e. flexion and extension of the wrist.
6. The hand is thrown into position by a quick action at the elbow.[177]

In addition to her advice regarding passages of double thirds, fourths, and sixths, Whiteside also makes recommendations on how to play octaves. She recognized that because of the large span involved, octaves could cause more difficulties than thirds and sixths. However, Whiteside claimed that if the player has the capacity for fluid passagework along with the hand span of an octave, then the player can achieve fluid octave passages.[178]

Whiteside was convinced that a rigorous daily octave "work-out" would not of its own accord lead to virtuosity.[179] Whiteside discussed several faulty habits which could interfere with octave production. Her first concern was the tendency to maintain the octave hand span by reaching and holding with the tips of the thumb and fifth finger. To cure this problem, Whiteside recommended maintaining the span between the metacarpophalangeal (MCP) joint (which she termed "hand knuckle") of the fifth finger and the distal interphalangeal (DIP) joint (closest to the tip) of the thumb.[180] This will

177 Ibid., 96-97.

178 Ibid., 97.

179 Ibid., 98.

180 Ibid., 98.

result in a "kind of diagonal pull" across the palm.[181] The palm should be open and the fingers should not be stretched. The thumb should only be abducted in combination with opening the palm, which is easier if the thumb is somewhat flexed.[182]

Another potential difficulty in octave playing is reaching for key position with the fingers and hand. In order to avoid reaching with the fingers, Whiteside stated that the fingers should be relaxed at the MCP joint; they should be allowed to drop while the palm is opened and the thumb abducted. When this is achieved, the fingers function as an extension of the palm action. Whiteside recommended that the player ignore that there must be action in the hand in order to maintain the octave span; she thought that the upper arm ought to be allowed to take over, keeping the action of the hand to a minimum.[183] The hand and fingers should move only at the last split second before striking the key.[184] Reaching with the fingers can be overcome by having a very active upper arm and forearm, which control the "finding of the key."[185] Whiteside believed the easiest way to feel the action of the upper arm was to "slip into" playing chromatic octaves in the midst of a pattern of skipping octaves. When the upper arm is used, she claimed that the player becomes unaware of the vertical action of the hand and arm, a result Whiteside found desirable.

Whiteside was also concerned about the production of power for octaves. Power should not be initiated in the action of the wrist. According to Whiteside, this is a common misconception because the movement at the

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181 Ibid., 99.
182 Ibid., 98.
183 Ibid., 99.
184 Ibid., 99-100.
185 Ibid., 99.

wrist is more visible than that of the upper arm and forearm; the "width of play" in the wrist motion is wider than that of the rest of the arm. However, this phenomenon is similar to the action of a whip; the initiating activity takes place in the upper arm and forearm and the wrist moves in reaction.[186]

Another bad habit in octave playing discussed by Whiteside is bearing down on the forearm, which will result in a visibly low wrist. Bearing down on the forearm is the result of octaves for which the power is initiated at the wrist, as discussed above. In this case, the forearm is forced to act as the fulcrum for the hand. This action is not coordinated. Instead, coordinated action of the forearm implements the action of the upper arm and moves upward, not downward. While the upper arm gauges distance and positioning of the hand, the forearm activates the key-drop and produces the tones by throwing the hand out and downward with a quick repeated motion. In a scalar passage, the top arm produces the power for the more important octaves while the forearm in coordination with the hand produces power for the less important octaves in between.[187]

Joan Last recognized that in executing double-thirds, there is a fundamental difference in how the thumb functions as compared with a single note scale. Last used the following double-note-scale fingering in the right hand:

3 4 5	2 3 4 5	3,	etc.
1 2 3	1 1 2 3	1	

Last incorrectly stated that the thumb passes over instead of under as it does in single-note scales.[188] Presumably, she was pointing out that the thumb

186 Ibid., 102.
187 Ibid., 102-3.
188 Last, 47.

does not line up behind the second and then the third finger after it plays, as it would in a single note scale. Instead, the thumb stays alongside the second finger, ready to fall on the note after the shift occurs. Last also noted a tendency to push the elbow toward the right and turn the hand sideways when passing from 3-5 to 2-1 at the hand shift. She instructs students to use minimal arm weight and release the tones after each third. Last stated that great care is needed to ensure legato between both voices, except at hand shifts where one voice must be released to facilitate finger movement.[189] Like Cortot, Last believes that once the basic patterns of fingering have been mastered, chromatic thirds are much easier to execute than diatonic thirds. She also stated that moving outward (as in the ascent of the right hand) was easier than returning toward the middle of the keyboard, though she does not offer any reasons or support for this belief.

Last also discussed octaves. She recommended a preliminary exercise of rapping out octaves on a closed piano lid using the same action as if one were knocking on a door. While the hand is still growing, she recommends that students practice the door-knocking rebound action playing a sequence of double thirds with 2-4 and sixths with 1-5. The hand should be kept close to the keys, with the arm supporting the hand and the action of key-drop supplied by a flexible wrist. Last pointed out that as tone intensity increases, the forearm must take a more active part in tone production; however, the wrist is never stiff. Last noted that the larger the hand span, the less the curve of the DIP joint of the fifth finger and the greater the upward inclination of

[189] Last, 47.

the wrist in relation to the MCP joints. The hand acts as a single unit, falling from the wrist.[190]

Last strongly believes that octaves should not be incorporated into the player's technique until the hand span was *larger* than an octave so that the octave span can be maintained without strain. Students should learn to play well back on the key, away from the edge, so that incorporating black key octaves into a scale does not necessitate a large forward jerk by the arm.[191] Last recommended that the key attack take place from approximately six inches above the key. After the keys are depressed, the hand should rebound to its starting position, simultaneously closing the fingers into the palm of the hand. She claims that from this position, the player only has to "pounce on the next octave" and further states that this same technique can be used for playing consecutive chords.[192] However, it should be noted that Last is not quite accurate in her description of the rebound action which takes place in between octaves. In rebounding to their original position, the fingers *do not close* into the palm of the hand; there is not time. Instead, the fingers simply relax naturally while remaining extended. In order to achieve brilliant and fast octaves, power is supplied by the entire arm. The wrist, according to Last, gives an extra "punch" toward the keys.[193] She seems to have described a movement pattern in which the upper arm is supplying power and momentum, and the wrist also supplies additional force for key depression by quick flexion and extension.

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190 Ibid., 59.
191 Ibid., 60.
192 Ibid., 61.
193 Ibid., 61-62.

Last has acknowledged that hand size might cause difficulties in octave playing. She stated that for a player with small hands, executing octaves can be a challenge. The hand remains relatively flat when stretched and the wrist is lower than is normal. Thus, the player is forced to play octaves at the edge of the keys, requiring marked forward/backward adjustments when playing octave passages which contain black keys.[194]

Newman held a unique position concerning the execution of double notes. He believed that a single fingering should be used for all major and minor double note scales; he was of the opinion that this simplicity in fingering outweighs any small advantage to be gained from learning many different fingerings. He stated that the seven double-thirds within an octave may "invariably" be fingered with the same fingering outlined by Last:

3 4 5   2 3 4 5
1 2 3   1 1 2 3

The only problem is determining on which fingers the pattern begins in any given passage.[195] According to Newman, white-key diatonic double-third scales begin with the thumb on the tonic; black-key diatonic double-third scales begin so that the thumb will fall on a white key at the beginning of both fingering groups between the shifts.[196]

When performing chromatic scales on double minor intervals, the player should take advantage of the potential for sliding from black to white keys. This slide should only take place when the second finger plays, and

194 Ibid., 61.
195 Newman, 42.
196 Ibid., 43.

only from a black key which precedes two white keys. For example, when playing a chromatic scale in minor thirds in the right hand beginning on "C":

3 4 5	3 4 3 4 3 4 5	3, etc.
1 2 1	2 2 1 2 1 2 1	2

Newman stated that chromatic scales in thirds use the same fingering as diatonic-double-third scales; chromatic scales in major sixths may use a fingering similar to scales in double-thirds:

3 4 5	4 5	4 5	3 4 5, etc.
1 1 2	1 2	1 2	1 1 2

Sliding from black to white keys is not possible when playing chromatic scales in major sixths.[197]

Newman pointed out that, in general, staccato touch is very effective in executing octaves and other double notes. However, in cases where legato is required it is difficult to make two consecutive octaves or other double notes sound legato when one of the fingers has to be repeated. The solution, he claimed, was to release the key in the repeating finger before the other finger moves.[198]

According to Newman, successful octaves depend upon the structure of the hand and its ability to stretch. He stated that stretch was determined as much by the width of the webs of skin between the fingers as the length of the fingers themselves. Like Last, he observed that players with a small stretch often find that the effort to maintain the octave hand span inhibits or

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197 Ibid., 43.
198 Ibid., 60-61.

tightens wrist action, necessitating that the octave be played by the forearm working in one piece with the hand and fingers. However, these "forearm octaves" are not the desirable ideal; most pianists can more effectively use the hands with the forearm serving as a base for motion. Speed and power can both be attained if the entire arm is used to supply the initial impetus for a rhythmic group of three to four octaves. This can be accomplished by either dropping the wrist or by thrusting the wrist forward and upward for rhythmic emphasis. The wrist gradually returns to its natural neutral position during the playing of the less rhythmically important octaves of the group.[199] In order to gain a feel for the motion of the wrist, the student may want to practice exaggerating the motion of the hand through the complete range of motion at the wrist.[200] In order to execute octaves effectively, "key slap" must be eliminated. Maintaining a slightly arched hand and elevated wrist (stretch of the hand permitting) often helps reduce vertical distance from the fingertip to the surface of the key.[201] The hand works in conjunction with the fingers to connect the octaves. Newman states that the fingers and hand move laterally at the knuckles and wrist at least as much as they move vertically; that is, not much at all.[202] The fingers merely serve to transmit the impetus of the upper arm and wrist to the keys.

Newman concluded his comments regarding octaves with the observation that when octaves on black keys are played within a succession of white keys, 1-4 or 1-3 is frequently used for the black key octave to facilitate passage from the black key octave to a white key octave. This fingering

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199 Ibid., 62.
200 Ibid., 62-3.
201 Ibid., 63.
202 Ibid., 63.

reduces the forward/backward adjustments of the upper arm and allows for a more legato key connection between black and white key octaves. However, if the player must strain to reach the octave with 1-4 or 1-3 the result will be the opposite of that which is desired; the octaves will sound disconnected and clumsy.[203]

Sandor had relatively little to say about double notes. He did state that the wrist is lowered for notes played by the thumb and is raised for notes which follow. However, at a fast tempo this up-and-down (flexion/extension) motion at the wrist is transformed into a forward/backward motion by the upper arm. Thus, the original vertical motion of the wrist is converted to another motion which is more effective. Additional speed is imparted to the fingers, which must be slightly raised, by means of this extra impetus from the upper arm. Sandor insisted that flexion and extension of the wrist be used in slow to moderate double note passages, substitution of upper arm motion for wrist motion takes place at faster tempos and is completely unconscious.[204]

Ortmann's advice on playing double notes was as meager as Sandor's. In fact, the only type of double notes Ortmann addressed were octave scales. He stated that diatonic octave scales combined staccato touch in the repetition of fingering and lateral arm transfer in moving from key to key. While he was unsure, he thought that the arm was probably thrown through part of the distance in moving from key to key.[205] When producing heavy portamento octaves, Ortmann pointed out that the hand is lifted to its maximum height and poises for a moment before descending in an approximately vertical line

203 Ibid., 63.
204 Sandor, 153.
205 Ortmann, 259.

onto the appropriate keys. As intensity increases, Ortmann claimed that more and more of the arm is used to supply the force.[206] As he did with other skills, Ortmann photographed the movements involved in producing octaves on photosensitive paper. He concluded that excessive forward/backward motions should be avoided in executing chromatic octaves, though he fails to elucidate upon when motions are excessive instead of necessary. He observed that in comparison with a more coordinated execution, uncoordinated octave playing uses more backward/forward motion originating at the player's shoulder. From an overhead view of the keyboard, the uncoordinated movement pattern resulted in many convex arcs tracing the length of one key to the next. Coordinated players directed the motion of the hand forward near the middle of the next key; the return motion followed a straight line along the same key.

As she advocated in single-note scale playing, Taubman has recommended using double rotation to accomplish double-third scales. In fact, she has stated that double notes are *always* double rotations.[207] Use of double rotations will allow the weight of the arm to be equally behind all the fingers. The forearm and the hand impart the weight for key depression. In order to achieve legato between two consecutive thirds, one finger may be released while the other finger provides key connection. This is especially true at slower tempos; when the tempo is increased, Taubman has claimed that we do not lift the finger. When crossing from 3-5 to 1-3, the third finger should be released while the hand is slightly supinated. A quick pronation

206 Ibid., 260.
207 Taubman, tape 2, 2:32:03.

should be used to land on 1-3. Taubman has claimed that this action also prevents the fingers from feeling cramped and crowded.[208]

With regard to octaves, Taubman has generated many recommendations. She took issue with Ortmann's position that muscular actions used in a fast octave scale differ from those used at slower tempos, believing that the motions remain the same.[209] The upper arm can be used as a fulcrum for the activity of the forearm. The up and down motion necessary to move from one octave to depress another can be active or passive. That is, the forearm can fall due to its own muscular exertion or due to the outside influence of gravity. According to Taubman, using gravity yields more power and freedom in octave playing. In making this recommendation, Taubman has applied a basic law of Newtonian physics: every action has an equal and opposite reaction. Thus as the weight of the forearm and hand fall into the keys, the keys respond by "throwing" the hand back up. In using this motion, the arm will feel very light.[210] Taubman has pointed out that traditionally, teaching of octaves has focused primarily upon the hand, leading some to the conclusion that octaves should be produced by the wrist. This mistaken belief is due to the fact that the hand action is more visible than the forearm action; it is functioning like the tip of a whip. However, the underlying motion is a movement of the forearm and hand, with the forearm initiating the action. The hand and wrist simply have pliability in rebounding from one octave to the next.

208 Ibid., 2:29:23.
209 Ibid., 1:54:22.
210 Ibid., 2:00:00.

This rebounding effect is facilitated by slight plucking motions by the *fingertip alone.*[211] The fingers are not collapsed or limp, but are supported by the arch of the hand. There is a feeling of the finger descending with the key, yet the fingers do not grasp the octave as it is depressed. The PIP joint is merely momentarily stabilized in order to impart the weight of the forearm onto the key. The plucking motion of the fingertip is very slight; if visible, the exertion is likely too much.[212] This plucking action is the only active motion made by the fingers. The shape of the octave should not be set in the air, but should rather result from the playing of the keys.[213] Taubman has also recommended using rotation in octave scales. One side of the octave is released toward the other side. The hand, wrist, and forearm are rotating as a single unit. The hand is not opening and closing between octaves; this action interferes with speed.[214] In order to prevent fatigue, the player may add little impulses (slight forward motions) from the forearm on some of the octaves in the passage to help stimulate rebounding.[215]

As was recognized by Last, Taubman has noted that playing octaves with a small hand presents some special challenges. According to Taubman, if the hand is actively stretched to reach the octave, opposing sets of muscles take over, resulting in "dual muscular pulls." The muscles tire quickly, and the hand will actually get smaller in size. In most cases, this problem can be solved by allowing the keys to passively open the hand up to the octave; the pressure of the keys helps open the hand to its maximum. However, if the hand still feels stretched, Taubman has firmly advised against playing

211 Ibid., 1:57:40.
212 Ibid., 2:06:06.
213 Ibid., 2:12:00.
214 Ibid., 2:02:00.
215 Ibid., 2:04:30.

octaves, as she feels it may contribute to an injury.[216] Even for a player with normally sized hands, Taubman has stated that all octaves should be played with the thumb and fifth finger, even octaves on black keys. Trying to provide an actual physical connection between octaves often causes tightness. Furthermore, the weight gets stuck and is prevented from getting to the next octave. Legato octave scales are best achieved by use of the damper pedal or by providing a sweeping motion with the upper arm; octaves need not be physically connected to sound legato.[217]

Like Ortmann, Pichier has little to say regarding double thirds and sixths; he limited his advice to octave playing. He stated that the octave was "grasped" with the thumb and fifth finger and staccato was employed in order to repeatedly play the same octave. When playing a sequence of octaves, the wrist should make continual small movements, not while moving from octave to octave, but as the keys are depressed and released. Thus, the wrist is cyclically low, moderately high, high, moderately high, low, etc. The palm is spread and the thumb guides the sequence of touches. According to Pichier, such movements supposedly keep the wrist free from tension.[218] However, what Pichier seemingly described was the natural rebound motion of the wrist in octave playing. The player need not concentrate on producing these motions; they will result naturally from depression and release of the keys in combination with the directional impetus of the upper arm.

216 Ibid., 2:09:00.
217 Ibid., 2:15:10.
218 Pichier, 258-59.

Biomechanical Description of Double-Note Scales

Double-Third Scales

The following is a description of a diatonic scale performed in double-thirds at a fast tempo for a distance of two octaves. This description applies to the right hand; the left hand will conceivably use the same motions in mirror-image. The general fingering pattern alternates 1-3 and 2-4, and in some cases, 1-3, 2-4, 3-5. Because of the morphological constraint of finger length, the player should try to play the black keys with the longer fingers. Just as in a single note scale, the upper arm provides direction for the double-third scale. Likewise, the center of gravity falls slightly above the hips and gradually shifts from left to right and back as the scale ascends and descends. In describing the motion of the right hand playing alone, the center of gravity will be slightly shifted to the right side of the torso. If the left hand were playing simultaneously, the center of gravity would be more centered in the torso; in the course of the scale execution, the center of gravity would shift farther to the left than is the case with the right hand playing alone. The upper arm makes slight backward and forward adjustments to allow for the playing of black keys.

In the ascent, unlike the ascent of the single-note scale, the thumb is not passed under. Instead, the entire hand is lifted completely off the keys in order to facilitate the shift. The hand begins in a position of slight ulnar deviation; as the hand ascends, there is some movement toward radial deviation, but not as much as is the case in a single-note scale. This is due to the demand for all the fingers and the thumb to remain directly over the keyboard at all times. In the descent, whereas in the single-note scale the hand was thrown over to effect the hand shift, in the double-third scale, the entire hand is lifted from the keyboard, just as it is in the ascent.

Whereas in a single-note scale the palm opens and closes as the thumb and hand are passed, in the double-third scale, the palm is maintained throughout in a relatively open position. The hand functions as a single unit, receiving its power from the vertical impetus of the forearm; the wrist is maintained in a relatively straight line between the hand and the forearm, serving to transmit the impetus of the forearm to the fingers. The wrist rebounds very slightly as each third is depressed. In sharp contrast with the single note scale, there is very little lateral wrist motion employed. Shifts are accomplished by lifting the entire hand off the keyboard and guiding its placement into the new position with the upper arm.

At the moment they are used, the fingers are stabilized at the MCP, DIP and PIP joints. The fingers merely serve to transmit force for the depression of the key; the force is supplied by flexion and extension of the wrist in combination with the vertical motion contributed by the forearm. After the depression of the keys, the fingers rebound. They remain extended and ready to be activated, but the joints are loose. When playing at a fast tempo, the fingers will appear to "flutter" slightly. Making an actual key connection between thirds necessitates holding the depressed third, or at the very least one voice of the third, by one set of fingers while the next set of fingers is activated. The forearm can provide an additional small impulse to aid the fingers in transmitting force to the keys. Some radial deviation is required of the hand.

Octave Scales

Octave scales are usually executed by repeated use of the thumb and fifth finger, with occasional interspersing of the thumb and the fourth or third finger on black-note octaves. Using the fingers in such a way reduces the backward and forward adjustments of the upper arm in moving from white to black keys and also enhances key connection. However, as was noted by Taubman, using the thumb and the fifth finger consistently for all octaves often reduces tension and does not necessarily disrupt legato.

Though they may be lessened by this substitution of the fourth finger on black keys, backward/forward adjustments by the upper arm are still frequent. It is logical that these backward/forward adjustments are more noticeable in the octave scale than in the single note scale. In a single note scale, backward/forward adjustments, though necessary to allow for playing black keys, are moderated somewhat by radial deviation of the hand. As the wrist deviates toward the fifth finger, the thumb loses contact with the key surfaces rising upward. However, in an octave scale, the thumb must remain in continuous contact with the key surface and, moreover, must remain aligned enough to transmit the force of the hand and forearm in depressing the key. Also, due to the thumb's continuous active role, the hand remains in a position of ulnar deviation throughout the octave scale.

In general, a staccato touch is used to execute octave scales since the repeated use of the thumb and fifth finger rules out true key connection. If legato effects are desired, some key connection can be attained by alternating the fifth finger with the fourth or third finger as earlier described along with prudent use of the damper pedal. As was noted in the description of the double-third scale above, the center of gravity and the movement of the upper arm describes an arc in the frontal plane similar to that observed in a single-note scale. Since movements of the right hand playing alone were described, these arcs are more shifted toward the right.

The upper arm provides direction for the ascent and descent of the octave scale and also makes backward/forward adjustments as already described. The force for actual key depression is provided by the forearm, with the added weight of the wrist and hand. The wrist is raised in comparison with its normal playing position, and the arch of the hand is more flattened, though it is still present. Slight giving of the wrist may be noticeable at the moment when force is transmitted onto the keys, followed by the wrist rebounding upward. The MCP, PIP, and DIP joints of the thumb and fifth finger are stabilized at the moment of impact, transmitting the weight from the forearm into the key bed. The rebound of the key helps lift the hand out of the key bed to prepare for the next key stroke. Between each key depression, the hand remains open between the PIP joint of the fifth (or fourth) finger and the PIP joint of the thumb. Thus, the hand is always ready to play, aiding both speed and accuracy in moving from one octave to the next. Yet the hand is not rigid as there is a slight rebounding in the palm between octaves. The inner fingers do contact the key surface as each octave is played. Even so, since the PIP and DIP joints of these inner fingers are not stabilized at the moment of key impact, these fingers do not produce a tone. Moreover, the MCP joints of the inactive fingers suspend weight at the moment of impact in such a way as to prevent them from depressing keys.

As was pointed out by some of the piano pedagogues surveyed, hand size is an important factor in octave playing, especially in sequential octave playing. In a small hand, the arch (which is must be somewhat flattened due to the demands of the task anyway) may have a tendency to collapse completely. If the arch collapses, the player will likely have difficulty keeping the inner fingers from producing tones (the MCP joints may themselves contact and depress the keys) and in moving from one octave to the next, especially if black keys are involved.

Broken Chords and Octaves

Observations and Recommendations of Noted Pedagogues

Piano pedagogues widely agree that the execution of broken chords and octaves directly depends upon forearm rotation. This is readily confirmed upon observation of this skill.

Ortmann stated that it is easy to play broken chords by using forearm rotation so long as the accented note of the pattern falls on the downbeat. If the accent falls on any other note within the broken chord figure, he claimed we must rely upon finger strength.[219] This remark seems unfounded. If the accent falls on a beat other than the downbeat, it is possible to effect an accent through a short impulse initiated by the forearm and transmitted through the wrist to the fingers without disturbing forearm rotation. Ortmann also noted that the muscles which allow for supination are naturally stronger than those which cause pronation.[220] According to Ortmann, it is therefore easier to supinate than to pronate. He advocated caution as the fifth finger is approached within any broken chord figure. He claimed that if supination was continued past the point where the fifth finger contacts the key, then the basic movement changes from one of forearm rotation to upper arm rotation.

219 Ortmann, 195.
220 Ibid., 193.

This change in the center of rotation, Ortmann purported, was inevitable because the hand is lifted as the fifth finger rests upon the key and a lift of the forearm with the elbow bent is only possible through rotation of the upper arm at the shoulder joint.[221] In other words, the upper arm must be abducted away from the torso. He therefore recommended that when first learning forearm rotation, the student should play the broken chord figure only up to the point where the fifth finger depresses the key. The student should not follow through to the point where the fifth finger is more or less vertical in relation to the key.[222] Ortmann is correct in implying that the actual forearm rotation ends when the fifth finger is depressed. However, motion cannot stop at this point if the pattern is to proceed. While following through to the point where the fifth finger is vertical is probably excessive, there should be some slight lifting of the hand. If the student does not follow the initial forearm rotation through with the upper arm, he or she will be unable to pronate in order to begin the next pattern. Thus he or she will only learn to supinate, which is but one-half of the forearm rotational cycle.

Like Ortmann, Newman advised using rotation to play broken chords. However, while he recommended using forearm rotation to play a tremolo, he did not equate tremolo playing with the execution of broken chords. He offered the confounding suggestion that broken chords be played by using rotation at the shoulder and wrist; rotation at the shoulder allows for the arm to change its direction at both the bottom and top of the broken chord pattern, while wrist rotation extends hand position in both ascent and descent. With this statement, he is specifically referring to rotation of the humerus and

221 Ibid., 194.
222 Ibid., 194.

wrist in the frontal plane. Newman reasoned that these rotary motions compensate for the shortness of the thumb and fifth finger and also ease the burden of tiresome circular passages.[223] The obvious question when confronted with this statement is how it can be possible to rotate the shoulder and wrist without rotating the forearm, since it is connected between the wrist and shoulder. Newman presumably meant that the shoulder and wrist should be free to rotate *in addition to* the forearm. If the wrist is allowed to make its own rotational movements, it will assist in alternately reaching black and white keys. Rotational movements at the shoulder will allow the entire arm to make in and out adjustments to the same end. Understood any other way, Newman's statement concerning wrist and shoulder rotation is clearly contradicted by anatomic design. Newman concluded his remarks regarding broken chords and rotation by stating that rotation can never replace all finger action. Moreover, he pointed out that a slumped posture impedes rotation at the shoulder.[224]

Joan Last concluded that we impose tension on the forearm in the simple act of placing the hands on the keyboard, since this action requires pronation. She claimed this tension was due to the natural inclination toward supination, which is easier than pronation. She accordingly believes that the natural way to relieve this tension is through supination. She viewed the execution of broken chords as a natural application of this tendency. She cautioned that in playing some accompaniment patterns and broken chords, Alberti bass serving as a typical example, we need to be careful in supinating so that we do not unduly accent the repeated note at the

[223] Newman, 65.
[224] Ibid., 65.

bottom. Last is convinced that the most taxing application of forearm rotation is broken octaves, which require complete rotary freedom. Like Newman, she cautions against allowing forearm rotation to take the place of finger firmness.[225]

In playing broken chords, Seymour Fink recommended using a "pushing" arm staccato to produce sharp, accurate, moderately paced sounds. He advised combining this pushing stroke with an upward wrist stroke to help control and lengthen the fingers in their contact with the keys. He claimed that these forward strokes should rarely involve supination. Instead, the forearm should move directly forward or pronate. According to Fink, cycling in a pushing direction with the arms moving outward from the body to depress the key minimizes key bedding and encourages quick key release. In direct contrast, using "pulling" arm cycles generates slower and more complicated key releases which can lead to shoulder tightening and tension in the neck and upper torso.[226] In discussing an example of broken chords played by the right hand, Fink advised that the right hand make gentle pronating circles to control the sound and pace the tempo. He generalized that large outside-to-center shifts on the keyboard require supinating circles, while large center-to-outside shifts require pronating circles of the upper arm and forearm.[227] This advice seems to be directly opposite of the actual motions encountered: in initiating outside-to-center shifts, it makes more sense to pronate while using supination to play center-to-outside shifts. Fink asserted that a repeated broken note pattern, a type frequently encountered as an accompaniment figure, should be executed by cycling the upper arms over

225 Last, 50-54.
226 Fink, 86.
227 Ibid., 91-92.

"unfolding" fingers.[228] Fink pointed out that the wider the pattern, the more pronounced is the movement. Instead of pronounced forearm rotation, in this case the motion Fink has recommended is abduction and adduction of the upper arm, which will result in the wrist describing a flattened circle or a zig-zag on the frontal plane. The fingers must remain firm; they must not collapse.

Cortot offered several pages of exercises of broken chords and octaves. In making general observations about broken chords, Cortot defined the playing of broken chords as a "movement of impulsion." According to Cortot, movements of impulsion, which include broken chords, arpeggiated chords, and tremolos, require more active participation of the hand than of the fingers. They also require rebounding from the key and in and out displacements of the arm.[229] Cortot further noted that a "rocking" motion, i.e., alternating radial and ulnar deviation, can facilitate playing broken chords, especially when these patterns move up or down the keyboard. If broken chords alternate one or more simultaneously activated notes with single notes, Cortot believed that the fingers must make a perpendicular attack on the simultaneous notes. Cortot defined measured tremolos and Alberti bass accompaniment figures as "batteries," which involve alternating a pedal note with a moving note. Cortot claimed that these patterns also required a "rocking" motion from the wrist, which was also noticeable on the back of the hand.[230]

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228 Ibid., 157.
229 Cortot, 73.
230 Ibid., 85-86.

Biomechanical Description of Broken Chords and Octaves

The following description is the ideal for the right hand. As is the case in previous descriptions, these generalizations apply equally to the left hand in mirror image.

Broken Chords

This description applies to a broken major triad ascending and descending by inversions in the right hand. Supinating and pronating motions are less marked than in broken octaves. The more prominent motion is radial deviation in moving toward the fifth finger and ulnar deviation in moving toward the thumb. This results in a visible circle being described by the wrist in the frontal plane. This lateral motion is directly related to the size of the hand; smaller hands necessitate the use of more lateral wrist motion. Although slight, supination and pronation are still used. In the ascent, radial deviation is accompanied by a slight lifting of the wrist as the fifth finger is approached. This lifting allows the thumb to be dropped on the first note of the next inversion and prevents the fingers from feeling crowded together while the thumb and fifth finger are a short distance apart. In the descent, an opposite motion is used: the wrist is raised as the thumb is approached and the hand is deviated toward the ulnar side, allowing the fifth finger to drop on the first note of the next inversion. This dropping of the thumb or the fifth finger is not accompanied by high lifting of the fingers above the keys. However, as was the case in broken octaves, the dropping motion lifts the finger which played the previous note off of the key. As noted by the surveyed experts, neither the lateral motions of the wrist, nor forearm rotation replaces the need for a firm finger. At the moment of key impact, the joints of the playing finger must be stabilized in order to transmit the motion of the wrist and forearm.

Broken Octaves

Broken octaves are not synonymous with octave scales. Whereas octave scales depend upon staccato touch combined with key rebounding, broken octaves are effected through forearm rotation. The forearm is rotated with the wrist directly aligned; rotation occurs in one unit from the elbow to the fingers. It is easier to attain momentum in playing a scale in broken octaves than when sounding both voices of the octave simultaneously. This is because the forearm is capable of rotating very quickly. Moreover, the movement toward one voice of the octave directly causes the release of the other voice. As the hand is supinated and the fifth finger plays, the thumb is released; as the hand is pronated, the fifth finger is released.

In executing broken octaves in scale form, there is notable ulnar deviation of the hand in both the ascent and the descent. This is because the thumb must be kept continuously over the keys. Unless it is necessary to play black keys, both the thumb and the fifth finger play on the forward end of the key, where the key offers the least resistance. If black keys are played, the arm makes a forward (in) adjustment to allow for placement of the fingers over the black keys. The arm moves back out to play white keys. These in and out adjustments are made gradually; there should be no sudden lurching toward the black keys.

Even when playing black keys, there is little to no vertical adjustment by the wrist. Simple forearm rotation and backward and forward adjustments for the black keys are all that is necessary. The forearm and the upper arm provide direction for the broken octaves as they move up and down the keyboard. The fingers are not tensed; in fact, the joint stabilization force required is minimal due to the positioning of the thumb and fifth finger at the ends of the hand in combination with forearm rotation.

CHAPTER IV

PREVENTION OF KEYBOARD INJURIES BASED ON MEDICAL, BIOMECHANICAL, AND ERGONOMIC OBSERVATIONS

Overuse Injuries in Pianists

Overuse injury has become a familiar term within the musical world during the past ten years. Among musicians with music-related health problems, more than half are keyboardists.[1] A study conducted by Dr. Ralph Manchester determined that string and keyboard players have a significantly higher rate of injury as compared to wind instrument players.[2] Drs. Sataloff, Brandfonbrener, and Lederman corroborated these results, stating that the inordinately high risk of injury from playing keyboard instruments results from several factors including playing posture, pressure of the piano where it contacts the body, repetitious muscular movements, and the physical demands of the piano, especially the weighted key action.[3] Numerous studies have demonstrated that overuse injuries are more prevalent among females, especially adolescent females, than they are in males.[4] However, it is speculated that in reality, many overuse injuries in men may go unreported;

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[1] Nancy S. Grant, "Arts Medicine: When Practice Turns To Pain," *Keyboard* (Feb. 1988): 90.

[2] Ralph A. Manchester, "Medical Aspects of Music Development," *Psychomusicology* 7 no. 2 (1988): 149.

[3] Robert Thayer Sataloff, M.D., Alice G. Brandfonbrener, M.D., and Richard J. Lederman, M.D., *Textbook of Performing Arts Medicine* (New York: Raven Press, 1991), 36.

[4] Alan H. Lockwood, "Medical Problems of Musicians," *The New England Journal of Medicine* 320 (26 January 1989): 222; Hunter J.H. Fry, "Prevalence of Overuse (Injury) Syndrome in Australian Music Schools," *British Journal of Industrial Medicine* 44 (1987): 37..

males may suffer as many injuries as females.[5] The incidence of injury in music students at the college or conservatory level may be as high as 10-20%, according to one study. [6]

Overuse Injury Terminology Conflicts

Debate over the terminology used to describe overuse injuries has been ongoing for at least a century. Dr. George Vivian Poore was the first to document this type of injury in the late 1800's. Dr. Poore primarily focused upon occupational injuries found in industrial settings, such as factories; however, in his writings he did give mention to injuries suffered by writers and musicians, referring to them as "occupational cramp" or "musician's cramp." Around the same time, the term "occupational neurosis" was applied to injuries which afflicted musicians and writers.[7] These terms are now obsolete, having not been used after the turn of the twentieth century.

"Tenosynovitis" and "tendinitis" have been the terms used most frequently in published literature from the beginning of the century to the present.[8] However, both of these terms have been criticized in the past ten to fifteen years because they refer specifically to inflammation of tendon sheaths and tendons respectively.[9] Another phrase coined to describe these types of injuries is "repetitive strain disorder." Although this term has been widely applied to injuries of all types suffered by pianists, it is not entirely accurate.

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5 Hunter J.H. Fry and others, "Music-Related Overuse in Secondary Schools," *Medical Problems of Performing Artists* 3 (December 1988): 134.

6 Hunter J.H. Fry and others, "Music-Related Overuse in Secondary Schools," 133.

7 Hunter J.H. Fry, "Overuse Syndrome in Musicians: Prevention and Management," *The Lancet* 2 (27 Sept. 1986): 728.

8 Ibid.

9 Hunter J.H. Fry, "What's in a Name: The Musician's Anthology of Misuse, " *Medical Problems of Performing Artists* 1 (March 1986): 37.

Motions made at the piano are not merely repetitive.[10] While the pianist may use some repetitive motions in controlling the fingers, he/she is also using sustained motion to maintain the position of the upper back and arms.

Piano teachers often prefer to label these injuries as cases of "misuse." However, this term is not widely used by medical practitioners or biomechanists. Teachers base the use of this term on the widespread belief that injuries are caused by problems arising directly out of piano technique, not from actual overuse. The term "overuse" is widely used among doctors, ergonomists, biomechanists, and pedagogues to apply to injuries sustained in performing any number of activities, from participating in a sport, to cutting meat in a processing plant. Moreover, "overuse" best describes the etiology of these types of injuries. Use of the term "overuse" does not preclude the notion that improper technique can lead directly to injury. In fact, since overuse results from use of body tissues within their normal ranges of use, as will be discussed below, these injuries are seemingly the result of a multiplicity of factors, including the way in which forces are applied. Empirical evidence supports the assumption that overuse injury is the eventual result of prolonged overuse, which frequently begins early in the player's career.[11]

Acute Versus Overuse Injuries

Injuries may generally be considered as belonging to one of two categories: acute injuries or overuse injuries. Acute injuries take place when the biological limits of body tissues are suddenly exceeded and the muscle or

10 Hunter J.H. Fry, "How To Treat Overuse Injury: Medicine For Your Practice," *Music Educators Journal* 72 (May 1986): 48.

11 Hunter J.H. Fry and others, "Music-Related Overuse in Secondary Schools," 133.

tendon fiber fails, actually tearing in some cases. These types of injuries are frequently encountered in sports. Although it is possible that an acute injury might result from piano playing, injuries suffered by pianists are typically overuse injuries.

The etiology and pathology of overuse injuries is not fully understood. Both statistical data and observations of performing arts medicine specialists point to a sudden increase in the time and/or intensity of practice as the most common cause of overuse injury.[12] A change in playing technique has also been suggested as a factor which may lead to injury.[13] Intrinsic factors, such as size, strength, muscle tone, flexibility, and genetic predisposition toward muscular injury are also contributing factors.[14,15]

Hypothesized results of overuse include microscopic tearing, swelling and hemorrhage, invasion by inflammatory lymphocytes at the site of overuse, and possibly the formation of scar tissue.[16] Microscopic studies of affected muscle fibers indicate degeneration and microhemorrhage. Various cellular abnormalities, including mitochondrial differences and increased nuclei counts, have also been noted.[17]

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[12] Fry, "How To Treat Overuse Injury," 48; Fry, "Overuse Syndromes in Instrumental Musicians," 139; Lockwood, 222..

[13] Alice G. Brandfonbrener, M.D., "The Medical Problems of Musicians," *American Music Teacher* 37, no. 55 (April/May 1988): 24.

[14] Fry, "How To Treat Overuse Injury," 47.

[15] Fry, "Overuse Syndromes in Instrumental Musicians," 139.

[16] Richard J. Lederman, M.D., and Leonard H. Calabrese, M.D., D.O., " Overuse Syndromes in Instrumentalists," *Medical Problems of Performing Artists* 1 (March 1986): 7.

[17] Xenia Dennett and Hunter J.H. Fry, "Overuse Syndrome: A Muscle Biopsy Study," *The Lancet* 2 (April 23, 1988): 907.

Force Characteristics

Mechanical characteristics have been studied in vitro (cadaver studies) and in vivo (animal studies). The response of biological tissues to mechanical forces can be distinguished from the response of nonliving tissues in the ability of living tissue to adapt to applied forces and repair themselves. When body tissues are loaded, either tissue adaptation is successful and the tissue becomes stronger, or the adaptation is too slow in relation to the rate of tissue damage. Overuse injuries result when repetitive trauma caused by excessive loading occurs faster than repair of the body tissues can proceed.[18] It is therefore apparent that the development of overuse injury is dependent upon how affected body tissues react to applied forces.

In vivo, force magnitudes of isolated tissue in excess of biological limitations have been reported to exceed biological limitations without resultant injury; this is believed to be due to the ability of surrounding tissues to mitigate the excess force. However, injury frequently occurs in response to force magnitude well within biological tolerance. This observation suggests that tissue injury is not solely dependent upon the amount of stress (force) applied, but also other factors including tissue temperature, amount of tissue deformation (strain rate), frequency of load application, how many times the load is applied (number of load cycles), and the rate of load application (loading rate).[19] Bone, cartilage, tendon, and ligament tissues respond negatively to repetitive loading, exhibiting greater deformation with each cycle. Tendons and ligaments also demonstrate greater elastic stiffness as

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[18] Charles Roger James, "Effects of Overuse Injury Proneness and Task Difficulty on Joint Kinetic Variability During Landing" (Ph.D. diss., University of Oregon, 1996), 22.

[19] Ibid., 24.

cyclic loading progresses.[20] The manner in which the force is applied, whether smoothly, intermittently (jerkiness), gradually increasing (acceleration), or at a steady rate is also relevant.

Muscle Characteristics

A single muscle cell is threadlike in shape, and is hence called a "muscle fiber." There is much variation in length and diameter of muscle fibers from one adult individual to another. Though humans are born with their full complement of muscle fibers, the number of muscle fibers present is genetically determined and varies widely among individuals. The diameter of the muscle cell increases by five times between birth and adulthood; muscle fiber diameter can also be increased through physical training.[21]

Most muscle cell fibers in humans are "twitch type," that is, they respond to nerve stimulus by developing tension in a twitch-like or spasmodic fashion. Tension in a twitch fiber after stimulus rises to peak value in less than 100 milliseconds, and then immediately falls off. However, in the human body, fibers are usually activated by a rapid-fire succession of nerve impulses rather than a single impulse. In this case, tension in the fiber is progressively raised until its maximum tension level is reached. When maximum tension level is maintained for a time, the muscle fiber is in "tetanus." As tetanus is prolonged, the muscle fiber gradually becomes fatigued, causing a decline in the level of tension produced. The only type of muscle fibers in the human body which are not of the twitch type are found in the muscles which control the eye and its movements; these muscle cells

[20] Ibid., 31.

[21] Susan J. Hall, *Basic Biomechanics* (St. Louis: Mosby Year Book, 1991), 92.

require more than a single stimulus before tension can be developed. Individual muscle fibers are organized into larger motor units, which consist of a single motor neuron and all the fibers it controls.[22] Movements that are precisely controlled, such as movements of the fingers, are usually produced by motor units with a relatively small number of muscle fibers. Larger, more forceful movements are generally controlled by larger motor units.[23] For a detailed explanation of muscle fiber architecture and mechanical factors refer to Appendix C.

Actions of Muscles

In vivo, muscles assume one of four roles: agonist, antagonist, stabilizer, or neutralizer. When a muscle initiates movement at a joint by developing tension concentrically, it is acting as an agonist. Frequently, more than one muscle contributes to a movement. Therefore, a distinction can often be made between primary and secondary agonists. A muscle can also oppose a movement at a joint by developing eccentric tension, and so act as an antagonist. Antagonists most often provide controlling or braking actions, especially serving to slow down fast, forceful motions. Another role assumed by muscles is that of stabilizer, which involves stabilizing a portion of the body against a force. This force may consist of tension from other muscles or be applied externally. The final muscular role is that of neutralizer, which prevents unwanted secondary reactions which usually accompany development of concentric tension by agonists. For instance, if a muscle (acting as agonist) is capable of executing both flexion and abduction at a joint

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22 Ibid., 93.

23 Ibid., 95.

and only flexion is desired, then a neutralizer must enact adduction to counteract the abduction that would normally be produced by the agonist.[24]

Muscular Strength

When scientists study muscles in vitro, they can directly measure the force generated by the muscle. It is largely from animal studies that an understanding of force-velocity and force-length relationships has been derived.[25] However, it is not possible to study muscle tissue in vivo in this manner. Instead, the common practice for measuring muscle strength in humans is measurement of torque generated by an entire muscle group at a joint. Thus muscle strength is typically viewed in terms of the collective strength of a muscle group. Torque is equal to force times the perpendicular distance at which the force acts from an axis of rotation. Torque generated by a single muscle is a product of the part of the muscular force perpendicular to the bone and the distance from the muscle's attachment to the center of joint rotation. When a muscle pulls at a 90° angle to the bone (as far from joint center as possible), 100% of the force acts to rotate the bone.[26] Less force pulls perpendicularly on the bone as the angle of pull becomes larger or smaller than 90°. Muscular strength is the result of the maximum amount of tension which can be generated by the muscle tissue and from the amount of joint torque produced by contributing muscles in relation to the center of the joint. Tension-generating capability of muscle tissue is related to its cross-sectional

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24 Ibid., 113-14.
25 Ibid., 104.
26 Ibid., 105.

area. It is also possible that strength training of a muscle with heavy loads may result in improved innervation of the trained muscle.[27]

Muscular Power

Muscular power is the product of muscular force and the velocity of muscular shortening. Maximum power is achieved at approximately one-third of maximum velocity and one-third of maximum concentric force. Since neither muscular force nor speed can be directly measured in vivo, muscular power is functionally defined as the rate of torque production at a joint. Thus muscular power is affected both by muscular strength and speed of movement. A high concentration of FT fibers is beneficial for developing maximum power at fast velocities, since these fibers develop tension faster than ST fibers. A person with a higher concentration of FT fibers can generate more power at a given force load than a person with a relatively high concentration of ST fibers and can also shorten their muscles more quickly, developing their maximum power faster.[28]

Muscular Endurance

Endurance describes a muscle's ability to exert tension over a period of time. Muscular endurance is a relatively non-specific concept, because force and speed of the activity being performed directly affect the length of time the activity may be performed.[29] There are three basic histochemical sources of muscle energy. Adenosine Triphosphate (ATP) provides enough muscle fuel for 2 seconds of activity. After the initially available ATP is consumed, the

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[27] Ibid., 106-7.
[28] Ibid., 109.
[29] Ibid., 110.

body converts creatine phosphate into more ATP, providing enough fuel for 15 more seconds of activity. After this ATP is burned, the muscle consumes glycogen; there is enough for only 2 more minutes of activity. After the glycogen is consumed, the muscles will begin to produce lactic acid, which is a by product of muscle metabolism and is sometimes associated with local muscular changes that may contribute to fatigue. These sources of fuel are used in an anaerobic metabolic process when there is a need for immediate muscular activity. If muscles are primed for activity, they will burn glycogen in an aerobic metabolic process which will provide enough fuel for an indefinite period of time so long as circulation is maintained adequately.[30] Muscle fatigue can occur when the body depletes its stores of energy in anaerobic burning and produces lactic acid. However, this is not the only cause of muscle fatigue. It has been demonstrated that fatigue at high force levels occurs with less energy being expended than fatigue at low but sustained contraction levels. In general, however, muscle fatigue is influenced both by energy depletion and lactate accumulation.[31]

Muscle temperature has a large bearing upon muscular endurance. Muscle function is most efficient at 38.5° Celsius (101.3° F). As body temperature rises, speed of nerve and muscle function increases. This causes the force-velocity curve to shift, raising the muscle's maximum capacity for isometric tension and velocity of muscular contraction. As discussed above, raising body temperature also allows for aerobic metabolic processes to proceed which maximizes oxygen supply to the muscles and the removal of

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30 Don G. Chaffin and Gunnar B.J. Anderson, *Occupational Biomechanics*, 2nd ed. (New York: John Wiley and Sons, 1991), 47.

31 Ibid., 49.

waste products, resulting in increased muscular strength, power, and endurance.[32]

Tendon Characteristics

A tendon is an extra-muscular fibrous connective tissue which connects a muscle to one or more elements of the musculoskeletal system.[33] The function of tendons is to attach muscle to bone and transmit tensile loads from muscle to bone thereby producing joint motion. Tendons also allow the thickest part of the muscle, the muscle belly, to be positioned at an optimal distance from the joint on which it acts without requiring an extended length of muscle between the point of origin and the point of attachment.[34] For an explanation of tendon fiber architecture refer to Appendix C.

Tendons demonstrate strength-related characteristics in response to tensile loading, a process which is analogous to stretching a rubber band.[35] Tendons are strong enough to withstand enormous tensile forces, yet must also be flexible in order to angulate around bone surfaces, in some cases changing the direction of muscle pull.[36]

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32 Hall, 110.

33 J. Steven Moore, "Function, Structure, and Responses of Components of the Muscle-Tendon Unit," in *Occupational Medicine Ergonomics: Low-Back Pain, Carpal Tunnel Syndrome, and Upper Extremity Disorder in the Workplace* 7, ed. J. Steven Moore and Arien Gary (Philadelphia: Hanley & Belfus, 1992), 713.

34 Carl A. Carlstedt and Margareta Nordin, "Biomechanics of Tendons and Ligaments," in *Basic Biomechanics of the Musculoskeletal System*, ed. by M. Nordin and V.H. Frankel, (Philadelphia: Lea & Febiger, 1989), 59.

35 Moore, 716.

36 Carlstedt and Nordin, 63.

Elastic Properties of Tendons

If tensile force is considered to be distributed equally through the tendon, the force may be expressed in terms of force per unit area, a concept termed "stress." The stretching, or elongation, of the tendon is usually expressed as a percentage of the resting value and is termed "strain." The graph used to compare applied tensile force to elongation is called the "stress-strain curve" (Figure 4.1).[37]

Tendons have a stress-strain curve with characteristic regions. The first region is termed the "toe region." When tensile forces are initially applied, the normally crimped fibrils of the tendon merely straighten out, with minimal resulting increase in stress. This first portion of the curve is concave and corresponds to approximately 0-1.5% strain. Even repeated loading within this region does not usually cause permanent deformation of tissue or residual strain.[38] As loading is increased to 3.0%, the fibrils are fully straightened and begin to take more of the tensile load; stiffness of the tissue increases and more force is required to produce elongation. The second region of the curve is known as the "linear region" and corresponds to approximately 3.0-5.0% strain.[39] The relationship between stress and strain is linear; the more stress applied, the more resultant strain. Once the linear region is exceeded, major failure (rupture) of individual fiber bundles occurs randomly in the "plastic region" of the curve.[40] Failure at both macroscopic and microscopic levels essentially reduces the cross-sectional number of bundles available to handle the tensile load, effectively weakening the

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37 Moore, 716.
38 Ibid., 716-17.
39 Ibid, 717.
40 Carlstedt and Nordin, 64.

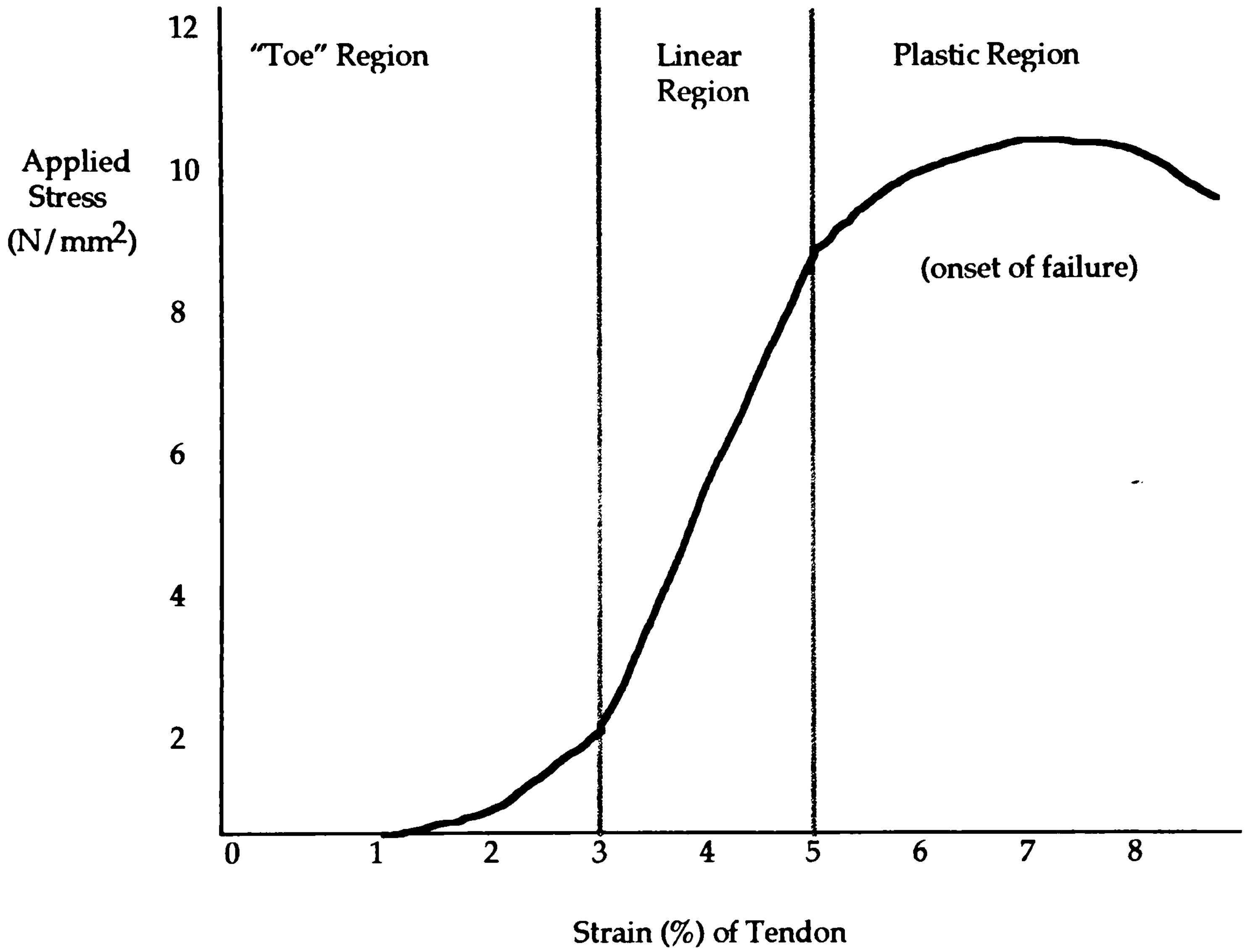

Figure 4.1. Stress-Strain Curve for Tendons

tendon. Estimates of the strain at the point of rupture range widely from 9-30%, having been drawn from in vitro studies. However, the ultimate tensile strength of tendon tissue is of limited interest because under normal conditions of physiologic functioning, tendon strain remains below 3%, well within the elastic limits of the tissue. It has, however, been conclusively demonstrated that permanent deformation of tendon tissue occurs at about 3% strain; this number represents the elastic limit of tendon tissue. Repetitive stress loading, even without exceeding the linear region of the stress-strain curve, has been correlated to tissue deformation. Although repetitive loading usually does not result in immediate rupture, permanently deformed tendons rupture at lower levels of stress, i.e. they are weaker under subsequent stress.[41]

Viscoelastic Properties of Tendons

The mechanical properties of tendons change with different rates of loading. In general, tendons can withstand larger loads when they are applied rapidly. When a tensile load is applied to a certain level and the degree of tendon strain is held constant, the magnitude of the internal force within the tendon decreases somewhat to an equilibrium level. This phenomenon is known as "stress relaxation." Tendon "creep" is another concept related to viscoelasticity. Creep is observed in the tendon tissue when internal stress magnitude is held constant resulting in increased strain on the tendon. This elongation results in an equilibrium level of strain. In repetitive loading, the tendon usually exhibits creep or stress relaxation while the load is applied, and will then recover while the load is reduced or removed. This recovery

41 Moore, 718.

does not take place instantaneously, nor does it follow the original stress-strain curve. If the time interval between loading cycles is shorter than required recovery time, an accumulated creep occurs, even if the loads being applied are below the elastic limit. Some of the long forearm tendons controlling the fingers have exhibited as much as 40% strain under repetitive loading cycles with long loading times and short recovery periods. [42]

Summary of Forces Relevant to Tendon Loading

In addition to the most commonly encountered tensile loading, there are additional types of forces which may be applied to tendons. Tendons may also be exposed to compressive forces. Tendon compressive forces typically act along the longitudinal axis of the tendon but may also act perpendicular to the longitudinal axis, arising when loaded tendons turn corners around deviated joints. Shear force is related to this second type of compressive force, acting across the long axis of the tendon, especially when the tendon deviates around joints. Since some of the tensile force applied to the tendon is lost as shear force in this case, the tensile force in the tendon on the other side of the joint is lower.[43]

In considering tensile loading, the critical factors for describing either single or repetitive ergonomic stresses are:

1. magnitude of the applied tensile force
2. duration of applied force
3. strain rate
4. number of cycles of repetitive loading
5. duration of recovery time between loading cycles.[44]

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[42]Ibid.

[43]Ibid., 719-20.

[44]Ibid., 722.

Considerations for describing ergonomic stresses with regard to compressive and shear forces are:

1. magnitude of applied tensile force
2. radius of curvature of surface around which tendon bends
3. length of arc of contact between the tendon and the supporting surface
4. coefficient of friction between the tendon and adjacent structures.[45]

Preventing Keyboard Injuries

Keyboardists typically suffer from injuries of the upper limb. It should also be noted that in addition to the primary site of injury, other body tissues may be "simultaneously or sequentially" affected.[46] Regardless of the original site of injury, there are general principles of medical treatment which apply, the predominant one being rest of the affected area.[47] It is imperative that the injured musician seek medical help from practitioners with knowledge of and experience in treating musicians.[48]

Common Sites and Types of Injury

Overuse of the upper limb typically involves a problem (or combination of problems) occurring between the neck and the fingertips. Though the exact etiology of overuse is not fully understood, occurrence of

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[45] Ibid., 723.

[46] Richard J. Lederman, M.D. and Leonard Calabrese, D.O, "Overuse Syndromes in Instrumentalists," *Medical Problems of Performing Artists* 1(March 1986), 7.

[47] Alice G. Brandfonbrener, "The Medical Problems of Musicians," *American Music Teacher* 37 (April/May 1988): 13; Alan H. Lockwood, "Medical problems of Musicians," *The New England Journal of Medicine* 320 (26 January 1989): 223.

[48] For a comprehensive listing of Performing Arts Medical Centers in the United States and elsewhere as well as information concerning treatment of common injuries, see Brenda G. Wristen, "Overuse Injuries and Syndromes in Keyboard Players: The Roles of Performing Arts Medicine Specialists and Piano Teachers" (M.M. thesis, Texas Tech University, 1995), 114-21.

these injuries may be theoretically linked to undue strain of body tissues. It is possible for acute injuries to occur if the normal range of functioning of a given body tissue is suddenly exceeded. However, keyboard injuries more typically progress slowly, often over a period of months or even years, resulting from an extended period of stress. As discussed above in relation to the stress-strain curve, body tissues may be subjected to stress well within normal areas of function and still develop a high level of strain. This observation is especially true when stress is repetitive, or cyclic, in nature.

A frequently encountered type of overuse involves strain of the statically loaded muscles of the forearm, arm, shoulders, or neck.[49] For instance, the trapezius and deltoid muscles are frequently sites of overuse. Muscle-tendon units of the hand, wrist, and forearm are also commonly affected. Problems with the extensor tendons and muscles of the wrist and fingers, as well as difficulties controlling the fourth and fifth fingers, may be attributed to overuse.[50] Cleft spaces between the fingers, the carpometacarpal ligaments, and the basal joint of the thumb are other frequent sites of overuse.[51] Bursitis can result when the bursas, which are fluid-filled sacs located where muscles and tendons connect to bones, become inflamed due to repeated motion or static body position.[52] Joints are also subject to damage. Radiographic studies of the joints of the hand have revealed degenerative changes, especially in the right hand, and especially affecting the fourth and fifth fingers.[53] When a joint is injured, pain is transferred to the attached

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49 Robert E. Markison, M.D., "Hands On Fire," *Keyboard* (April 1994): 97.

50 Lockwood, 223.

51 Hunter J.H. Fry, "Overuse Syndrome of the Upper Limb in Musicians," *Medical Journal of Australia* 144 (17 February 1986): 183.

52 Lederman and Calabrese, 8.

53 Ibid.

ligaments, especially when these ligaments are stretched.[54] If the ligaments become overstretched or damaged, laxity (excessive flexibility) of the adjacent joint can result, making the player more prone to joint dislocation. Joint laxity at the shoulder and finger joints is especially likely to result in dislocation. Pianists who have laxity of the distal interphalangeal (DIP) joint may have trouble controlling the finger when striking the key.[55] Though pianists may suffer from one or several of a multiplicity of ailments, the most frequently encountered injuries are summarized below.

Tendinitis and Tendon Entrapments

Tendinitis refers to inflammation of a specific tendon anywhere in the body; pianists frequently suffer from tendinitis of the upper limb. Use of the term "tendinitis" has been widely criticized as vague and non-specific, but it is still the prevailing term used in the literature in description of this general type of injury. Tendinitis is characterized by pain and tenderness, often described as burning or stabbing in nature, over the affected area. There is increased pain upon stretching the involved muscle-tendon unit or contracting it against resistance.[56] Tendinitis of the extensor tendons of the forearm which cross the wrist is a frequently suffered malady.[57] Lateral epicondylitis (commonly called "tennis elbow") which affects the tendons of the elbow is also common. Tendon sheaths can also be affected, a disorder

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54 Hunter J.H. Fry, "Overuse Syndrome and Its Differential Diagnosis," *Journal of Occupational Medicine* 30 (30 December 1988): 966.

55 Robert Thayer Sataloff, M.D., Alice G. Brandfonbrener, M.D., and Richard J. Lederman, M.D., *Textbook of Performing Arts Medicine* (New York: Raven Press, 1991), 91.

56 Lederman and Calabrese, 8.

57 Markison, 108.

termed "tenosynovitis." If the tenosynovitis is associated with a narrowing of a fibroosseous canal, it is called "stenosing tenosynovitis"[58]

Tendon entrapment syndromes are common at both the wrist and elbow. DeQuervain's stenosing tenosynovitis is a tendon entrapment syndrome occurring at the wrist. The long extensor tendons which originate in the forearm cross the dorsal wrist via six different fibroosseous "tunnels" before inserting into the phalanges. The first extensor tunnel is located on the radial side of the wrist and contains at least two (in some cases, as many as eight) tendons which control flexion and extension of the thumb (Figure 4.2). In DeQuervain's syndrome, any of the tendons running through the first extensor tunnel and their associated synovial wrappers swell, pressing and catching against the bony sides of the extensor tunnel.[59] Pianists afflicted with this disorder will often notice pain when "crossing" the thumb under the other fingers, as in a scale.[60] Pain is also elicited when the fingers are spread as far apart as possible, or when the thumb is flexed into the palm while the wrist is in a position of ulnar deviation (Finkelstein's sign).[61]

"Trigger finger" is another tendon entrapment syndrome which is prevalent. The flexor tendons of the fingers pass through a series of fibrous sheaths which function as pulleys in order to extend and contract the fingers.[62] At the point where the tendons enter the pulleys at the base of each finger and the thumb, nodules may develop on the tendon. This nodule gets "hung up" against the pulley causing the tendon to initially resisting gliding into the sheath (Figure 4.3). Once the resistance of the nodule is overcome,

[58] Moore, 732.
[59] Markison, 108.
[60] Sataloff, Brandfonbrener, Lederman, 84.
[61] Ibid., 83.
[62] Ibid., 215.

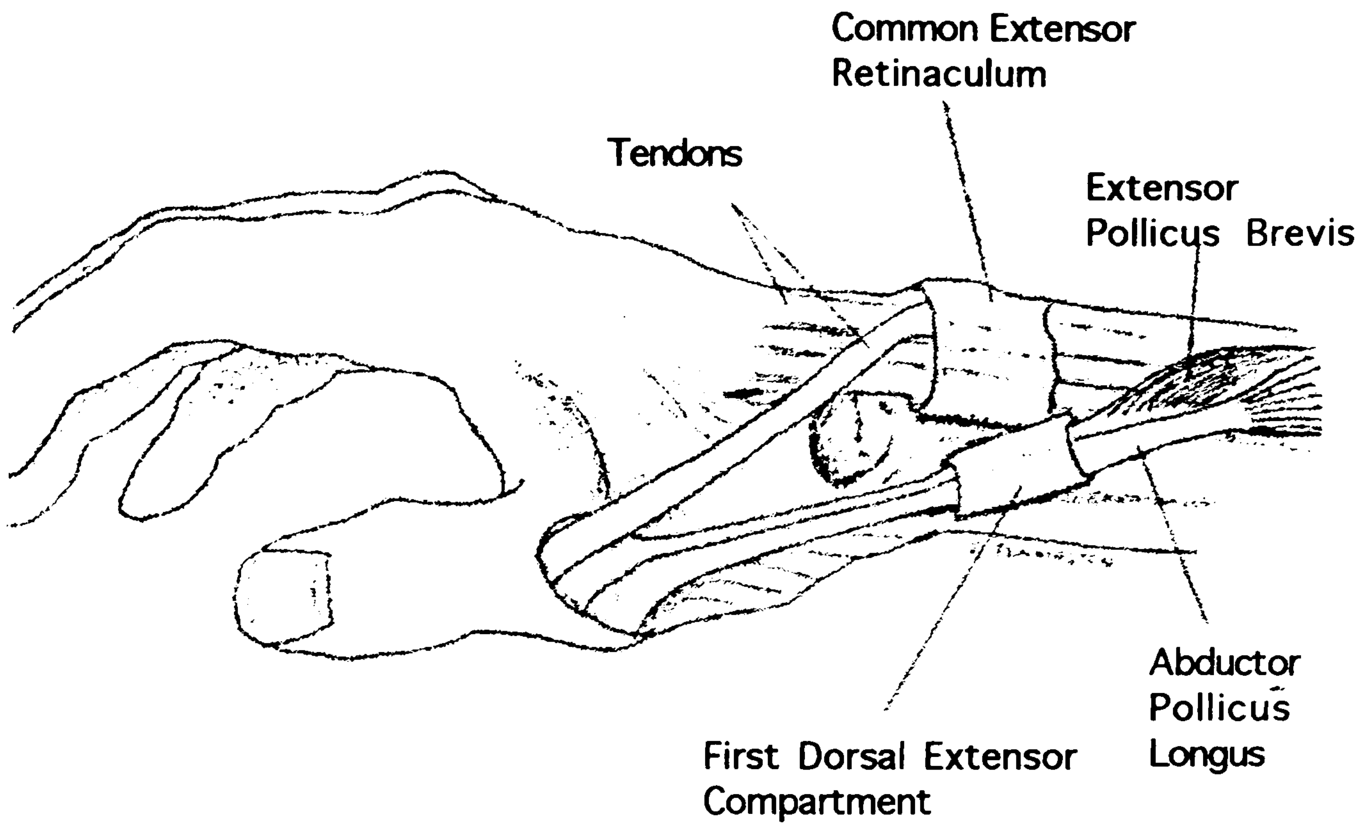

Figure 4.2. The First Dorsal Extensor Compartment

Source: Richard Norris, *The Musician's Survival Manual: A Guide to Preventing and Treating Injuries in Instrumentalists* (St. Louis: MMB Music, 1993), 69. Reprinted with permission of the International Conference of Symphony and Opera Musicians.

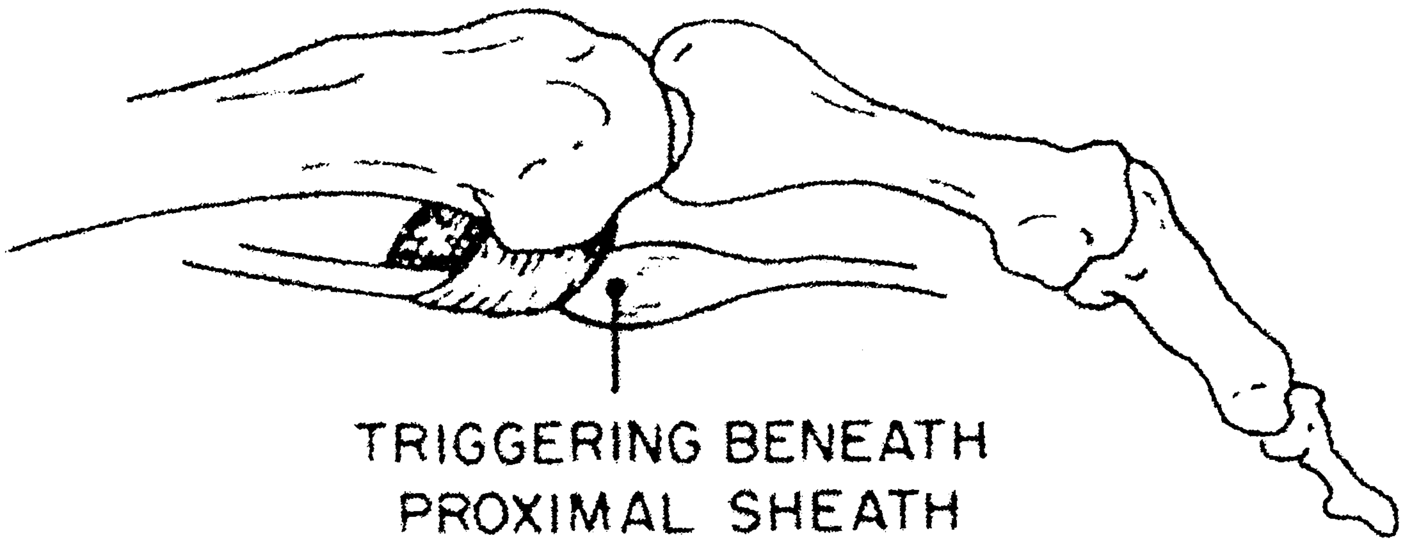

Figure 4.3. "Trigger" Finger

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the tendon suddenly "triggers" into the sheath. This "triggering often accompanied by a "snapping" noise which is frequently misattributed to a nearby joint. In extreme cases, the affected flexor tendon can become locked into position when the nodule swells to the extent that it cannot pass through the sheath at all.[63]

Nerve Entrapments

Nerves, like tendons, may become entrapped when they are constricted by other body tissues. Carpal Tunnel Syndrome (CTS) is the most commonly encountered nerve entrapment syndrome in the upper extremity, both in the general population and among musicians. The carpal tunnel runs through the middle of the wrist and is enclosed by a bony arch on the dorsal side and the transverse carpal ligament on the palmar side. Within this rigid sheath lie the median nerve and nine flexor tendons. This tunnel is crowded; any superfluous structure–including synovia, bony tumors, dislocated bones, a blood vessel, an extra nerve, or even extra fat–can compress the median nerve, resulting in carpal tunnel syndrome (Figure 4.4). Carpal Tunnel Syndrome is characterized by tingling, burning, itching, and/or numbness of the fingers, especially the third and fourth fingers. These symptoms frequently worsen at night; additionally, the hand may pull into a flexed position during sleep.[64]

Like the median nerve, the ulnar nerve may be compressed at the wrist. This entrapment occurs in Guyon's canal, located on the ulnar side of the wrist adjacent to the carpal tunnel. Numbness and tingling of the ring

63 Ibid., 216-17.

64 Ibid., 209.

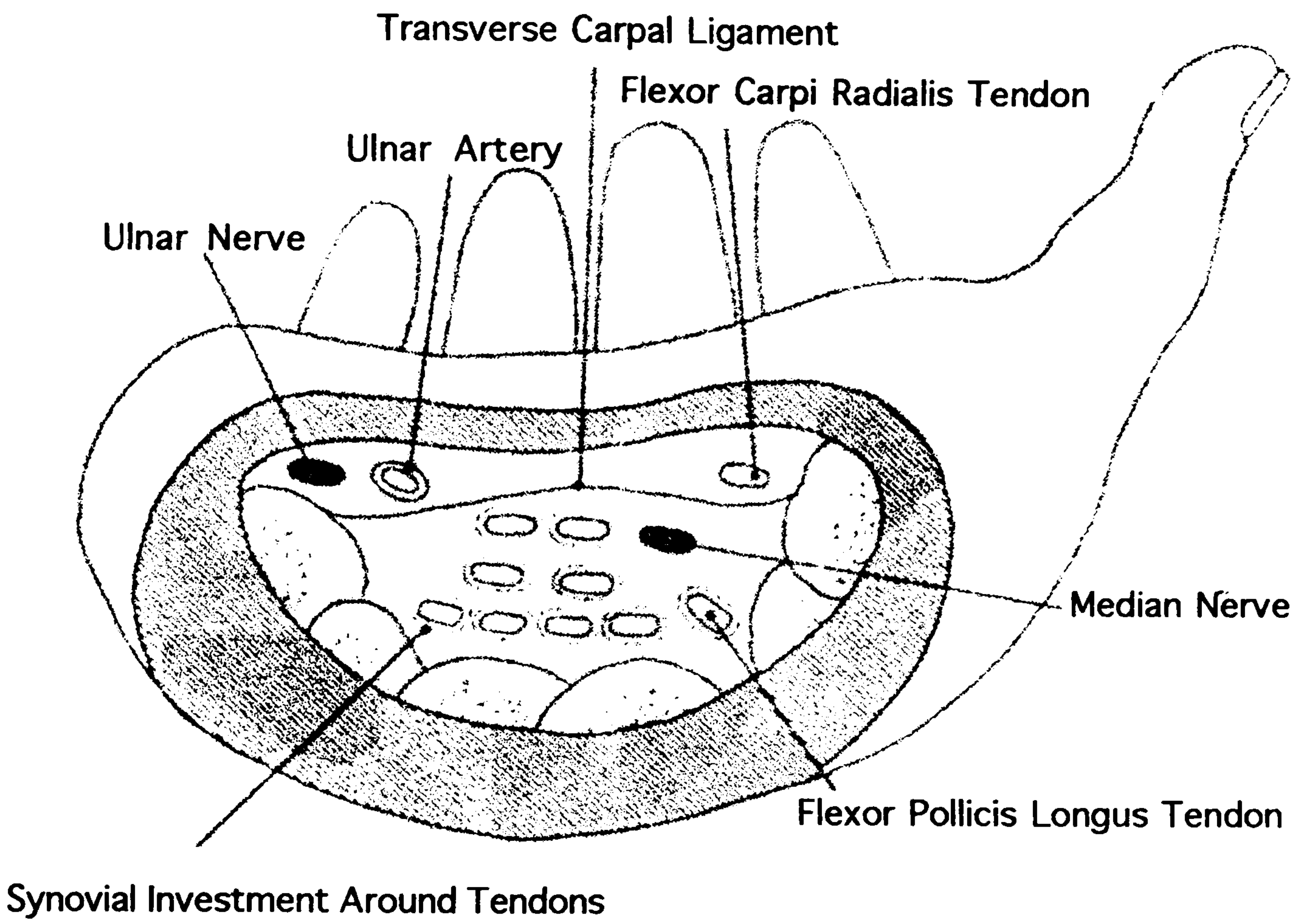

Figure 4.4. The Carpal Tunnel

Reprinted, by permission of the publisher, from Robert Thayer Sataloff, M.D., Alice G. Brandfonbrener, M.D., and Richard J. Lederman, M.D., *Textbook of Performing Arts Medicine* (New York: Raven Press, 1991), 211.

and little fingers accompanied by a loss of dexterity may be noticed by the pianist, especially when the hand is opened to its full span. Phalen's maneuver is a simple test which is indicative of either ulnar or median nerve entrapment at the wrist and involves placing the backs of the hands together and pointing the fingers toward the floor for 30-60 seconds. Although most people will eventually experience tingling in the fingers while maintaining this position, symptoms are typically provoked faster in individuals suffering from wrist nerve entrapment.[65]

Another frequent site of nerve compression is the elbow. The ulnar nerve is superficial and can be palpated when the elbow is flexed.[66] Cubital Tunnel Syndrome results when the ulnar nerve is trapped in the cubital tunnel located behind the bony epicondyle of the inner elbow (Figure 4.5).[67] Common complaints are pain on the outer side of the elbow accompanied by tingling in the fourth and fifth fingers. The pain is often described as aching, shooting, or burning and may be aggravated by flexing the elbow while applying resistance at the fingers or wrist.[68]

The thoracic outlet, where the neck, chest, and shoulder meet, is also a site of nerve, and occasionally blood vessel, compression. The subclavian artery and vein, the brachial artery and vein, and several major nerves pass through the thoracic outlet; any of these structures may be compressed between the scalene neck muscles, beneath the pectoralis minor muscle, or in between the clavicle and the first rib resulting in Thoracic Outlet Syndrome (TOS) (Figure 4.6). The most predominant symptoms of this malady are

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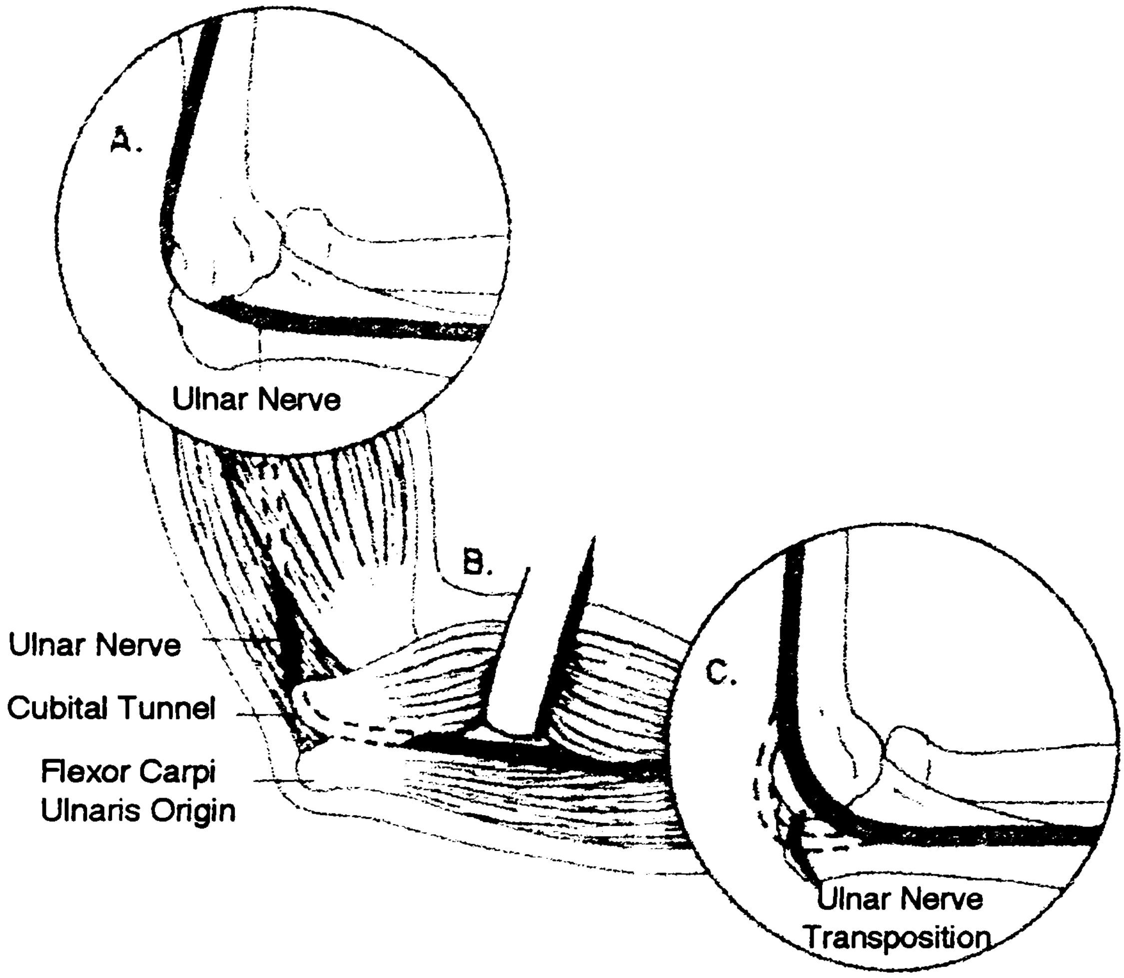
65 Markison, 108.
66 Sataloff, Brandfonbrener, and Lederman, 213.
67 Markison, 102.
68 Sataloff, Brandfonbrener, and Lederman, 214.



A.: The ulnar nerve is seen passing behind the medial epicondyle of the humerus, through the cubital tunnel. B: The relationship of the ulnar nerve to the surrounding muscle and fascial structures is demonstrated. The ulnar nerve may be compressed as it passes through the cubital tunnel or beneath the fascial origin of the flexor carpi ulnaris. C: With an anterior transposition, the ulnar nerve is placed outside of the cubital tunnel, and held in that position by a fascial sling.

Figure 4.5. Cubital Tunnel Syndrome

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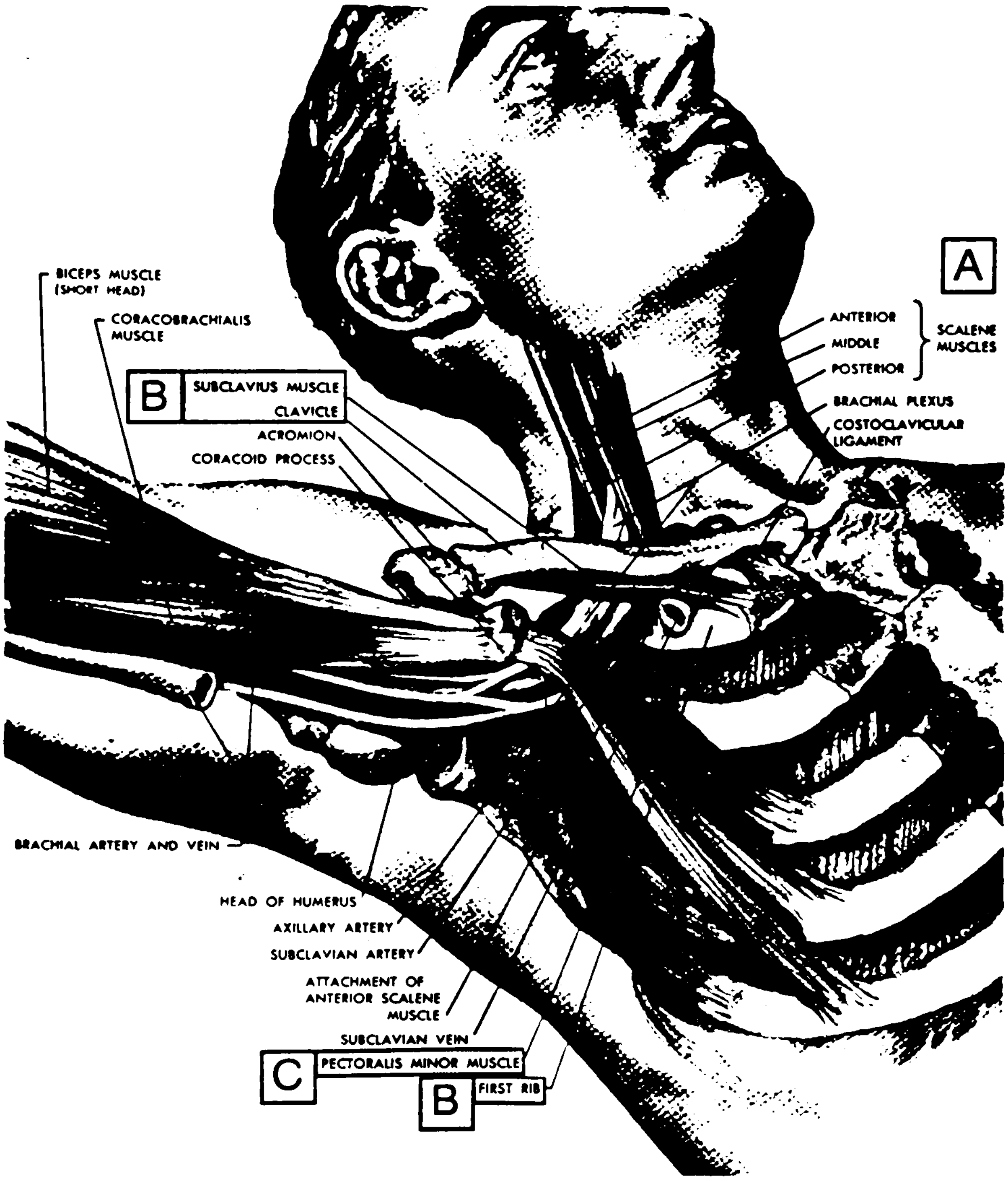

The three main sites of neurovascular compression: A) between the scalene neck muscles; B) between the clavicle (collarbone) and the first rib; and C) underneath the origin of the pectoralis minor muscle. As illustrated, the compression is increased with elevation of the arm, a frequent occurrence in the left arms of some string players playing in certain positions

Figure 4.6. Thoracic Outlet Syndrome

Source: Richard Norris, *The Musician's Survival Manual: A Guide to Preventing and Treating Injuries in Instrumentalists* (St. Louis: MMB Music, 1993), 30. Reprinted with permission of the International Conference of Symphony and Opera Musicians.

tingling and pain along the ulnar side of the forearm and hand. These symptoms are usually positional; if the sufferer changes position or walks around, they may disappear entirely. Many pianists suffering from TOS exhibit the characteristic "droopy shoulders" configuration–a long relatively thin neck and shoulders which slope downward and forward. The most effective diagnostic tool is applying downward traction of the arm in combination with shoulder rotation.[69]

Focal Dystonias

Focal dystonias have been documented in occupational injury literature for over 100 years. It was described in the early nineteenth century as "writer's cramp," "occupational neurosis," "craft palsy," and a number of other outmoded terms.[70]

Focal dystonias are among the most disruptive injuries suffered by pianists, as there is no known cure and results of experimental treatments to date have been ineffective. If the pianist is to continue performing, he or she must effectively retrain other muscles to take over the work of the muscle afflicted with the focal dystonia. This poorly understood ailment causes disruption in motor control. The initial symptom is usually a cramp or spasm in the affected muscle, along with pain or aching. The most notable effect of a focal dystonia is incoordination while playing; at first the difficulty arises after prolonged playing, but as the injury progresses, incoordination is often noticed immediately.[71] The most common type of focal dystonia in

69 Ibid., 187.
70 Ibid., 193.
71 Lederman and Calabrese, 9.

pianists manifests itself by involuntary flexion of the ring and little fingers.[72] The etiology of focal dystonias is almost completely unknown. Though cerebral lesions are often responsible for general and segmental dystonias, this is not the case with the focal dystonias exhibited by pianists.[73] In fact, neurological examinations of affected musicians is usually completely normal; the only aberration is the presence of the cramp itself.[74] Many musicians suffering from a focal dystonia report previous incidences of overuse injury in the affected part of the body, and at least one study has linked previous traumatic injury with the development of focal dystonias.[75] Focal dystonias are the only malady suffered by pianists which affect more men than women, at a two to one margin; the reasons for this dissimilarity, like the disorder itself, are unknown.[76]

In summarizing common types and sites of keyboard injuries, it is apparent that keyboardists fall prey to a number of types of injury. These injuries tend to occur at certain sites within the upper limb. Any muscle, muscle-tendon unit, joint, ligament, may be strained. Tendinitis, especially epicondylitis, is prevalent. Tendons may also be trapped due to inflammation, as is the case in DeQuervain's syndrome and "trigger" finger. Nerve entrapments, including Carpal Tunnel Syndrome, Cubital Tunnel Syndrome, and Thoracic Outlet Syndrome are also common. Focal dystonias are perhaps the most devastating type of injury suffered by pianists; treatments have not been effective to date. Fortunately, unlike focal dystonias, most of the ailments described above respond positively to medical

72 Sataloff, Brandfonbrener, Lederman, 194.
73 Lockwood, 224.
74 Sataloff, Brandfonbrener, Lederman, 195.
75 Lockwood, 224-5.
76 Sataloff, Brandfonbrener, Lederman, 194.

treatment. Conservative measures, such as rest, oral anti-inflammatory drugs, injection of steroidal medications, or splinting of the injured area, often relieve symptoms and allow for healing. Even if conservative measures fail, prudently undertaken surgery may prove successful, especially in cases of tendon or nerve entrapment.

Risk Factors for Developing Keyboard Injuries

Medical Observations

Having treated hundreds of injured musicians, performing arts medicine specialists have arrived at several recommendations for preventing injuries based on empirical evidence. Perhaps the most important observation made by medical specialists has been that the most common cause of music-related overuse injury is a sudden increase in the time and/or intensity of practice.[77] Since this factor is completely within the pianist's control, taking several precautions may prevent injury development. First, practice segments should be divided into segments no longer than 25-30 minutes, with an arbitrary break of 5 or 10 minutes interposed between segments.[78] The break between segments will allow muscle tissues to relieve themselves of residual waste products, and also provides for relief from the static playing posture. After the break, muscle response time will be faster, and mental concentration will also be improved. The pianist can always make productive use of break time by listening to taped practice segments, analyzing the music, doing visualization exercises, or planning future

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77 Lockwood, 222; Alice G. Brandfonbrener, "Medical Problems of Musicians," *American Music Teacher* 37, no. 55 (April/May 1988):24; Lederman and Calabrese, 9.

78 Fry, "Overuse Syndromes in Instrumental Musicians," 144; Fry, "Overuse Syndrome of The Upper Limb," 183.

practice objectives. More demanding practice sessions should be alternated with those of lesser intensity, and after a particularly physically taxing day of practice, a lighter day should be scheduled. Practice segments should be spread throughout the day for maximum benefit. When more practice time is desired, the number of segments should be increased gradually. The actual length of the segment should remain unchanged, or even be shortened slightly.[79]

The importance of never practicing through pain cannot be overstated. If acute pain is suddenly experienced, the pianist should stop playing immediately and seek medical attention if the pain does not abate. For less severe pain, the pianist should stop practicing until the pain subsides and then only gradually resume practicing. As a temporary measure to relieve muscular discomfort, using the R-I-C-E (Rest, Ice, Compression, and Elevation) formula is often helpful.[80]

Chances of injury are lessened further by adequately warming up muscle tissue. As discussed above with regard to muscular endurance, muscle tissues perform most effectively at 38.5° Celsius (101.3° F). Warm-ups should gently stretch all components of the upper limb through their full ranges of motion.[81] Doctors have warned against playing with cold hands, pointing out that cold hands indicate that circulation to the hands is not optimal.[82] Dr. Alice Brandfonbrener, director of the Medical Program for

[79] Fry, "Overuse Syndromes in Instrumental Musicians," 144.

[80] Kella, John J., Ph.D., "Musculoskeletal, Neurological, and Ailments of Musicians," *International Musician: Official Journal of The American Federation of Musicians of The United States and Canada* 87 (July 1988): 19.

[81] Ibid.

[82] Markison, 97.

Performing Artists in Chicago, recommends 10-15 minutes of warm-up using the following exercises:

1. Shoulder flexion–both arms raised overhead, then relaxed to sides–7 repetitions
2. Shoulder abduction–both arms at sides, raise outward and upward over head, then relax to sides–7 repetitions
3. Shoulder shrugs–7 repetitions
4. Pinch shoulder blades together–7 repetitions
5. Elbow flexion and extension–bend and straighten elbows fully–7 repetitions
6. Shoulder circles–arms at sides, rotate shoulders in circles–7 repetitions forward and backward
7. Forearm rotation–turn palms up and then down–7 repetitions
8. Wrist flexion and extension–bend wrist up and down–7 repetitions
9. Radial and ulnar deviation–bend wrist laterally to little finger side and then to thumb side–10 repetitions
10. Finger abduction and adduction–spread fingers then squeeze together–10 repetitions
11. Finger PIP and DIP joint flexion–bend fingers at top two joints without flexing at MCP joints–10 repetitions[83]

According to performing arts medical experts, after any vigorous activity, muscles are prone to cramping and fatigue. Stretching the muscles their entire length, then relaxing them, prevents cramping and discomfort.[84] Dr. Brandfonbrener recommends 10-15 minutes of cool-down activities and suggests the following exercises, each of which should be held for 5 counts:

1. Shoulder flexion–raise arms overhead–5 repetitions
2. Touch shoulder with opposite hand and hold–5 repetitions
3. Bend neck to the right then to the left, holding for 5 counts each side–5 repetitions
4. Clasping hands behind head, bend neck to each side–5 repetitions
5. Clasp hands behind hips and roll shoulders toward back–5 repetitions
6. Wrist flexion and extension–make a fist and bend wrist up and down–5 repetitions
7. Wrist hyperextension–straightening fingers, bend wrist toward top of forearm–5 repetitions

83 Alice G. Brandfonbrener, Xeroxed list given to author on October 1,1994.
84 Ibid.

8. Finger abduction and adduction–spread fingers then relax–5 repetitions.[85]

In addition to using warm-up and cool-down exercises, Brandfonbrener has advised that pianists should maintain good general physical conditioning because the well-toned body is less prone to injury. She believes that flexibility and endurance are more important than muscle mass or strength.[86] Brandfonbrener has advocated swimming as the ideal form of exercise for musicians because it offers excellent cardiovascular benefits and strength training without unduly straining the back, neck, and shoulders. She has also observed that that the pianist who gets adequate amounts of sleep, engages in recreational activities, and maintains a healthy diet is less prone to injury.[87]

In addition to offering practical suggestions regarding practice segments, warm-ups, and cool-downs, performing arts medical specialists have made observations concerning the playing apparatus as a whole. Sitting at the instrument properly is considered of major importance. When not required for pedaling, both feet should be placed on the floor, in a straight line down from the knees, and the spine should be elongated.[88] Support for body weight is provided by the ischia (bony knobs) of the pelvis, the thighs resting on the seating surface, and the feet on the floor. Anterior-posterior motion is enabled by rocking the pelvis through the hip joints, while rotation at the hip joints allows for some lateral trunk motion. The axis through the shoulder

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85 Ibid.

86 Brandfonbrener, "Medical Help For Musicians," 31.

87 Brandfonbrener, "Medical Help for Musicians," 31; Brandfonbrener, "Medical Problems of Musicians," 25..

88 Ans Samama, "Posture and Movement in Making Music," in *Current Research in Arts Medicine* ,ed. Fadi Bejjani (Chicago: A Cappella, 1993): 328.

joints and the transverse axis through the pelvis should remain parallel to the floor, which requires a flexible spine.[89]

Ans Samama has observed that pain in the articulations of the upper extremity is often caused by incorrect distribution of work between muscles used for postural support or balance, and playing muscles. A forte sound level is often achieved by maintaining too much tension in the arm muscles while keeping the wrist joints stationary. To prevent overtaxing, Samama suggests keeping the wrist flexible and playing forte with the fingers while tensing the back muscles as a counterforce, although there is no mechanical evidence given to support this opinion.[90]

Some motions have been correlated to incidence of injury. Forearm muscle strain has been linked to twisting of the muscles and tendons of the forearm, as is the case when playing in the outer reaches of the keyboard. This is especially true when the twisting is combined with repetitive and forceful use. Likewise, epicondylitis has been directly related to twisting of the upper limb.[91] Dr. Sakai, a "music medical" practitioner, conducted interviews of forty Japanese pianists suffering from hand and forearm overuse caused strictly by piano practice. The varied diagnoses included: lateral or medial epicondylitis, muscular pain, pain in the flexor carpi radialis or ulnaris tendons, pain in the extensor retinaculum tendon, DeQuervain's tenosynovitis, flexor tendinitis in the second through fifth fingers, abductor digiti minimi tendinitis, MCP joint pain, and PIP joint pain. Thirty of the patients interviewed reported that they developed symptoms directly as a

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[89] Raoul Tubiana, "Fundamental Positions for Instrumental Musicians," *Medical Problems of Performing Artists* 4 (June 1989): 74.

[90] Samama, 328-29.

[91] Markison, 100.

result of practicing a particular skill or articulation. The skills which most frequently caused injury within this study were: octaves (15 cases), chords (8), fortissimo playing (2), presto playing (2), arpeggios (1), passage which covered wide range on keyboard (1), and staccato (1).[92] The practice of the first two skills, octaves and chords, accounted for a total of 77% of injury cases. These techniques involve abduction of the thumb and little finger in conjunction with stabilized wrist joints. Hochberg and others suggested that not only octaves, but also trills and arpeggios may be related to extensor forearm and dorsal pain.[93] Sakai also hypothesized that hand size may have some relation to the development of these injuries, since his survey population demonstrated relatively small hand size in comparison with their European counterparts.[94]

Biomechanical Observations

As briefly discussed in the literature review in Chapter I, several studies have addressed the biomechanics of the playing apparatus. These studies generally present ideal positions for reduction of stress on various parts of the playing apparatus. These studies regarding the biomechanics of the playing apparatus are reviewed below in greater detail as they relate specifically to preventing keyboard-related injuries.

92 Naotaka Sakai, "Hand Pain Related to Keyboard Techniques in Pianists," *Medical Problems of Performing Artists* 7 (June 1992): 63.

93 Fred Hochberg, and others, "Hand Difficulties Among Musicians," *Journal of the American Medical Association* 249 (1983): 279-82.

94 Sakai, 65.

Observations Regarding the Entire Playing Apparatus

Raoul Tubiana and others have described a theoretical biomechanical norm for the playing apparatus as a whole. The arms of the pianist are always in front of the body. As they move away from the center of the keyboard, movement is accomplished through shoulder abduction, adduction, and external rotation. Scapulothoracic motion also contributes by separating the arm from the axis of the trunk through upward and outward gliding of the scapula. The forearm is partially pronated with its transverse axis above the wrist forming an angle of approximately 30° with the keyboard. The hand itself is completely pronated, creating an arch that increases the force in the fingers and allows maximal contact of the finger pads with the keys. The wrist is slightly extended, and the axes of the hand and forearm describe an angle of 15° toward the ulnar side. This hand and forearm position allows for more efficient finger flexion as it aligns the forearm tendons along their ideal physiological axis. Each finger is somewhat independent, but must be equilibrated with the entire hand (as discussed in Chapter II with regard to the finger independence exercise). Equilibrium is maintained by maintaining the longitudinal and transverse arches of the hand. At the wrist, the agonistic and antagonistic contraction of the extensor carpi ulnaris and abductor pollicis longus stabilizes the arch between the thumb and the fifth finger. When the thumb must reach to strike a note, the ulnar side of the hand reacts to preserve the arch underneath the MCP joints by flexing the fourth and fifth MCP joints.[95]

Finger flexion follows a sequence. It is initiated at the PIP joint followed by the MCP joint, and finally by the DIP joint. Flexion of the

[95] Tubiana, 74.

proximal phalanx (finger bone) of the second finger is effected by slight finger abduction without rotation. The first phalanx of the third finger will also demonstrate radial abduction as the joints are flexed. With flexion, the fourth and fifth fingers also abduct, but the motion is toward the ulnar side of the hand. Thus, the fingers are spread contributing to the stability of the hand and maintenance of a metacarpal arch.[96]

Tubiana points out that extension of the fourth finger is a significant problem for the pianist, which may be partly ameliorated by proper alignment of the finger with its metacarpal (hand) bone. He also points out that the thumb is vitally important in stabilizing the arches of the hand due to its strength throughout a wide range of motion, especially forward positioning and radial deviation.[97]

John Chaffin and Gunner Anderson have modeled the optimal position of the shoulder in relation to a desk surface in the performance of seated work. A work surface placed higher than the elbow requires the elbow to be flexed or the shoulders to be abducted or lifted. These postures increase the stress on the shoulder joints, and perhaps most significantly, upon the muscles of the shoulder and neck. The ideal position for performing desk work has a shoulder abduction angle of 15° to 20° or less and a flexion angle of 25° or less. This position places minimal stress on the muscles of the shoulder.[98] In such a position, the elbow is parallel with or slightly above key level. Though describing an ideal position for desk work (most generally,

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[96] Ibid.

[97] Ibid., 74-75.

[98] Don B. Chaffin and Gunnar B.J. Anderson, "Guidelines For Seated Work," in *Occupational Biomechanics*, 2nd ed. (New York: John Wiley & Sons, 1991): 357.

typists) this recommendation might also be brought to bear upon piano playing to minimize shoulder stress.

Observations Regarding Finger Position

As discussed in the review of literature, a study conducted by David Harding and others generated several finger positioning norms for reduction of joint and tendon forces in the fingers of pianists. First, the study underscored the observation that amount of finger force is inversely related to years of experience, with experienced subjects generating forces approximately 20% lower than subjects with little experience.[99] This finding has been verified by later studies.[100] Harding then proceeded to describe the finger positions which minimized the forces acting upon various joints. His models represent biomechanical norms for positioning of the index finger. As a function of DIP and PIP joint flexion, he found that the position which most reduced force in the DIP joints was a curved finger with a finger to key contact angle=5°, DIP flexion angle=35°, PIP flexion angle=20°, and MCP flexion angle=40° (Figure 4.7).[101] This position results in a finger which describes a gradual curve, with most of the curve occurring at the MCP joint. Harding underscored the importance of DIP loading, observing the force at the DIP joint is frequently higher than at either the PIP or MCP joint. He believes this discrepancy may explain why so many pianists suffer more injuries of the fourth and fifth fingers than of other fingers, since these

99 David C. Harding and others, "Minimization of Finger Joint Forces and Tendon Tensions in Pianists," *Medical Problems of Performing Artists* 4 (September 1989): 104.

100 B.M. Hillberry, "Joint and Tendon Forces in Pianists' Hands," *Current Research in Arts Medicine,* ed. Fadi Bejjani (Chicago: A Cappella, 1993), 170.

101 Harding, 106.

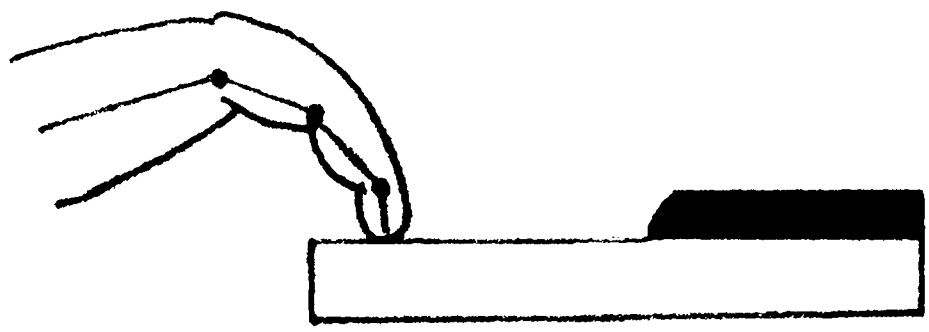

Figure 4.7. Optimum Position for Reduction of DIP Joint Force

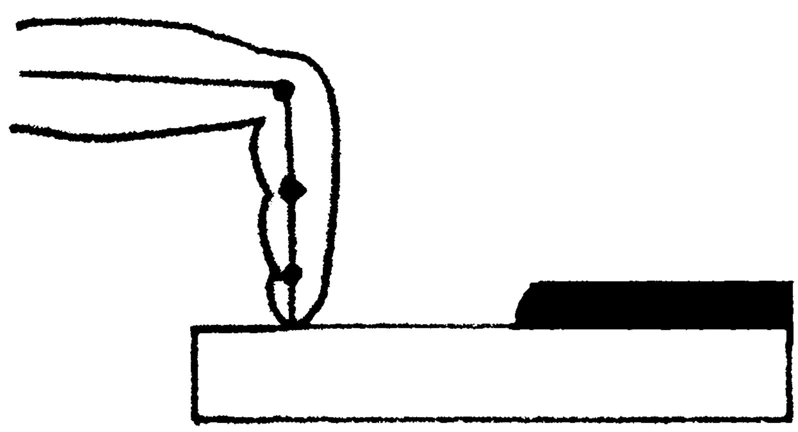

Figure 4.8. Optimum Position for Reduction of MCP Joint Force

fingers are required to produce the same acoustic intensity as the larger fingers, yet have the smallest joint contact areas.[102]

MCP joint force as a function of MP and PIP flexion was also described. Harding found that MP joint force was minimized in a position of high MCP flexion in combination with low PIP flexion (contact angle=5°. MCP flexion angle=85°, PIP flexion angle=5°, DIP flexion angle= 5°) (Figure 4.8). When a finger posture of low MCP flexion/high PIP flexion was adopted in the study, MCP joint force rose to 300% of the minimum value produced by the high MCP flexion/low PIP flexion position.[103] This recommended position for minimum tension results in a sharply flexed MCP joint, with the rest of the finger remaining virtually straight.[104] Harding did not describe an ideal position for minimizing PIP joint force.

Harding also investigated the relationship between force and strain of the flexor digitorum profundus tendon. The position representing a minimum force value was found to be one of high DIP flexion angle combined with low key contact angle (contact angle=5°, MCP flexion= 59°, DIP flexion=5°, PIP flexion=5°) (Figure 4.9). When this position was reversed to one of low DIP flexion/high contact angle, the force acting on the flexor digitorum profundus tendon was found to be 880% of the minimum value produced in the high DIP flexion/low contact angle position.[105] This position is similar in appearance to the MCP ideal (although with a slightly less severe flexion at the MCP joint). Harding acknowledged that this position is physiologically difficult to assume and not commonly used in piano

102 Harding, 108.
103 Harding, 105-6.
104 Ibid.
105 Ibid., 105.

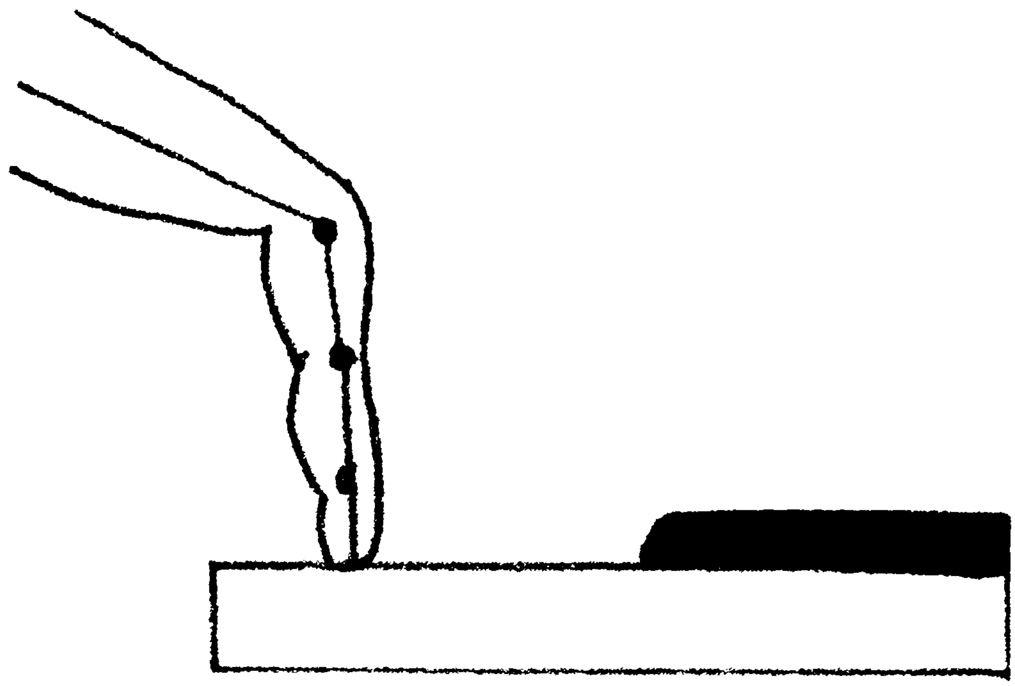

Figure 4.9. Optimum Position for Reduction of FDP
Tendon Force

playing.[106] He did claim, however, that both the MCP ideal and the flexor profundus digitorum tendon ideal can provide valuable information when designing a finger position for practical use.[107]

It seems important to note that neither Harding's DIP ideal, MCP ideal, nor flexor digitorum profundus ideal may be actually utilized in piano playing, since they represent force values only in regard to the joint or tendon under consideration. Piano playing involves simultaneous loading of the three joints of the finger (MCP, PIP, and DIP) and several tendons, and therefore the player must adopt a position which minimizes forces throughout all component parts. Harding did point out, however, that decreasing joint or tendon forces by adoption of the ideal positions does not necessarily produce corresponding increases in forces elsewhere in the finger. For example, he stated that minimizing the tension in one tendon usually leads to reduction of tension in other tendons and forces in related joints.[108]

In addition to modeling finger positions for reduction of forces in the finger joints and tendons, Harding also described keystrike forces as they function in staccato versus legato playing. In general, he showed that there is less keystrike force present in legato playing than in staccato playing, which he attributed to better muscular control throughout the legato keystrike.[109] Harding examined two randomly selected legato key strikes; acoustic volume produced by the two legato keystrikes was identical. In comparison to the staccato keystrike, there was little or no impact generated. Instead, the highest forces were brought to bear on the finger immediately after the key "bottomed

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106 Ibid.
107 Ibid., 108.
108 Ibid.
109 Ibid., 107.

out" (came to rest at the bottom of the key action).[110] This led Harding to theorize that the large peak in force produced after the "bottoming out" of the piano key could be eliminated if the pianist accelerated the key during its downward motion and then released the finger immediately before the key reached the end of its travel. Since the fingertip force would be released past the point where the hammer contacted the string, this would have no impact upon sound production.[111]

Harding concluded with the observation that optimization of finger forces is helpful in preventing tendinitis and Carpal Tunnel Syndrome, since unnecessarily high forces in tendons due to suboptimal finger position (especially in combination with a high degree of wrist flexion) can produce swelling and result in median nerve compression.[112]

In addition to demonstrating that keystrike force used by pianists was inversely related to years of experience, Hillberry compared biomechanical forces in the fingers of computer users with and without Carpal Tunnel Syndrome. He measured keystrike forces via a dynameter on the second and third fingers of the right hand. He found some interesting discrepancies between the keystrike forces in the two groups. Hillberry discovered that subjects with CTS hit the key with a mean keystrike force 30% higher than those subjects without CTS. He also found that although there were no statistically significant differences in finger and hand angular positions between the groups, subjects with CTS held the wrist either perfectly aligned

110 Ibid., 106.
111 Ibid., 107.
112 Ibid., 108.

(straight) or slightly drooped between the forearm and hand.[113] One should note that a direct cause and effect relationship cannot be determined from these data.

F.J. Bejjani and others compared three piano techniques using different finger positions during the performance of various pianistic tasks. The optimal kinematic position for reduction of forces throughout the finger was found to be a finger in which the MCP, PIP, and DIP joints were all flexed, with the greatest degrees of flexion present at the MCP and PIP joints. He also pointed out that experienced pianists switch from one position or technique to another many times during the course of a single piece of music in order to fit the demands of the moment, and thus optimization of finger position is somewhat tentative.[114]

Observations Regarding the Hand and Wrist

Chung and others conducted a study which quantified average range of motion of the wrist for various playing activities. This study demonstrated that the average wrist motion required to perform standard technical exercises was 13° right wrist and 14° left wrist flexion/extension motion (FEM), and 12° right/13° left radioulnar deviation motion (RUD). Within passages of Classical music, the average wrist motion increased to 21° right/24° left FEM and 14° right/17°left RUD. The range of flexion/extension motion for exercises was extension (E) of 26° to a flexion (F) of 16° in the right

113 Benjamin M. Hillberry, " Dynamic Effects of Work on Musculoskeletal Loading," *Repetitive Motion Disorders of the Upper Extremity* (Rosemont: Academy of Orthopedic Surgeons, 1995): 107-8.

114 F.J. Bejjani, and others, "Optimizing Kinematics and Kinetics of Piano Performance," Paper presented at the 13th Annual Meeting of the American Society of Biomechanics, University of Vermont, Burlington, VT, 13-25 August 1989; abstract in *Journal of Biomechanics* 23 (1990): 730.

wrist, and E 16°-F 19° in the left wrist. Range of radioulnar deviation was U 53°- R 28° in the right wrist, and U 28°-R 12° in the left wrist. In Classical music, range of flexion/extension was E 29°- F 18° in the right wrist and E 20°-F 23° in the left, while range of radioulnar deviation was U 54° to R 28° in the right, and U 33°- R 17° in the left.[115] The findings of this study are remarkable when compared with standard biomechanical norms for functional range of wrist motion in daily living activities. Palmer and others described functional wrist motion as 5° flexion, 30° extension, 10° radial deviation, and 30° ulnar deviation.[116] When the ranges of wrist motion for piano playing as described by Chung are compared with these functional ranges of motion, it is immediately apparent performing both exercises and Classical repertoire requires a larger range of radioulnar motion than is normally used in daily activities.

The participants in the study were divided into two groups: weight-playing, and "traditional" (emphasis on finger). Chung found that the weight-playing group averaged less wrist motion when playing exercises as compared to the finger-playing group. Of the skills examined, some required wider wrist motion than others, including the trill as performed in Classical repertoire, and the arpeggio as performed in an exercise. When performing these two skills, the weight-playing group exhibited greater flexion-extension activity, while the "traditional" group used more radioulnar activity. Overall, the right wrist used much more motion, especially ulnar deviation, than the left, which led Chung to theorize that this finding may explain why

[115] In-Seol Chung, and others "Wrist Motion Analysis in Pianists," *Medical Problems of Performing Artists* 7 (March 1992): 5.

[116] Ibid., 3.

more overuse injuries are reported in the right wrist of pianists than in the left.

Several studies have suggested that increased pressure in the carpal tunnel plays a role in the development of Carpal Tunnel Syndrome, and possibly in finger flexor tenosynovitis as well.[117] Subtle and temporal variations in carpal tunnel pressure (CTP) are strongly related to wrist angle. Gelberman and others observed that passive extension or flexion of the wrist causes CTP to increase on average from 2.5 to 30 mm Hg. An even higher pressure was observed at extremes of wrist extension and flexion in patients with Carpal Tunnel Syndrome (CTS). Among both normal groups and groups afflicted with CTS, CTP increases by a factor of two to ten with passive flexion or extension.[118] Building on this finding, Rempel demonstrated that the relationship of CTP to wrist angle was parabolic, increasing with greater degrees of wrist extension or flexion. He observed a similar parabolic relationship with regard to increased degrees of radioulnar deviation.[119] Magnetic resonance imaging has shown that when the wrist is flexed the median nerve is compressed between the flexor digitorum tendons and the flexor retinaculum. In addition to this mechanical compression, the median nerve may also be subjected to hydrostatic compression from the fluids in the carpal tunnel during extreme wrist flexion and extension. There are frictional interactions between the median nerve and the flexor tendons which may be increased or decreased by carpal tunnel pressure. These

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117 David Rempel, "Musculoskeletal Loading and Carpal Tunnel Pressure," *Repetitive Motion Disorders of the Upper Extremity* (Rosemont: American Academy of Orthopedic Surgeons, 1995): 125.

118 R.H. Gelberman and others, "The Carpal Tunnel Syndrome: A Study of Carpal Canal Pressures," *Journal of Bone and Joint Surgery* 63A (1981), 380-3.

119 Ibid., 125-6.

interactions may add stretching (traction) of the median nerve to compression as a possible cause of CTS.[120]

In addition to extreme degrees of flexion or extension, another extrinsic risk factor which has been identified is pinch force. Increased CTP has been shown to result from loading at the fingertip. In live subjects, active increase of fingertip loading led to an increase in CTP when the wrist extended 15°.[121] This suggests that playing the piano with a wrist which is dropped below the level of the keyboard might hypothetically cause increase CTP and therefore contribute to the development of Carpal Tunnel Syndrome and other maladies.

Yet another factor which might contribute to CTS is repetitive motion. CTP is elevated and fluctuates dramatically in subjects performing repetitive hand activities.[122] Several studies have shown that repetitive motion of the wrist causes cyclic hydrostatic compression of the median nerve.[123]

Ergonomic Observations

Ergonomic and epidemiological studies have been conducted to determine the frequency of upper limb disorders in the workplace and identify possible causes. With regard to use of the finger, William Meinke criticized Harding's models for minimization of joint and tendon forces. He pointed out the Harding had no clear description or definition of the total work done by pianists; Harding's observations represented a rather a limited

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120 Robert M. Szabo and Michael Madison, "Carpal Tunnel Syndrome as a Work-Related Disorder," *Repetitive Motion Disorders of the Upper Extremity* (Rosemont: American Academy of Orthopedic Surgeons, 1995): 426-7.

121 Rempel, 127.

122 Ibid., 128.

123 Szabo and Madison, 428.

and isolated segment of the "work cycle." Meinke further noted that even within the fragment of the work cycle where the model does have validity, applying the finger positioning ideals is not straightforward, and attempting to play each note with the fingers held in any static position, even an ergonomically appropriate one, is to invite physical problems. Instead, Meinke claimed that the optimal position of the finger for any given note is heavily impacted by the musical context in which the note occurs.[124]

Many epidemiological studies have documented the occurrence of Carpal Tunnel Syndrome in various occupational settings. These studies confirm the biomechanical findings of greater degrees of flexion and extension as risk factors. Other positions have also been related to the development of CTS and other disorders when used repeatedly or for prolonged periods. In addition to flexion and extension, potentially stressful positions include radial and ulnar deviation, pinching with the fingers, and extreme pronation or supination.[125] Several of these positions have been demonstrated to increase risk of injury in computer keyboardists; they also potentially relate to the pianist. If the elbow and forearm are lower than the keyboard, the wrist will be placed into a position of extreme flexion. Ulnar deviation and inward forearm rotation will also be required when playing in the mid-range of the keyboard.[126]

In addition to the degree of flexion and extension at the wrist, at least one study has demonstrated a relationship between the kinematics of flexion

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124 William B. Meinke, "Musicians, Physicians, and Ergonomics: A Critical Appraisal," *Medical Problems of Performing Artists* 9 (September 1994): 67.

125 Thomas J. Armstrong, "Cumulative Trauma Disorders of the Upper Limb and Identification of Work-Related Factors," in *Occupational Disorders of the Upper Extremity*, ed. Lewis H. Millender and others (New York: Churchill Livingstone, 1992): 37.

126 Ibid., 36.

and extension and high risk for developing CTS. William Marras conducted a study of 40 industrial workers and found that since force is a function of mass and acceleration, wrist force can be disguised in an occupational setting as dynamic wrist motion. He found a positive correlation between greater acceleration of flexion/extension movements and the risk of developing CTS, concluding that average wrist accelerations of over 800°/second^2 significantly increase risk of suffering a wrist disorder.[127]

Certain risk factors have also been linked to the development of specific injuries. Forceful pronation has been associated with pronator syndrome, while extreme elbow flexion and extension has been linked to Cubital Tunnel Syndrome. Repetitive movements of the wrist and forearm have been associated with nerve entrapments in both locations.[128] There has been a strong correlation demonstrated between manually strenuous tasks and tenosynovitis. Most of these afflictions are preceded by trauma or by a change in work exposure, either resuming activities after a leave, or changing the quantity or quality of work.[129] This finding supports the empirical observation by performing arts medicine specialists that most music-related injuries are directly caused by a sudden increase in the time and/or intensity of practice. Epidemiological statistics also validate medical advice against practicing when muscles are cold, showing acute tendinitis has resulted after

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127 William S. Marras, "Toward An Understanding of Dynamic Variables In Ergonomics," in Occupational *Medicine Ergonomics: Low-Back Pain, Carpal Tunnel Syndrome, and Upper Extremity Disorders In The Workplace*, ed. J. Steven Moore (Philadelphia: Hanley & Belfus,1992): 660-1.

128 Eira Viikari-Juntura, "The Role of Physical Stressors in the Development of Hand/Wrist and Elbow Disorders," in *Repetitive Motion Disorders of the Upper Extremity* (Rosemont: American Academy of Orthopedic Surgeons, 1995): 13.

129 Ibid., 14.

sudden exposure to temperatures below 0° Celsius (32° F).[130] Cooling of the innervated fingers has been shown to greatly affect strength, dexterity, and sensitivity. When working in a cold environment, people with normal sensory function tend to exert more force than is required.[131]

Several studies also demonstrate a correlation between strenuous manual tasks and epicondylitis, though this finding has been contradicted by other studies. However, there has been a conclusive finding with regard to repetitiveness and forcefulness of work and the prevalence of epicondylitis as it relates to work experience. Workers who had been in their current job for less than 12 months had a higher rate of injury when repetitiveness and force of the task was increased. A similar trend was observed in workers who had been on the job for 12-60 months. However, a reverse trend was seen in workers who had been on the job over 60 months, leading to speculation that those workers who had suffered epicondylitis had left the job by this time.[132]

High incidences of injury have been correlated to tasks which require wrist movements of high force and high repetitiveness. In fact, this correlation has been demonstrated so strongly that it substantially increases risk of CTS development more than any other factor.[133] Punnett demonstrated that the relative risks of shoulder, arm, and hand disorders were significantly increased for computer keyboard work of at least 4 hours per day.[134] She further concluded that injuries related to computer keyboard

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130 Ibid., 15.

131 Armstrong, 39.

132 Ibid.

133 Barbara A. Silverstein and others, "Hand Wrist Cumulative Trauma Disorders in Industry," *British Journal of Industrial Medicine* 43 (1986): 783.

134 Laura Punnett, "Work-Related Musculoskeletal Disorders in Computer Keyboard Operation," in Repetitive *Motion Disorders of the Upper Extremity* (Rosemont: American Academy of Orthopedic Surgeons, 1995): 44.

work are not entirely explained by the risks associated with wrist position. The most consistent evidence for injury work-relatedness involved the intensity of and cumulative exposure to keyboard work.[135]

Meinke applied the laws of motion economy to playing the piano. Of all the laws of motion economy which apply to human endeavors, Meinke identified four which apply to the pianist's task:

1. Use of momentum to assist work
2. Use of smooth, curvilinear rather than straight, jerky motions
3. Use of the best-suited sets of muscles to accomplish work
4. Avoidance of wrist positions that deviate from neutral.[136]

Momentum should assist the pianist; where it does not, it should be eliminated or minimized. Meinke identified several ways in which momentum can be used. Some of these are powered by sources inside the human body, and some from without. The most helpful extrinsic force is gravity. There is the potential to let the acceleration of gravity (the "free-fall" referred to by many pedagogues) generate and deliver force to the key. Since the gravitational pull of the earth and the weight of the upper limb are fixed, the force imparted through this method will be exactly the same for each keystroke. There would therefore be no opportunity to change the quality of the sound produced. However, there are two variables under the pianist's control: the distance over which gravity is allowed to exert itself and the kinetic state of the limb at the point where gravity begins to act upon it. Gravitational force is additive and manifests itself as an acceleration. If gravity is allowed to act while the finger is resting lightly on the key surface, then the effective distance is only the quarter of an inch between the surface

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135 Ibid., 47.

136 William B. Meinke, "The Work of Piano Virtuosity: An Ergonomic Analysis," *Medical Problems of Performing Artists* 10 (June 1995): 54.

of key at rest and the point at which sound is produced. The resulting tone is soft. If, instead, gravity is allowed to exert itself while the finger is still an inch or two above the key, the distance in which gravity accumulates momentum is greater, and the sound will be louder.[137]

The state of the limb at the point which gravity begins to affect it is also relevant. The amount of energy needed to move the limb laterally is more than would be required to depress several keys. It is possible to divert part of this energy of the limb downward in order to augment the force of gravity. Meinke speculated that the small movement sometimes observed by Ortmann and others to precede actual key movement is, in fact, a movement used to impart kinetic energy to the limb in order to produce the desired effect from the keystroke.[138]

Another type of momentum is the "equal and opposite reaction" concept of Newtonian physics. When the downward keystroke is arrested by the key bed, there is an immediate recoil of the key which sends force in an upward direction. This momentum can help position the limb for the next keystroke. The final type of momentum which may be utilized by the pianist is the intrinsic elasticity of the tissues of the limb. For example, if the pronated forearm is thrown upward for a short distance, the flexors of the wrist, hand, and fingers are slightly stretched and there is a natural tendency for these tissues to return to the position of minimal stretch.[139]

Meinke pointed out that there is frequently adverse momentum applied in piano playing. Expenditure of unnecessary energy must be minimized. A common example is the failure to recognize that sound may

137 Ibid, 54.
138 Ibid., 55.
139 Ibid.

not be altered after the point of sound has been reached. Any additional force applied (aside from natural follow-through of a motion assisted by gravity) after this point is passed is wasted effort.[140]

Meinke argued that no movement of the upper limb is actually straight, because movement around a joint is invariably an arc. In rapid play or wide leaps, this observation is confronted by another physical law that states that the shortest distance between two points is a straight line. The limb compromises by superimposing a rotary motion of the forearm on a larger motion made by the upper arm. Thus, the arc described by the forearm is relatively flat while that of the striking finger is more curved. Sudden abrupt changes in direction of motion are counterproductive. It takes much more energy to neutralize momentum in one direction and then generate momentum in another than it does to apply a small amount of force obliquely in order to gradually change the direction of movement.[141]

Many factors influence which sets of muscles in the limb are the most appropriate for a given pianistic task. They include the strength and speed required, the inherent biomechanical advantage in each set of muscles relative to the task, the repetitiveness of the motion, and the ability to take advantage of the momentum implied by muscles employed. Whatever is gained in speed and dexterity by using only the fingers or the fingers and hand is offset by significant losses of strength, mechanical advantage, the ability to use momentum to assist in the work, and, perhaps most importantly, the ability to resist fatigue. The relative importance of each of these factors will vary with the musical context in which the task is found.

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140 Ibid.

141 Ibid., 56.

Meinke generalized that the single most important factor that limits use of the fingers or fingers and hand alone is the inability of these small units to either generate or utilize momentum to assist work. The addition of the forearm to the finger and hand provides at least one large muscle (pronator) which adds resistance to fatigue and has the strength and mechanical capability to cover larger distances at the keyboard. At the other extreme, an attempt to play "from the shoulder" would entail unnecessary energy expenditure and would not provide the speed required for motion. There is a division of labor at work in the arm; the upper arm and shoulder generate kinetic energy while speed and control of the kinetic energy is provided by the forearm, hand, and finger. Since the muscles of the upper arm are large and the mass of the limb is great, a huge amount of kinetic energy may be imparted to the arm even though movements in the shoulder and upper arm which generate the energy are quite small.[142]

If the force used in piano playing is generated by the muscles of the upper arm, it follows that anything which interferes with energy conduction into the finger which is playing the key is detrimental. Thus, the wrist should be maintained in a neutral position as much as possible. The most useful vector of momentum for the keystroke and the movements which precede it, according to Meinke, is the central axis of the forearm to the fingertips. Any deviation of the wrist from neutral tends to dissipate that vector into other nonproductive directions. Additionally, as has been discussed, deviation from neutral wrist posture is a risk factor for developing CTS and other wrist disorders.[143]

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142 Ibid., 56-57.

143 Ibid.

Recommendations for Preventing Keyboard Injuries

Based upon the observations and statistical findings of performing arts medicine specialists, biomechanists, and ergonomists, there are many measures which pianists may take to prevent injury. Sudden increases in the time and/or intensity of practice have been conclusively linked to incidence of injury and are an easily controllable factor. The pianist should avoid practicing for prolonged periods. Instead, practice should be divided into segments of a maximum of 30 minutes with breaks taken between sessions. Before playing, the pianist should warm up body temperatures, since muscle and tendon tissues do not function well when cold. After playing, engaging in cool-down exercises will allow body tissues to gradually revert to a lower temperature and will prevent cramping and swelling. In order to maintain a healthy body, the pianist should participate in a conditioning activity which will not overtax or overbuild muscles. With this aim in mind, very strenuous weight training should be avoided in favor of activities which offer good general muscular conditioning and overall cardiovascular benefits.

In order to minimize risk of injury in the fingers, the pianist should avoid applying pressure after the key has "bottomed out" on the key bed since this practice has been shown to cause unnecessary joint and tendon stresses and will not contribute to sound production. Static finger or hand positions will likely lead to undue tension and inefficient motion; therefore, a variety of positions should be employed. To avoid forearm strain and elbow injury, pianists must be cautious when playing in the outer reaches of the keyboard. In this position, the upper limb is twisted and prone to injury when combined with greater application of force (as when playing forte) and repetition. The pianist can ameliorate this danger somewhat by keeping the spine elongated, and by abducting the elbow somewhat to keep the forearm, wrist, and hand aligned. Stress on the joints and muscles of the shoulder may be minimized by employing a seating position in which the elbows are parallel with or slightly above key level.

Several medical and biomechanical studies have shown a correlation between pianistic tasks which require maintaining a large hand span (octaves and chords) or skills which use a wide range of wrist motion (arpeggios and some trills) and injury, especially wrist injury. Therefore, care should be taken when using these motions. As much as possible, extreme flexion or extension at the wrist should be avoided since these motions cause increased carpal tunnel pressure, which contributes to the development of Carpal Tunnel Syndrome. Dropping the wrist below key level should also be avoided; increased carpal tunnel pressure has been shown with as little as 15° extension at the wrist. As discussed, increased carpal tunnel pressure may be one of the contributing factors in the development of Carpal Tunnel Syndrome. Wrist motions should be made gently and smoothly due to the demonstrated relation of sudden accelerations of wrist motion and injury.

In general, the pianist should develop a technique characterized by integrated, coordinated motions, so that forces are distributed throughout the anatomy instead of being localized. Avoiding jerkiness in motion will allow tendons and muscles to stretch gradually and smoothly, avoiding impulse loading. Momentum should be used to aid in the playing task. This includes the use of the free force of gravity in combination with kinetic motions of the limb, as discussed by Meinke. Where motion does not contribute to the task, it should be minimized or eliminated. The larger muscles of the upper arm and shoulder should be used to generate the kinetic energy need to move the upper limb over distances and provide strength and endurance. The forearm, hand, and fingers should be used to control this kinetic energy and provide speed for rapid movements at the level of the key. The need for this kinetic energy to pass unimpeded from the upper arm to the fingertips offers an additional reason to maintain neutral wrist position. The pianist should avoid abrupt, arresting, or jerky motions in changing the direction of movement. Abruptly changing direction requires much more energy than does applying a small amount of force obliquely to gradually change direction. Curvilinear motions should be used since movements through joints always describe arcs; curvilinear motion is especially important in covering distances at the keyboard, as when playing large leaps.

Because repetitive motion has been suggested as one of the factors which directly contribute to injuries, the pianist should attempt to use a variety of motions. Practice segments should be varied so that the pianist is not practicing the same physical motion (or by extension, the same musical passage) repeatedly. Finally, pianists should always be conscious of the relationship between experience and proclivity toward injury. When learning a new motion or skill, the player is most vulnerable to injury, and extreme care should be taken so that injury does not result.

CHAPTER V

CONCLUSION

The Need For Biomechanical Analysis of Piano Technique

Focusing on human anatomy as a critical factor in piano technique is a somewhat recent innovation. Only since the late-nineteenth and early-twentieth centuries have pedagogues begun to address the motions of piano playing from a scientific or objective perspective. Some of their beliefs have been validated by later scientific observation. For example, Ortmann's strong opinion that abruptly changing direction of movement requires undue energy expenditure has been supported by ergonomic studies. However, many of these pedagogues based their recommendations upon an incomplete or even incorrect knowledge of anatomy and human motions. Their terminology in discussions concerning anatomy is frequently imprecise. For example, Pichier refers to the trapezius as the "hood muscle." Moreover, many of the recommendations of these pedagogues are contradicted by medical, biomechanical, and/or ergonomic observations. For instance, the "after-motion" recommended by Pichier is unnecessary, and therefore represents wasted effort. Additionally, this motion may place undue forces upon the flexors of the fingers and hence be potentially harmful. Likewise, Pichier's recommended hand position using the "vaulted hand" with the finger bones spread and the finger ligaments taut may lead to the development of undue tension and restricted finger movement. Deppe's idea of total relaxation has been replaced with the concept of economy of muscular effort with support provided by various parts of the playing apparatus. Whiteside at times overemphasized the role of the upper arm in piano playing, neglecting the smaller, faster motions provided by the fingers. As has been demonstrated, much of the advice given by well-known piano pedagogy experts is based on an imprecise understanding of anatomical function and thus must be regarded with caution. Some of the practices and techniques recommended by these pedagogues has potential to do harm.

Since the invention of the pianoforte, pedagogues have advocated repeatedly practicing exercises consisting of commonly encountered pianistic skills. Recently, however, the efficacy of using technical exercises isolated from repertoire has been widely debated. While many pianists continue to advocate using them, other pianists have pointed out that mastery of a given task may not translate to mastery of a similar task encountered in repertoire. This view is supported by studies from the field of motor studies, which demonstrate that repeated practice of the same task with little variability imposed has no impact upon retention of skill, and can actually be detrimental when transferring the same skill to a novel situation.

In addition to their questionable effectiveness, some technical exercises are potentially physically dangerous. Perhaps the most glaring example of biomechanically inappropriate motion at the piano is the traditional insistence upon practicing finger-independence exercises. As discussed, the fingers are not equal in strength due to their mechanical design. The fourth finger is especially limited in its independence. The extensor tendons which control the third, fourth, and fifth fingers are interconnected. Moreover, the small intrinsic muscles and tendons of the hand are relatively mechanically weak. Since the power and endurance for playing comes from the more proximal parts of the upper limb, namely the shoulder, upper arm and forearm (in order of greater relative strength), there is no need to build strength in the fingers themselves. Instead, there is a need to develop speed and control of finger motions. This requirement is best answered by striving for coordination of all parts of the playing apparatus, including the fingers, rather than by brute strengthening of the fingers.

Pianists suffer from a variety of injuries which may be directly ascribed to practicing and/or performing. These include muscular maladies, tendinitis, tendon entrapments, nerve entrapments, focal dystonias, and a host of other injuries. An injury is not necessarily the result of inappropriate technique. As discussed, individual genetic predisposition toward injury plays a central role in injury development. Some individuals simply seem to be injured more easily than others. However, there are some easily controllable factors which are related to injury development. The single most important recommendation to prevent injury is to avoid a sudden increase in the amount or intensity of practice. Other easily controllable factors include the need for warming up muscles to their optimal functional temperature and cooling them down after practice is concluded to prevent muscle soreness and cramping. A number of biomechanical and ergonomic studies have identified specific positions and motions as risk factors for the development of certain injuries; thus, these positions (which are discussed in Chapter IV) should be viewed as potentially hazardous and avoided, especially for prolonged use. A list of general recommendations for preventing overuse injury, including the most potentially hazardous motions, is provided in Figure 5.1.

It would be futile to attempt to describe in great detail the motions used by an individual player to accomplish a given skill. After all, every human body has slight idiosyncrasies and variations. However, apart from these

- Avoid sudden increases in the time and/or intensity of practice.
- Divide practice into segments of 30 minutes with breaks interposed between segments.
- Use warm-up and cool-down exercises.
- Participate in a general conditioning exercise program.
- Avoid applying additional force after the key has "bottomed out."
- Avoid using a static hand or finger positions.
- Be especially cautious when playing in the outer reaches of the keyboard.
- Employ a seating position in which the elbow is parallel with or slightly higher than key level.
- Be cautious when executing tasks which require prolonged use of the hand extended to its full span or tasks which use a wide range of wrist motion.
- Avoid extreme flexion or extension of the wrist.
- Use smooth, coordinated motions. Avoid using jerky motions.
- Use momentum, including the free force of gravity, to aid in playing.
- Avoid abruptly arresting any motion.
- Avoid repetition of the same motion. Vary practice sessions.
- Be aware of the inverse relationship between level of experience and proclivity toward injury.

Figure 5.1. General Recommendations for Prevention of Piano-Related Overuse Injuries

individual differences, all human beings are constructed in basically the same way. Therefore, it is possible to derive general biomechanical observations which will apply to all pianists and can aid in building appropriate technique which should hypothetically lower the risk of injury by avoiding motions specifically identified as potentially hazardous. It is important to note that this type of biomechanical analysis can offer only visual information to the observer; it cannot inform the observer how motion feels to the player. Therefore, it is imperative that guidelines be used as just that; rigid adherence to these guidelines might actually contribute to tension or the use of inappropriate motions. However, if there are obvious visual cues of inefficient technique, biomechanical guidelines can help focus attention on certain areas of the playing apparatus.

Instructions for Performing Qualitative Analysis

Qualitative analysis can be used very effectively in examining piano technique. Instead of directly measuring and quantifying data, qualitative studies seek instead to describe and analyze the quality of movement. Qualitative analysis is generally conducted by visually observing a performance.

In order to conduct a qualitative analysis, basic knowledge of involved human anatomy and mechanical principles is necessary as is a thorough understanding of the motor skill or movement pattern to be analyzed.[1] Though skilled performers are usually better equipped to analyze the quality of a performance, this is not always the case. The best pianists do not always make the best teachers. Instead of relying solely upon personal experience,

[1] Susan J. Hall, *Basic Biomechanics* (St. Louis: Mosby-Year Book, 1991), 450.

the piano teacher should consider relevant biomechanical and ergonomic considerations in teaching piano technique. The checklists offered later in this chapter have integrated these factors and should aid teachers in making appropriate adjustments to an individual student's technique. There are several ways in which to pursue information about a given movement and the factors which affect it. One is to read pertinent articles from biomechanics research literature and from musical journals. One should remember that many of the movement patterns used in piano playing are subtle and complex; not all of these patterns have been researched. It is important to distinguish between articles based upon research and those based purely upon opinion.[2]

Performer characteristics affect performance of a movement. These characteristics include the performer's age, gender, anthropometry, and developmental and skill level. Other special considerations, such as learning style or personality type, may also impact performance. Other factors, such as whether the performer has recently experienced emotional upheaval, or is tired, may also need to be considered. When working with small children, basing observations upon adult norms may be counterproductive; children are not scaled-down adults.[3]

It is equally important to follow a protocol in conducting a qualitative analysis. The number of procedural factors which must be considered increases with the complexity and desired degree of mastery of the movement being considered. Since movement patterns involved in executing skills at the piano often occur on multiple planes, it is often necessary to observe

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2 Ibid., 451.

3 Ibid., 452-53.

movement in all the involved planes.[4] In the case of piano performance, motions are made in the frontal, sagittal and transverse planes. Most of these motions may be observed from the side of the player at the level of the keyboard, or from a top view looking down on the hands on the keyboard. These positions allow for the observation of motions in the sagittal and transverse plane, and to some extent, the frontal plane. Another perspective which may be informative is from directly behind the player, where motions in the frontal plane may be observed when not obscured by the player's torso. This may necessitate the participation of more than one viewer; videotaping can also be used with the same result. In fact, videotaping may be the better option since it minimizes variation in subjective response of multiple observers, and multiple cameras may be employed to record motion in all planes simultaneously. Viewing distance must be carefully considered and may need to be adjusted during the course of the analysis. The observer may need to focus attention on a specific small part of the anatomy, or concentrate on larger areas. Attention to eye movements of the performer may also yield helpful information; a movement may be uncoordinated simply because the performer is not looking in the right part of the keyboard. Another factor to consider is the number of trials or executions of the movement which should be observed before an analysis is undertaken. Highly-skilled performers may vary little from performance to performance, but less-skilled performers typically exhibit a large degree of variation. The greater the inconsistency in the performer's technique, the larger the number of observations which should be made.[5]

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[4] Ibid., 452.
[5] Ibid., 455.

It is important to remember that nonvisual cues can be useful in conducting qualitative analysis. The sound produced by a given movement can provide vital information about the relative success of the movement. For instance, is the sound harsh? Are there rhythmic inconsistencies? Perhaps the most important source of information is the performer him/herself. Since only the performer knows how a movement feels, his/her feedback is invaluable. However, it is important to note that not all performers are sufficiently kinesthetically attuned to their bodies to provide meaningful feedback. Moreover, often learning a new skill involves a certain degree of incoordination due to unfamiliarity (note, this incoordination or discomfort should not be confused with actual physical pain).

Generally, the first step undertaken in a qualitative analysis is the formulation of a major question or questions of interest. This may involve determining which motions or movement patterns are to be observed. The second phase of analysis involves studying the questions of interest and hypothesizing about the interplay of mechanical principles, anatomical, environmental, and morphological constraints, and practical considerations of the movement.[6] A useful, easily applied, systematic qualitative analysis will describe first what should happen, then what actually happens based upon observation. Finally, by comparing expectations with outcomes, the analysis should evaluate the performance and describe feedback appropriate for modifying subsequent performance. These steps describe the preobservation, observation, and postobservation phases of a qualitative analysis.[7] A worksheet detailing the procedure for conducting a subjective

[6] Ibid., 459.

[7] J.R. Higgins, *Human Movement: An Integrated Approach* (St. Louis: Mosby-Year Book, 1977), 126.

qualitative analysis was developed by J.R. Higgins and is provided in Figure 5.2.

The descriptions offered in Chapter III outline the preobservation phases for qualitative analyses for various movement patterns performed at the piano. These descriptions define the goal of the movement pattern, offer a breakdown of the component motions of a pattern, and describe the sequence in which these motions occur. With these basic norms in hand, the piano teacher will be able to observe an individual student performing one of the described skills and conduct a qualitative analysis based upon this assessment. For the convenience of the teacher, checklists for performing these skills are offered in Tables 5.1-5.7. The scale as described (Table 5.1) begins on a white key and is played hands-together for a distance of four octaves. The goal in scale playing is smooth linear projection of single notes with no rhythmic inconsistencies, tempo fluctuations, or accents. The arpeggio described (Table 5.2) also begins on a white key and is executed hands-together for four octaves. The goal is the same for scale playing. Trills (Table 5.3) involve rapid alternation of two adjacent keys on the keyboard with the goal of projecting both notes of the trill. Double-third scales (Table 5.4) involve simultaneously playing thirds in one hand in a scale. The goal is similar to that of a single-note scale: smooth linear projection of the double thirds with no rhythmic inconsistencies, tempo fluctuations, or accents. The octave scale (Table 5.5) is executed by one hand alone and has a goal similar to that of double thirds. The broken chord (Table 5.6) pattern described involves playing the tones of a major triad one note at a time from bottom to top in one hand alone. After the root position is played (four notes: root, third, fifth, and next root), the pattern ascends one

I. Pre-observation: What the observer expects to find. Classify, describe, and analyze the movement to be observed and relate the expected observation to the performer.

A. How would you classify the movement?
   1. Discuss the goal of the movement.
   2. Consider the role of the environment and spatial and temporal components and constraints.
   3. Describe the type of movement to be observed.

B. What is the most general (primary) method of decomposing this skill?
   1. Identify the categories of events or movements; break the movement into its more basic parts or phases.
   2. Provide a general description of the movement.

C. What is the second order of decomposition of the movement?
   1. Describe the movements in each category or phase in terms of the linear and angular kinematics, segmental and/or joint actions, shape considerations.
   2. Describe the movements in each category or phase in terms of of the linear and angular kinetics, temporal factors, effort considerations.

D. What is the third order of decomposition? Identify the appropriate biomechanical, kinesiologic, physiologic, aesthetic, strategic, and morphologic correlates of each phase of the movement.

E. What parts of the movement are essential for successful performance?
   1. Define the critical features of the movement for the observer and the performer to focus upon.
   2. Identify the parts of the movement that ther performer can most easily and least easily modify.

II. Observation: What is actively occurring during each trial. This should be systematic and include direct observation (perhaps videotaping).

A. Record observations systematically.

B. Be sure to note:
   1. The specific objective of the performer on each trial.
   2. If the performer executed the movement as he planned on each trial.
   3. Any extraneous movements.
   4. The direct environmental influences (spatial and temporal constraints).
   5. The indirect environmental influences (noise, attire, equipment, etc.).

III. Post-observation: Evaluation and feedback considerations made by the observer.

A. What single aspect of the performance was most noticeable?
   1. Note good and bad features of the movement.
   2. Address spatial and temporal components of the movement.
   3. Consider body position, joint and segmental action, etc.

B. Was the movement coordinated and efficient?
   1. Was the goal attained? (Consider observer's versus performer's assessment)
   2. Did the performer execute the movement the way he/she planned?
   3. Were there extraneous movements?
   4. Was the movement smoothly executedfrom phase to phase?

Figure 5.2. Worksheet For Conducting Subjective Qualitative Analysis of a Skill

III. C. What environmental factors appeared to affect this performance?
   1. Relate appropriateness of the movement and movement strategy to the type and condition of the environment.
   2. Discuss effectiveness of the performer's movement in matching environmental constraints.
   3. Identify and consider indirect environmental influences.

D. What is the most appropriate feedback to provide to the performer?
   1. Identify and consider feedback related to the movement, outcome of the movement, and skill level of the performer.
   2. List the hierarchical order for the presentation of the feedback.
   3. Consider the appropriate time for providing feedback.

Figure 5.2 Continued

Source: S. Arend and J.R. Higgins, "A Strategy for The Classification, Subjective Analysis, and Observation of Human Movement." *Journal of Human Movement Studies,* 2 (1976): 49-50.

Table 5.1. Checklist for Scales+

MOTION CATEGORY	MOTION DESCRIPTION
General Motions:	
Spine	Remains aligned with hips during ascent and descent
Torso	Shifts smoothly from left to right, moving slightly ahead of the arms
Shoulder	Not raised
Upper Arm	Abducts gradually as outer reaches of the keyboard are approached. Guides rest of arm in direction of scale ascent or descent.
Forearm	At right angles to the keyboard
Elbow	Not active. Remains loose, moving in direction of upper arm. Describes a "flattened" circle.
Wrist	Slightly above or level with forearm. Makes slight vertical and lateral adjusting motions smoothly without jerks.
Hand/Fingers	Fingers gently and naturally curved and not applying force to key after it has been depressed. Each finger releases its key as the next key is depressed. MCP joints are slightly flexed to support the arch of the hand. Neither the thumb nor the other fingers drop below keyboard level at any time. Fingers do not all contact the key in the same location relative to the fallboard; the longer fingers contact the key farther from the edge respectively according to length while the thumb plays closer to the edge.
Sequence of Motions: Right Hand Ascent/ Left Hand Descent	1. Hand begins in a position of ulnar deviation. There is more radial deviation and less ulnar deviation as the outer octaves are approached. 2. After the thumb plays the first note, it abducts first behind the second, and then the third fingers. It hangs in a relaxed position and is not grasped against the palm. 3. As the second and then the third fingers play, there is slight radial deviation and lifting of the hand. This causes slight wrist flexion. This motion is less pronounced as the outer register is approached. 4. As the third finger plays, the thumb approaches the next key, aided by slight pronation. 5. As the third finger releases, the thumb drops onto its note aided by the forearm and the wrist resetting to their neutral positions. At faster tempos, the slight gap at this hand shift will be inaudible. 6. There is slight radial deviation and lifting of the hand as the fourth finger is approached as the thumb lines up behind the second then the third fingers. 7. As the fourth finger plays, the thumb is hanging behind the third finger. The forearm is lifted and pronated slightly to aid in placing the thumb on its note.

+ For complete biomechanical description, refer to Chapter III, pp. 109-118.

Table 5.1 Continued

Right Hand Ascent/ Left Hand Descent continued	8. As the fourth finger releases, the thumb is dropped onto its key aided by lateral resetting of the hand and forearm to neutral position.
Left Hand Ascent/ Right Hand Descent	1. The hand begins with the wrist in a neutral position. There is more ulnar deviation as the middle of the keyboard is approached. 2. As the thumb is approached, the hand and wrist rise slightly. 3. As the thumb plays, it rolls over onto its thumbnail. A small, but rapid pronation is effected, throwing the third finger over the thumb and resulting in radial deviation. 4. As the third finger plays, the hand moves past neutral into a position of ulnar deviation as the thumb is approached again. This ulnar deviation becomes more pronounced as the middle of the keyboard is approached. 5. In passing the fourth finger over the thumb, there is more pronounced radial deviation and pronation to allow the fourth finger to land on its key.

Table 5.2. Checklist for Arpeggios+

MOTION CATEGORY	MOTION DESCRIPTION
General Motions:	Same as for scale (refer to Table 5.1) with adjustments made to accommodate extra distance covered. The elbows are maintained farther out from the torso. The hand is arched less and the fingers are more spread apart. Forearm and wrist generally remain aligned, with fewer lateral wrist motions.
Sequence of Motions:	
Right Hand Ascent/ Left Hand Descent	1. At outset, hand is in position of ulnar deviation. There is less ulnar deviation and more radial deviation as the outer reaches of the keyboard are approached. 2. After the thumb plays, it adducts behind the second then the third finger, but to a lesser degree than in the scale. 3. Gradual radial deviation accompanies adduction of the thumb. 4. The hand rises slightly toward the fallboard and the forearm pronates slightly to allow the thumb to approach its key. 5. As the third finger plays, the hand lifts and is propelled into its new position in the next octave by the arm. The hand is not lifted high, but instead describes a short, shallow arc. 6. The pattern continues.
Left Hand Ascent/ Right Hand Descent	1. Wrist begins in a neutral position. More ulnar deviation is observable toward the middle of the keyboard. 2. The fifth finger plays. As the thumb is approached, there is slight gradual ulnar deviation accompanied by forearm pronation. 3. As the thumb plays, the pronation continues, lifting the hand (which causes wrist flexion) and propelling the thumb under the third finger. 4. The third finger descends onto its key aided by gravity. As the third finger lands, the hand resets itself to neutral with the thumb emerging from beneath the hand.

+ For complete biomechanical description, refer to Chapter III, pp. 128-132.

Table 5.3. Checklist for Trills+

MOTION CATEGORY	MOTION DESCRIPTION
General Motions:	Weight suspended, but muscles of the upper back and shoulders are not strained Upper arm remains loose Forearm is at right angles to the keyboard. Forearm forms a straight line with the midpoint between the two active fingers Wrist is slightly flexed so that the bones and joints of the active fingers are in a position for maximum stability and leverage, freeing extensor tendons from unnecessary work. Hand is free of tension Fingers are curved naturally. Small finger motions are the impetus for trills. Unused fingers do not contact keys. Radial or ulnar deviation is required according to whether the trill is high (radial deviation) or low (ulnar deviation) on the keyboard and whether black keys are involved. In trilling from white key to white key, fingers play closer to key edge. If black keys are involved, the hand is positioned more toward the fallboard, sometimes even on top of the black keys. Player may make slight backward/forward adjustments with the arm or flexion/extension motions with the wrist while trilling to maintain velocity. Using too much forearm rotation will slow or stop trill Using too much arm weight will slow or stop trill

+ For complete biomechanical description, refer to Chapter III, pp. 141-145.

Table 5.4. Checklist for Double-Third Scales+

MOTION CATEGORY	MOTION DESCRIPTION
General Motions:	
Spine	Spine aligned with hips throughout
Torso	Torso shifts from side to side along with center of gravity. Torso moves slightly ahead of the arms
Shoulders	Shoulders are not raised
Upper arm	Upper arm provides direction, abducting gradually as extremes of the keyboard are approached. Makes forward/backward adjustments to allow for playing of black keys.
Forearm	Guides motion of scale
Wrist	Wrist is maintained in a relatively straight line between the hand and the forearm. It makes slight rebounding motions (small flexions and extensions) as each third is depressed. There is little to no lateral wrist motion.
Hand and Fingers	Palm maintained in relatively open position throughout, but not rigidly.
Sequence of Motions:	1. The hand begins in a position of ulnar deviation. As the hand ascends, there is some radial deviation, but less than in a single-note scale. 2. After each third is depressed, the fingers rebound. They remain extended and ready for use, but the joints are loose between key depressions. When playing double-third scales at a fast tempo, the fingers appear to "flutter." 3. To effect the hand shifts, the entire hand is lifted from the keyboard and propelled into the new position by the forearm.

+ For complete biomechanical description, refer to Chapter III, pp.161-163.

Table 5.5. Checklist for Octave Scales+

MOTION CATEGORY	MOTION DESCRIPTION
General Motions:	
Spine	Spine aligned with hips throughout
Torso	Torso shifts from left to right along with the center of gravity
Shoulder	Shoulders not raised
Upper arm	Upper arm makes marked backward and forward adjustments to reach black keys. These motions should be made smoothly, not in sudden jerks. Upper arm also guides direction of forearm.
Elbow	Not actively involved; remains loose
Forearm and Wrist	Provides impetus for keystroke. Sends small impulses through the wrist, which results in visible extensions and return to neutral wrist position with each keystroke. Forearm, wrist, and hand are laterally aligned with the wrist slightly higher than the forearm.
Hand and Fingers	Since the thumb is used continuously, the hand is in a position of ulnar deviation throughout. The arch of the hand is somewhat flattened, especially in a small hand, but is still present. Between each keystroke, the hand remains open between the PIP joints of the playing fingers. However, the palm is not rigidly maintained, but rebounds slightly between each key stroke. The unused inner fingers may contact the keys without producing a sound as each octave is depressed.

+ For complete biomechanical description, refer to Chapter III, pp.164-166.

Table 5.6. Checklist for Broken Chords+

MOTION CATEGORY	MOTION DESCRIPTION
General Motions:	
Spine	Spine aligned with hips throughout
Torso	Torso shifts from left to right with center of gravity
Shoulders	Shoulders not raised
Upper arm	Upper arm makes backward and forward adjustments to allow for playing of black keys. Gives direction to forearm
Elbow	Not actively involved; remains loose
Forearm	Supinating and pronating motion less pronounced than in broken octaves, but is still observable
Wrist	Lateral adjusting motions
Hand and Fingers	Fingers not lifted high over the keys
Sequence of Motions:	1. After the thumb plays, there is a slight radial deviation when moving toward the fifth finger. This motion is accompanied by a slight lifting of the hand, resulting in slight wrist flexion. 2. After the fifth finger plays, there is a resetting of the hand (slight ulnar deviation) in positioning the thumb over the first note of each new inversion. The smaller the hand, the more lateral wrist motion is observable. 3. The combination of lateral and vertical wrist motions results in a flattened circle described on the frontal plane.

+ For complete biomechanical description, refer to Chapter III, p. 171-172.

inversion at a time. The goal is even projection of tones with no rhythmic inconsistencies, tempo fluctuations, or accents. Finally, broken octaves (Table 5.7) involve alternate sounding of the two voices of an octave with the same hand in a scalar (ascending and descending) progression. The goal is the same as that of the other types of scales described.

There are several crucial considerations to be remembered in using these checklists. The first is that the checklists may be used to analyze the movement pattern either as it occurs in an isolated technical exercise, or within repertoire as long as the passage has the same skill parameters as that described in the checklist. The second consideration is that hand size will affect motion at the piano, most notably, lateral adjusting motions effected by the wrist. In general, the smaller the hand, the greater the required degree of radial and ulnar deviation. Another factor to consider is that variations in tempo will affect observable motion. In general, the slower the tempo, the more pronounced and visible the motion. When executing the movement pattern at a faster tempo, the same motions are usually still present; however, the motions become smaller and sometimes even invisible. Fourth, sometimes attempting to think about and consciously integrate motion can actually cause tension. In this way inappropriate technique can actually be promoted. In working toward a desired sound or movement, it is essential for the student to remain conscious of physical comfort.

Finally, and most importantly, these checklists should be used only as a tool for developing injury-preventative, effective technique. They should not be rigidly followed or used prescriptively; within the general movement pattern described, there is still room for individual execution variation and interpretation. In fact, teachers must be careful recommending a change in a

Table 5.7. Checklist for Broken Octaves[+]

MOTION CATEGORY	MOTION DESCRIPTION
General Motions:	
Spine	Spine is aligned with hips throughout
Torso	Torso shifts from left to right with the center of gravity
Shoulders	Not raised
Upper arm	Upper arm makes backward and forward adjustments to allow for the playing of black keys. These motions should be smooth, without any jerks.
Elbow	Not actively involved; remains loose
Forearm	Pronation and Supination
Wrist	Some vertical rebounding, little or no vertical motion
Hand and Fingers	Maintain loose shape; not rigid
Sequence of Motions:	Broken octaves are accomplished by alternately pronating then supinating the forearm with the wrist and fingers remaining aligned with the forearm. There is little or no vertical motion made by the wrist. Ulnar deviation of the hand is present in both the ascent and descent due to the continuous use of the thumb

[+] For complete biomechanical description, refer to Chapter III, pp. 172-173.

student's technique based upon these guidelines. Even if the student differs from the norm, an adjustment in technique may not be called for if the student feels completely comfortable and no injury has been sustained; this is especially true for students with many years of playing experience. However, some motions, such as extreme flexion or extension at the wrist, should be corrected even in experienced players due to the great potential for injury. While some motions have clear potential for damage, other motions may or may not be changed based on comfort benefits for the student. The teacher must weigh the student's level of experience and consider the potential of any motion outside the norm to cause injury before recommending a change. The background information provided concerning anatomy and potentially hazardous motions and habits (Chapters III and IV) and the list of preventive recommendations (Fig. 5.1) will aid the teacher in making an informed judgment.

Undertaking systematic qualitative analysis of movement patterns performed at the piano can offer valuable information in developing or modifying piano technique. In developing technique, students and teachers have typically relied primarily upon recommendations of skilled performers. However, as may be seen in the review of twentieth-century piano pedagogues, advice offered by individual players is most often based upon their own subjective experiences. Though such recommendations may prove helpful, in some cases, they may actually be counterproductive to the development of biomechanically appropriate piano technique. Understanding of human anatomy has vastly improved in the last hundred years. With input from the recently developed sciences of ergonomics and biomechanics, it is now possible to examine piano technique in order to determine how the human body may be used maximally and most efficiently. Since medical, biomechanical, and ergonomic studies have demonstrated that some physical motions, most notably extreme wrist motions, can contribute to the development of an injury, it is worthwhile to examine piano technique with the aim of minimizing these motions.

Suggestions for Further Research

Scientific observations regarding human motion continue to be generated at an ever-increasing rate. However, there are many vital questions which remain with regard to piano technique. Though range of motion has been normalized for most of the joints of the body, and studies have quantified the range of motion used by some joints used in playing the piano, there have been no studies conducted which examine the link between range of motion at the piano and the development of injury. Likewise, though biomechanical and ergonomic studies have concluded that certain physical motions contribute to injury development, it has yet to be determined how frequently and for what periods of time these motions must be used in order for an injury to result. This issue is complicated by the differences between in vitro versus in vivo tissue studies; scientists are still working to account for these variations. Though the nature of tendons has been extensively studied, at least in vivo, few studies have addressed muscle fiber tensile strength. Since many injuries suffered by pianists affect muscles, or muscle-tendon units, such studies might offer essential information about muscular tolerances at the cellular level. Studies need to be undertaken to determine whether there is a correlation between strength and occurrence of injury so that the role of strength conditioning, especially as it pertains to the fingers, may be defined. Quantified analysis of various motions employed at the piano would help answer whether those motions exceed biological tolerances. Studies which examine the correlation between hand measurements and/or characteristics and overuse injury might allow for identification of those players likely to develop an injury and thus aid in prevention. Finally, scientific studies of the biomechanical relationship between the parts of the playing apparatus could offer a general dynamic model for playing the piano.

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APPENDIX A

GLOSSARY OF TERMS

Abduction–moving a part of the body away from the median axis, which runs vertically through the middle of the torso, or away from another body part. Used in specific reference to the fingers, refers to moving the fingers away from the third finger, which is the median axis of the hand.

Adduction–to move or pull a part of the body toward the median axis, or toward another body part.

Acromioclavicular joint–connection of the distal top edge of the scapula with the distal end of the clavicle.

Anatomically neutral position–the erect standing position with all body parts, including the palms of the hands, facing forward; used as a starting position reference for discussion of body part movement.

Anterior–toward the front of the body; located on the front side.

Bicep–muscle of the radioulnar and glenohumeral joints which has two heads. The long head assists with abduction while the short head assists with flexion, adduction, inward rotation, and horizontal adduction at the shoulder.

Biomechanics–the field of study which investigates motion and the application of internal and external forces which occur during actions performed by living or once-living organisms.

Carpometacarpal (CM) joints–articulations between the bones of the wrist and the first metacarpals of the hands; the CM joint of the thumb is a classic saddle joint while the other CM joints are gliding joints.

Circumduction– movement of a limb around an axis so as to describe an imaginary cone. Combines flexion, extension, hyperextension, abduction, and adduction.

Clavicle–the collarbone; there are two, joined on either side of the sternum at the proximal end and the scapula at the distal end.

Concentric Muscular Action–results in the shortening of the muscle thereby pulling the attached bones closer together and causing a change in the angle of the joint between the bones.

Coracoclavicular joint–connection of the proximal top edge of the scapula with the underside of the clavicle.

Deltoid–muscle of the glenohumeral joint which is divided into three segments: (1) anterior, which is responsible for flexion and horizontal adduction, (2)middle, which is responsible abduction and horizontal abduction, (3) posterior, which extends and horizontally abducts the humerus.

Diagonal plane–any plane oriented diagonally to the traditionally recognized sagittal, frontal, or transverse planes.

Distal–farther away from the center of the body.

Distal interphalangeal (DIP) joints–the hinge-type articulations closest to the fingertips.

Eccentric muscular action–results in the lengthening of a muscle as tension is developed. Eccentric muscular action acts as a braking mechanism when lowering a weight.

Electromechanical delay (EMD)–the pause between nerve stimulus to a muscle and the point at which the muscle starts to develop tension.

Epicondyle– one of the two rounded parts at the distal end of the humerus to which muscles and tendons are attached, which forms a ball-and-socket with the elbow joint. The medial epicondyle is located closest to the trunk while the lateral epicondyle furthest away.

Ergonomics–the applied science of equipment design, as for the workplace, intended to maximize productivity by reducing operator fatigue and discomfort. Also called biotechnology, human engineering, human factors engineering.

Extension–the act of straightening a segment back to its anatomically neutral position; opposite of flexion. Produced by tension on one side (generally the bottom) of the segment and compression on the other side (generally the top).

Extrinsic muscle–a muscle which originates outside the anatomical part it controls.

Fast twitch (FT)–a type of muscle fiber which reaches peak tension and relaxes roughly twice as fast as slow twitch types. Most effective in activities which require fast, powerful motion.

Flexion–the act of bending a segment; opposite of extension. Produced by tension on one side (generally the top) of the segment and compression on the other side (generally the bottom).

Frontal plane–the plane in which lateral movements toward and away from the midline of the body occurs; divides the body into a front and rear section.

Glenohumeral joint–the primary joint of the shoulder connecting the scapula to the humerus.

Humerus–the bone of the upper arm situated between the shoulder and the elbow.

Hyperextension–the act of extending a body segment past the anatomically neutral position.

Intrinsic muscle– a muscle which originates within the anatomical part it controls.

In vitro–outside the living organism.

In vivo–within the living organism.

Isometric muscular action–Muscular tension is developed with no resulting change in muscle length. Developing isometric tension simultaneously in muscles on opposite sides of a limb (agonist and antagonist) results in the enlargement of the tensed muscles with no resulting movement.

Kinesiology–the field of study which investigates human movement.

Metacarpals–the bones of the hand.

Metacarpophalangeal (MCP) joints–the articulation between the rounded distal heads of the metacarpals and the concave proximal ends of the phalanges; imprecisely referred to by many piano pedagogues as the "hand knuckles."

Parallel–with regard to muscle fiber architecture, a configuration in which muscle fibers are oriented parallel to the longitudinal axis of the muscle.

Pennate–with regard to muscle fiber architecture, a configuration in which muscle fibers are arranged obliquely in relation to the muscle's longitudinal axis.

Phalanges–the finger bones.

Posterior–toward the back of the body; located on the back side.

Pronation–rotation of the forearm palm downward, which crosses the radius over the ulna.

Pronator quadratus–the muscle primarily responsible for pronating the forearm, which attaches to the distal ulna and radius.

Pronator teres–muscle crossing the proximal radioulnar joint which assists the pronator quadratus in pronation if the motion is resisted or rapid.

Proximal–closer to the center of the body.

Proximal interphalangeal (PIP) joints–the hinge-type articulations between the metacarpophalangeal joints and the distal interphalangeal joints.

Radial deviation–lateral motion at the wrist toward the thumb, i.e. the hand moves toward the radius; opposite of ulnar deviation.

Radiocarpal joint–the articulation between the radius bone and three of the proximal wrist bones.

Radius–one of the two bones of the forearm, located on the thumb side of the forearm.

Sagittal plane–the plane in which forward and backward movements of the body and body segments occurs; divides the body into right and left sections.

Scapula–the flat triangular bone in the back of the shoulder generally known as the shoulder blade.

Slow twitch–a type of muscle fiber which takes roughly twice as long as the fast twitch type to reach peak tension and relax. Most effective in activities which require muscular endurance.

Sternoclavicular joint–connection of the proximal end of the clavicle with the sternum and with the cartilage of the first rib; serves as the major axis of rotation for movements of the scapula and clavicle.

Supination–rotation of the forearm palm upward.

Supinator–the muscle primarily responsible for forearm supination, attached to the lateral epicondyle of the humerus and to the lateral proximal third of the radius.

Transverse plane–any plane that divides the body into an upper and lower section.

Trapezius–a large, flat triangular muscle that extends over the back of the neck and thorax, originating at the occipital bone at the base of the skull and attaching to the lateral third of the clavicle and the upper and medial borders of the scapula.

Ulna–one of the two bones of the forearm, located on the fifth finger side of the forearm.

Ulnar deviation–lateral motion at the wrist toward the fifth finger, i.e., toward the ulna; opposite of radial deviation.

APPENDIX B

ADDITIONAL ANATOMIC FIGURES

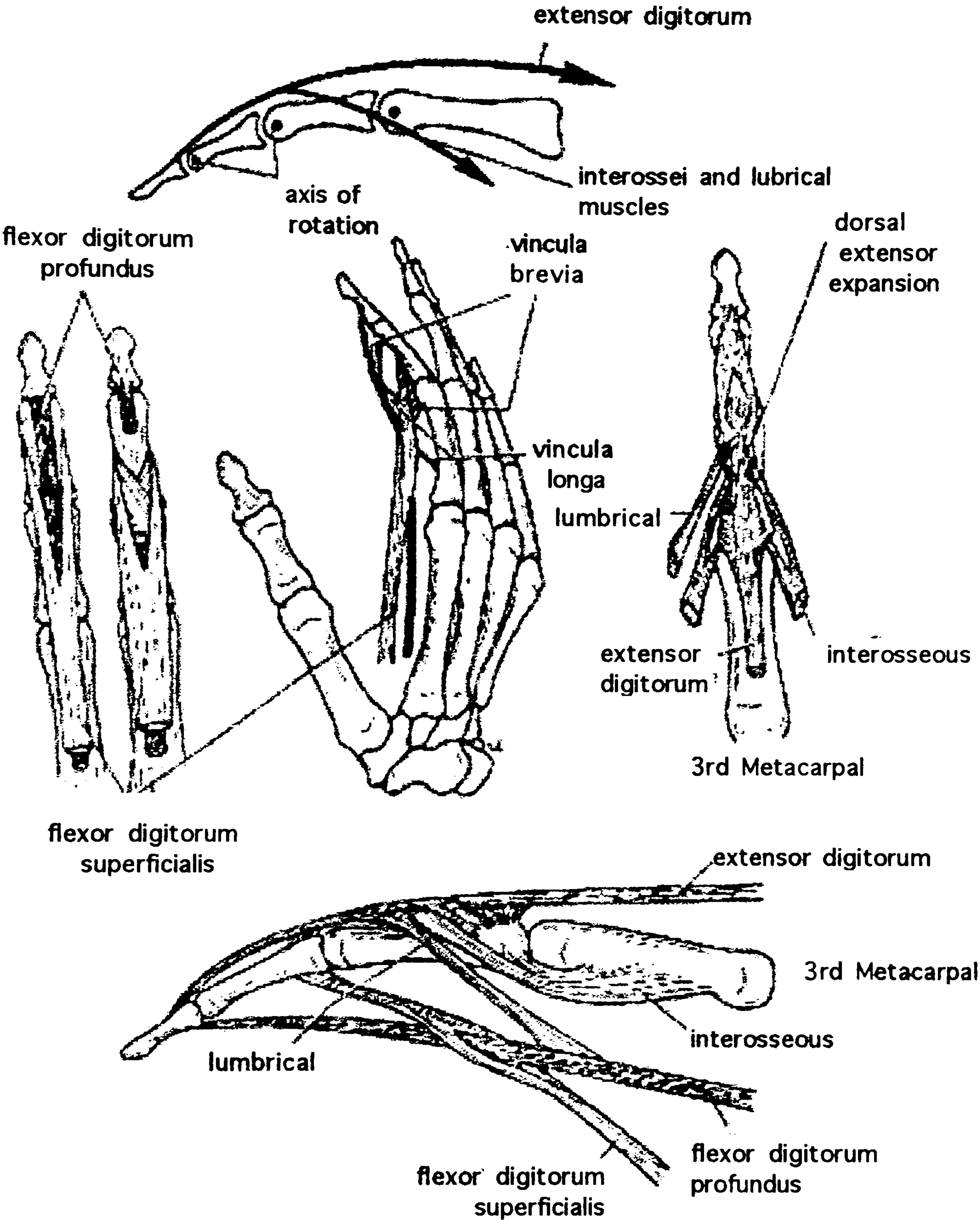

Figure B.1. Insertions of Long Flexor and Extensor Tendons in the Fingers

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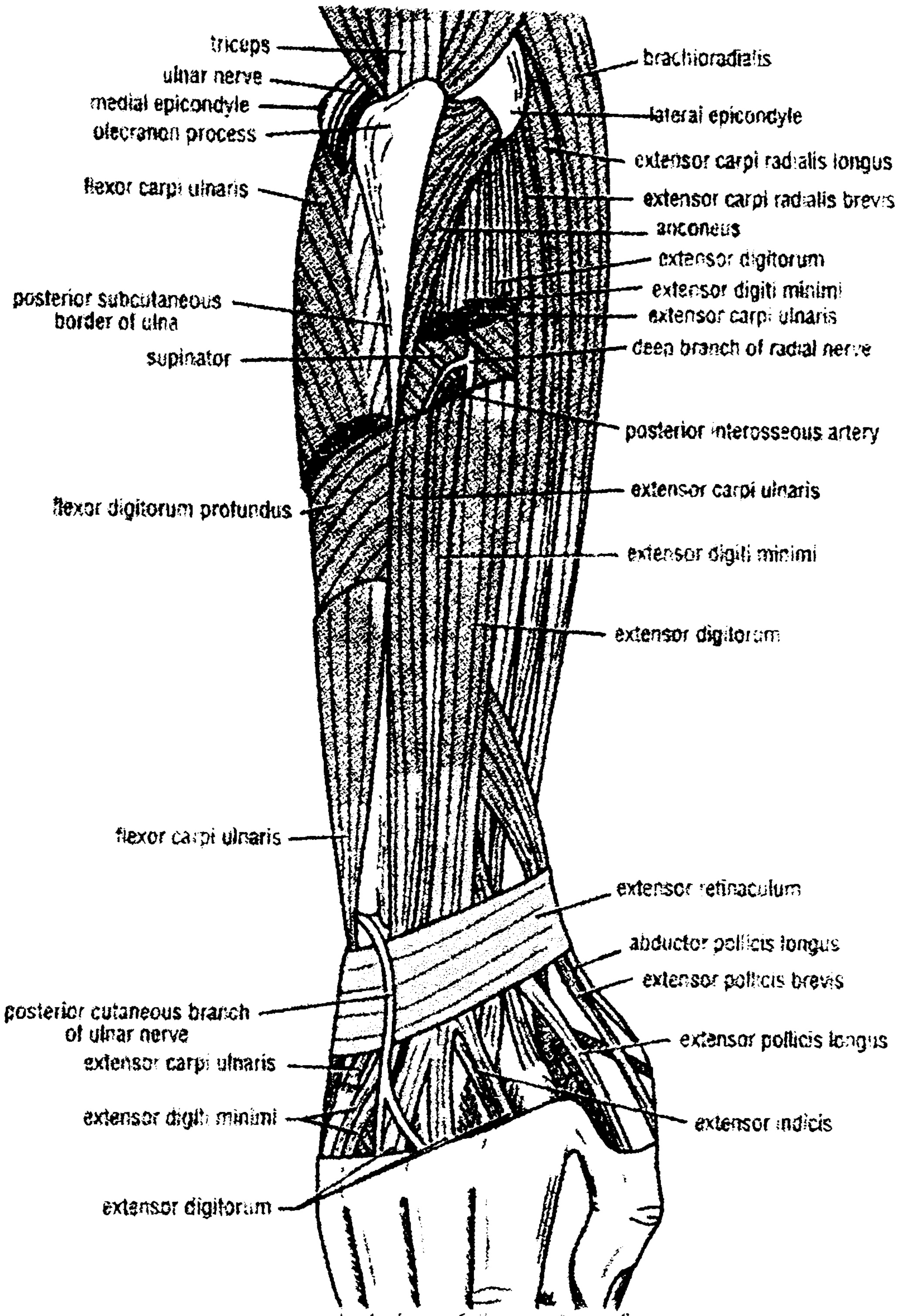

Figure B.2. Posterior View of the Forearm

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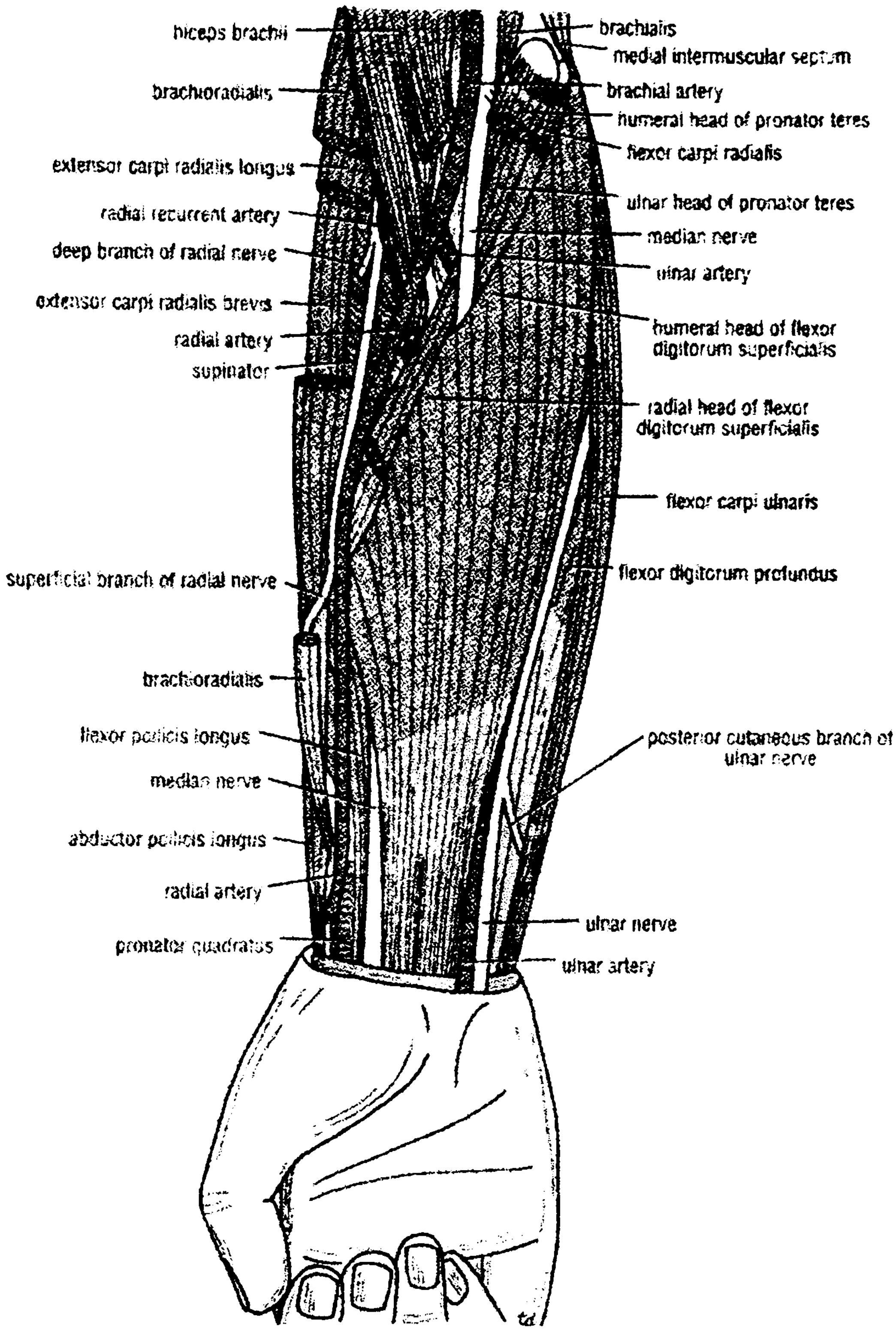

Figure B.3. Anterior View of the Forearm

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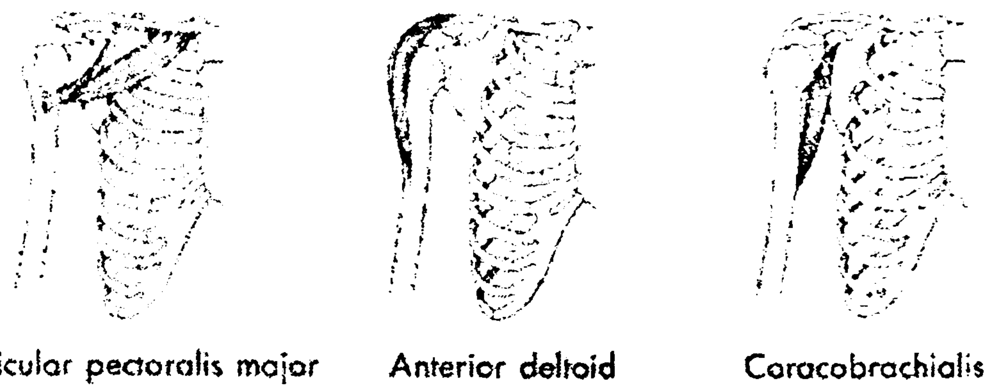

Figure B.4. Major Flexor Muscles of the Shoulder

Reprinted, by permission, from Susan J. Hall, *Basic Biomechanics* (St Louis: Mosby-Year Book, 1991), 152.

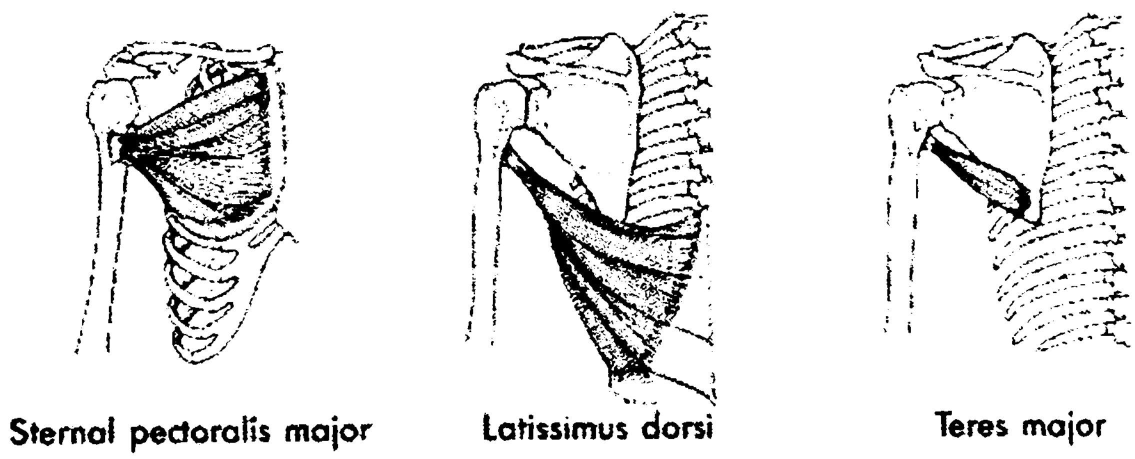

Figure B.5. Major Extensor Muscles of the Shoulder

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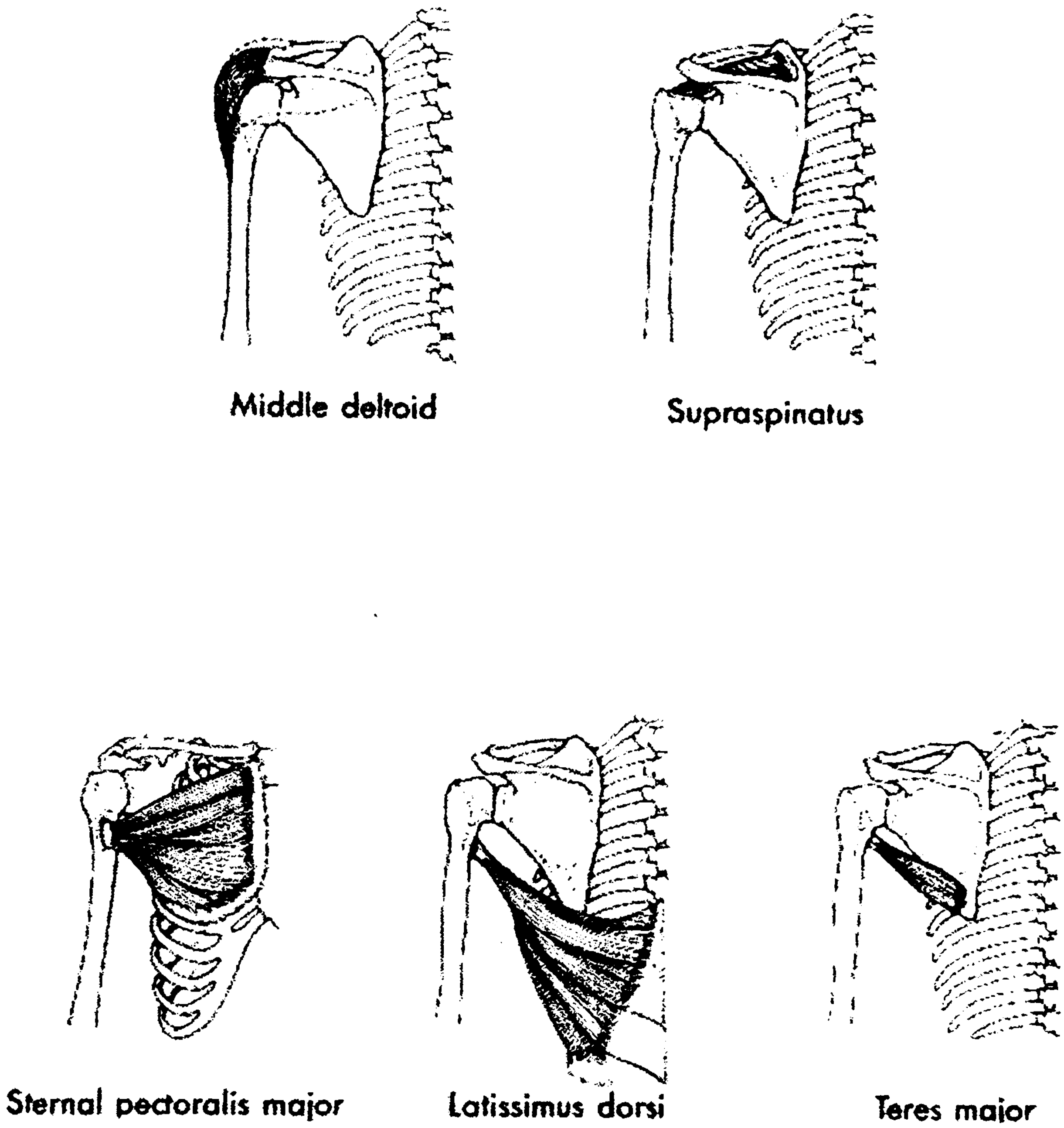

Figure B.6. Major Abductor and Adductor Muscles of the Shoulder

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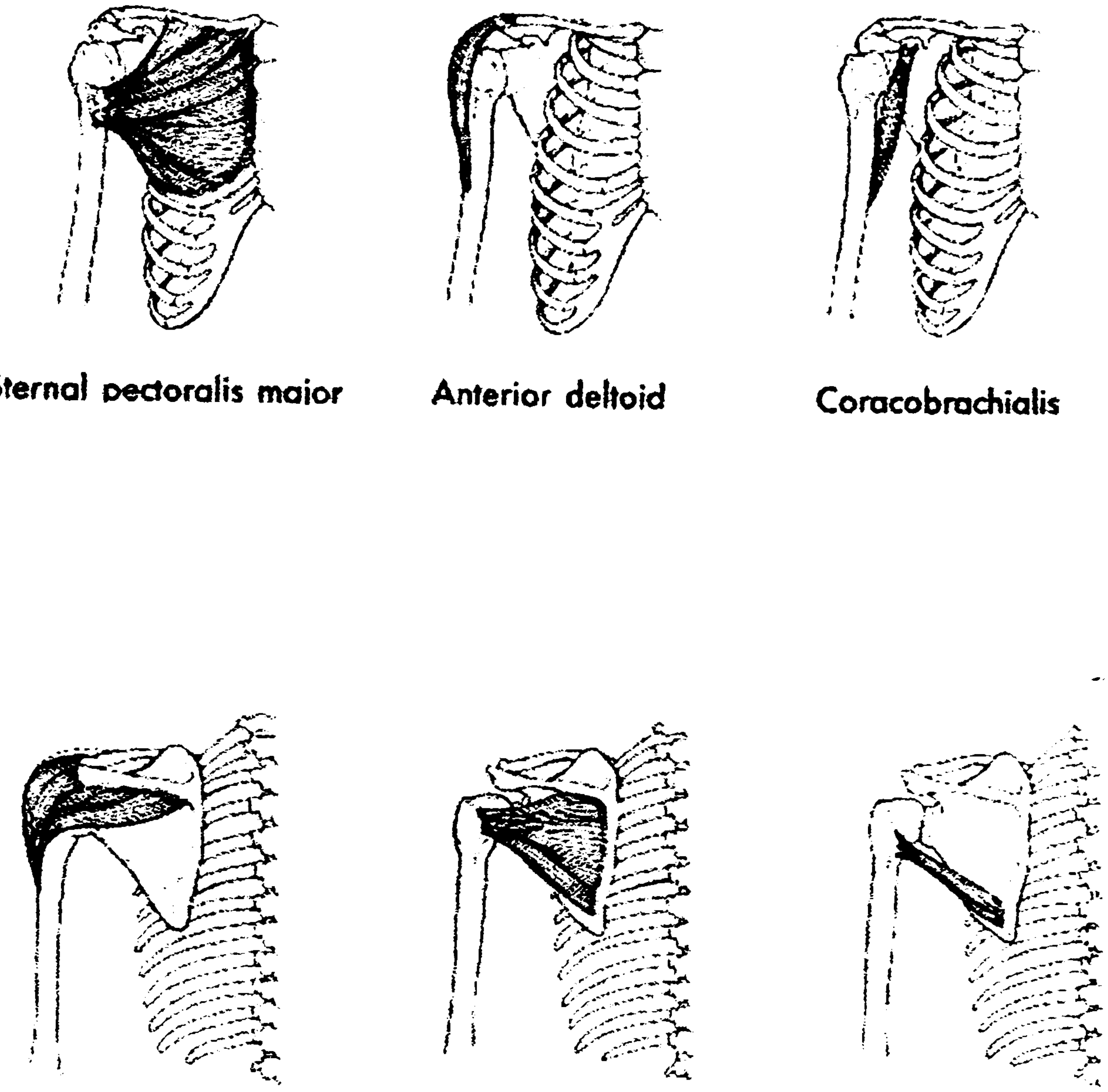

Figure B.7. Major Horizontal Adductor and Abductor Muscles of the Shoulder

APPENDIX C

ADDITIONAL FACTORS RELEVANT TO MUSCLE AND TENDON FUNCTION

Muscle Fiber Types and Architecture

Muscle fibers exhibit different structures and behaviors. Since these differences impact muscle function, much research has been directed toward identifying categories of fibers.[1]

Fibers have been generally classified into two basic types: fast twitch (FT) and slow twitch (ST). To these two types, and intermediate type of fast twitch has been added, yielding the classifications: (1) slow oxidative, (2) fast oxidative glycolitic, and (3) fast glycolitic. The two fast types are associated more with anaerobic metabolic processes while the slow type is associated with aerobic burning. The distinction between types is made based on how long it takes a muscle fiber to contract to its maximum tension level.[2] FT fibers reach maximal tension and then relax in about half the time required by ST fibers. However, there is wide variation in the time required to reach peak tension within both categories. FT fibers have a higher concentration of the enzyme myofibrillar ATPase, and are also larger in diameter than ST fibers. Because of these these and other factors, FT fibers are capable of producing higher tensions than ST fibers, but also fatigue more quickly.[3]

Most skeletal muscles consist of a combination of FT and ST fibers, with relative concentrations of each varying from person to person. It has been hypothesized that males may have a higher proportion of ST fibers than females; however, this has not been adequately demonstrated by research studies. FT fibers are important to a performer's success in events requiring

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1 Susan Hall, *Basic Biomechanics* (St. Louis: Mosby-Year Book, 1991), 96..

2 P.O. Astrand and K. Rodahl, *Textbook of Work Physiology: Physiological Bases of Exercise* (New York: McGraw-Hill, 1986), 33-9.

3 Hall, 96.

fast, powerful muscle contraction such as jumping or throwing. Endurance events such as distance running or swimming require higher concentrations of ST fibers, which are more resistant to fatigue than FT fibers. Most people have approximately balanced numbers of FT and ST fibers, though a small percentage have an unusually high number of either FT or ST fibers.[4]

Architecture of muscle fibers is also relevant to consideration of biomechanical function. Muscle fibers are arranged in either a parallel or pennate configuration. In a parallel arrangement, the fibers lie parallel to the longitudinal axis of the muscle. In a pennate configuration, muscle fibers lie at an angle to the muscle's longitudinal axis. Each fiber in a pennate muscle attaches to a tendon.[5] When tension is developed in a parallel muscle, the fibers shorten and hence shorten the muscle. Pennate muscles shorten by drawing up and rotating around their tendon attachments to progressively increase the angle of pennation. The greater the pennation angle, the less the amount of force actually transferred to the tendon to move the attached bone. After the angle of pennation reaches 60°, the amount of force transmitted to the tendon is less than half the force being produced by the muscle fibers. Though effective force is reduced in this way in pennated muscles, the pennate muscle fiber arrangement allows for the packing of more muscle fibers than in a parallel muscle occupying the same amount of space. Since pennate muscles thus contain more fibers per unit of volume, they are capable of producing more force than parallel muscles of the same size. Even so, the parallel fiber configuration allows for greater shortening of the entire muscle than does the pennate arrangement. Parallel-fibered muscles can thus

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[4] Ibid., 96-7.

[5] Ibid., 97.

move body segments through a greater range of motion than pennate-fibered muscles.[6]

Mechanical Factors and Muscular Force

There are three basic types of muscular action, or patterns of tension development. The first type, concentric action (Refer to Glossary of Terms), results in the shortening of a muscle thereby pulling the attached bones closer together and causing a change in the angle of the joint that lies between them. Concentric tension development is used in most voluntary movements of the limbs of the body.[7] Muscles can also develop tension without shortening. This type of tension development is termed "isometric." Developing isometric tension simultaneously in muscles on opposite sides of a limb enlarges the tensed muscles but results in no movement of bones or changes in joint angle.[8] Eccentric tension development results in a muscle being lengthened as tension develops. Eccentric action counteracts gravity to act as a braking motion in slowing movement, as when lowering a weight.[9]

Force-Velocity Relationship

The relationship between the concentric force exerted by a muscle and the velocity at which the muscle may shorten is inverse. When a muscle develops concentric tension against a high load, the velocity of shortening must be relatively slow; when resistance is low, velocity may be faster. However, this observation does not mean it is impossible to move against

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[6] Ibid., 99.
[7] Ibid., 89-90.
[8] Ibid., 90-1.
[9] Ibid., 91.

heavy resistance at fast speed. The stronger the muscle, the greater the magnitude of possible isometric tension. The maximum isometric tension level represents the maximum amount of force a muscle can produce before actually lengthening, being pulled by the resistance. The force-velocity relationship also does not preclude the moving of light loads at low speed. In fact, most activities of daily living require controlled movements of loads far below maximum. At such sub-maximum speed, the velocity of muscle shortening is under voluntary control. The force-velocity relationship for a muscle being subjected to eccentric tension differs from the concentric tension model. At loads less than the isometric maximum, the speed of muscle lengthening is voluntarily controlled. At loads greater than maximum, the muscle is forced to lengthen. Eccentric strength training involves using resistances that are beyond maximum capability to generate isometric force; this forces the muscle to lengthen. This type of training does increase muscle strength, but also frequently results in muscle soreness.[10]

Force-Length Relationship

The maximum amount of isometric force a muscle may produce depends partly upon the muscle's length. An unattached and unstimulated muscle (in vitro) is at equilibrium length. Muscle does not contract with its maximum force at equilibrium length, but produces more force as it is stretched. Tests conducted on muscle fibers in vitro (outside the living organism) reveal that in single muscle fibers, force generation is at maximum when the muscle is at its normal "resting length" (equilibrium plus approximately 20%). Within the living human body, the resting length is

[10] Ibid., 101-2.

about the normal length of a muscle attached to tendons and bones. Therefore, in vivo, muscles are very nearly primed for maximal contraction. Parallel-fibered muscles produce maximum tension at just over their resting lengths while pennate-fibered muscles produce their maximum at between 120% and 130% of equilibrium length.[11]

Force-Time Relationship

After a muscle is stimulated, a small amount of time elapses before tension begins to be developed. This pause, termed "electromechanical delay" (EMD) is likely necessary for muscle laxity to be eliminated to the point that tension can develop. There is wide variation among individuals in EMD, with reported values ranging from 20 to 100 milliseconds. Muscles with more ST fibers have longer EMDs than muscles with higher concentrations of FT fibers. After EMD, the time required for a muscle to develop maximum isometric tension may be a full additional second.[12]

Tendon Fiber Structure and Larger Architecture

Both tendons and ligaments are made up of parallel-fibered collagenous tissues. Collagen is a fibrous protein making up about one-third of the total protein in the body. Tendons and ligaments consists of a relatively small number of cells called fibroblasts structured within an extra-cellular matrix; the fibroblasts occupy about 20% of the tissue volume with the remainder consisting of the extra cellular matrix. The matrix itself consists of approximately 70% water, with the other 30% made of various

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[11] Ibid., 103.
[12] Ibid., 104.

solids including collagen and elastin. In tendons of the extremities (including the arm and hand), up to 99% of the total solid component of the matrix may consist of collagen.[13] Though they have different functions, both tendons and ligaments respond similarly to mechanical loading.

Tendon fibrils are formed by the aggregation of several collagen molecules in a structure in which one molecule overlaps another. Fibrils further join to form collagen fibers, which are visible under a light microscope. These fibers are single unbranching strands and may be many centimeters long. The collagen fibers further aggregate to form bundles. Fibroblasts are lined up in rows between bundles and run along an axis in the direction of the tendon function. These fibers which compose tendons are arranged in parallel fashion, which allows the tendon to withstand the high unidirectional loads they are subjected to during activity.[14]

Each muscle fiber has its own proximal and distal attachments to a tendon. The transition from muscle fiber to tendon is gradual rather than abrupt. As the end of the muscle belly is approached, tendon tissue becomes predominant, forming a white sheet- or ribbon-like tendinous expansion. As the tendon continues, it may maintain this sheet-like appearance, or it may become cord-like.[15] Many tendons of the upper extremity are of the cord-like type. This type of tendon often has a protective tendon sheath at points of high friction where the tendon changes direction relative to its associated muscle. For example, many of the tendons crossing the wrist have sheaths. These sheaths are usually tubular structures which contain synovial fluid to

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13 Ibid., 59-60.
14 Ibid., 61.
15 Moore, 713.

provide lubrication, protection, and resources for repair of the tendons which they encase.[16]

[16] Moore, 732.