The Physical Basis of Music

and its Implications for Musical Performance

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THE PHYSICAL BASIS OF MUSIC

PREFACE

The main purpose of the following work is to explain certain physical considerations useful not only to a beginner learning how to play a musical instrument, but also to an accomplished musician trying to gain full technical mastery of an instrument. Some conscious understanding of the facts of physics and physiology, while obviously not necessary, can speed up the learning process for a beginner and may help the good performer to acquire a level of technical skill, accuracy, and endurance unlikely ever to be attained otherwise. In some cases, what a musician can learn in a year of intense but undirected trial–and–error practicing on an instrument, might have been learned in a week of practice guided by this knowledge.

The idea of writing this book has been in my mind for many years, as my own research and experimentation gradually made me aware of more and more of this situation, and notes accumulated for the course which I taught for a number of years at Stanford University and Washington University. But when this loose collection of ideas was finally assembled, it appeared hard to say just what "*the*" purpose of the book is. The fact is that the final result has a number of secondary purposes.

I realized only gradually, from a repeated strange experience, that there is a need not only to explain technical facts; but also to provide young musicians with a general cultural background in the subject. The strange experience was that of making a passing reference in a lecture to something in the history of music, that I thought every literate person must know – only to find that my students, some of whom were already accomplished performing musicians, had no idea what I was talking about. Of course, a single small book can convey only the bare minimum of all the general historical information available in a good library; so we have tried to make this work also a guide to the literature, with extensive references showing where the interested reader may find more – in many cases, vastly more – material than we can include here.

But in the older literature there is also a great deal of misinformation, superstition, and downright error concerning not only the physical facts of musical instruments and technique; but even the simple historical facts concerning which instruments, scales, and styles of music existed in various earlier times. Different contemporary sources contradict each other – even on matters which were within living memory when they were written – and so today we are obliged to decide whom to believe, taking into account every scrap of relevant evidence we can lay our hands on. The further back we go, the more of this we find; before the 18'th Century most writers existed in a kind of dreamlike state, unable to distinguish between a real fact and a figment of the imagination. But a person with scientific training is in a very good position to judge what statements are plausibly true, which are conceivable but highly improbable; and which are manifestly impossible.

Unfortunately, the record does not always improve in modern times. In recent works, understanding of the original very practical reasons why music became associated with mathematics, why the violin has its peculiar shape, and similar matters, has been largely lost and replaced with folklore. Important facts about vibrating systems and acoustics, which were explained clearly and correctly by Lord Rayleigh and Hermann von Helmholtz over 100 years ago, were still not comprehended 40 years ago by the instrument technicians and music teachers who had the most need to know about them, and whose ideas still dominate much of the field today. So we aim to be critical, warning against common fallacies which tend to persist long after the truth is known. We lay the strongest emphasis on things which one cannot find at all – or cannot find explained clearly and correctly – in recently published works.

Music has many different aspects: the historical evolution, the mathematical connections, the very different aesthetic considerations involved in composing and performing, and the unavoidable physical considerations that must be faced in building and playing instruments. We want to say something about each of these so that our main purpose, the last, is seen in better relation to the whole.

Since no author can be intimately familiar with every instrument and every musical tradition, we end up with a very uneven treatment whoever tries to write such a study as this. While I have been playing pianos seriously and studying their inner workings and the physiology of the piano–playing hand for over forty years, and have some slight experience with the clarinet and violin, my total hands–on experience with brasses is probably less than ten minutes; accordingly we devote three Chapters to pianos, and none to brasses.

Fortunately, what I lack here has been supplied admirably by Arthur Benade (1976), another professional physicist[†] who has specialized in just the areas where I am weakest. Practically everything I know about the inner workings of wind instruments has been learned from reading Benade; and so it seemed best to refer the reader to his work rather than attempting to repeat it here. We urge the reader who is seriously interested in this material to obtain also a copy of Benade's work to read in connection with this one.

In other words, the present work is in no sense a competitor of Benade's; it is rather a companion piece, in which the viewpoint is more that of a musician, and we concentrate more on the history and playing of musical instruments (and indulge, in Chapter 7, in musical aesthetic judgments which Benade, no doubt wisely, avoids). Also, compared to Benade's even treatment, ours has a schizoid character; in the main part of a Chapter a musician is talking to musicians, in their language, about physics; in the ending Sections of several Chapters this switches to a physicist talking to physicists, in their language, about music. This is done for the following reason.

A major concern was the question of the proper technical level for this presentation. To make it too technical would defeat our purpose by making it inaccessible to the very people we want most to reach; but to make it too elementary would only perpetuate errors and frustrate those who have enough mathematical training to follow the whole story. In the end we decided that to accomplish our goal it is necessary to give the presentation at both levels simultaneously. Accordingly, at the end of several Chapters there is a "*Mathematical Supplement*" of two or three pages in which we repeat the verbal

[†] It is a sadness to report that Arthur Benade, a former graduate student in physics here at Washington University, died in 1987, so the 1990 edition of his book, revised from his marginal notes, will be the final one.

statements in the much more complete form of the mathematics, at the highest technical level yet attained. Readers without mathematical training may skip these parts; yet they may still gain some useful understanding merely from skimming over them. Equations, like books, do not bite; a musician with no mathematical training has no reason to fear the sight of an equation – particularly when that equation indicates exactly what scientists know about his/her instrument. A little of its meaning will come through; if not the quantitative details, then at least a qualitative feeling for the *kind* of information that is and is not known.

Mathematics is simply an enormously efficient shorthand language; a single equation states simultaneously thousands of quantitative details, which we could not say in words in an entire book. So the Mathematical Supplements are not merely restatements of the text in a more esoteric language; they are vast extensions of the text. One who can read the meaning of the equations can extract from this book far more detailed information than is contained in the words alone; and that information, far from being dull, is often highly interesting – even exciting – to one who did not suspect some of the wonderful things that are happening in musical instruments. Indeed, we fancy that some readers, perceiving this, may be inspired to learn some mathematics for that reason – just as Theodore Steinway did 130 years ago.

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CHAPTER 1

DEFINING OUR GOALS

Our basic goal here is to help a musician to get technical facility in playing a musical instrument, more quickly and to a higher level, than would the traditional trial–and–error practice. There are some secondary goals which will become evident as we proceed.

Many persons who might have become important performing artists, give up and leave the field because a few years' practice failed to give them the technical facility needed before one can concentrate on the music; and it was evident that further practice was not producing any improvement and their teachers were unable to help them. We need first to explain why the information we have to offer is important to such persons, why it is difficult to communicate, and how – for that reason – the reader needs to cooperate with the writer. The reader's responsibility is not to learn some science first; but rather to understand why we do things in a particular way and bear with us as we do them.

Communication Difficulties

In the writer's experience, a person without any musical education has heard the names: *Bach, Mozart, Beethoven*, but has no conception of exactly who they were, when they lived, what they did. Furthermore, in the mind of the musically untrained person such terms as *symphony, sonata, concerto, string quartet, cadenza, melody, harmony* are all lumped together, indistinguishably, all having vaguely the same meaning to him as the word *music.*

Then imagine a musician trying to discuss music with such an untrained person. The musician will use those words, which have to him clear and distinct meanings; but the listener will not grasp those meanings, and will not understand what the musician is saying. And this works both ways; the musically untrained person, trying to say something about music, will use indiscriminately whichever of those words happens to pop into his mind. The musician will naturally try to interpret the words as having meanings that they do not have to the speaker and will not be able to make sense out of them; and so again, the message will not get across. The trained and untrained persons, having no common vocabulary of musical terms, are unable to communicate any definite ideas about music.

It is exactly the same with our present topic. For a trained physicist, the words *force, momentum, energy, velocity, action* all have very precise, and entirely different, technical meanings; and all those terms are necessary in order to describe precisely how things move. For one without this training, all those words have, vaguely, the same meaning as the word *motion*; and he uses them indiscriminately when talking about anything moving. The result is that, lacking a common vocabulary, they are unable to communicate to each other any definite ideas about how something moves.[†]

But the problem is even worse when the movement occurs in playing a musical instrument, because not only are the meanings of the technical terms needed to describe

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[†] There is a book on piano technique in which the author fails to distinguish between the words *force* and *energy*, so we can make no sense out of what he is trying to say.

motion blurred, the very distinction between what is happening *objectively* in the hands and instrument and what is felt *subjectively* in the mind of the player, is equally blurred. Indeed, this is almost sure to happen even if the player does have scientific training, so all of us need to take extraordinary precautions to counteract it. Our communication can be blocked for two equally troublesome reasons, either one potentially fatal.

So this is the difficult task we have set ourselves: how to explain to a person with musical training but not scientific training, what is actually happening in a played musical instrument and in the arms and fingers of the player, and what this means for acquiring good technical control over the instrument.

What Use is Mechanical Knowledge to a Musician?

But why is it important to convey this information? After all, musicians have been getting along without it for Centuries (in fact, since long before scientists knew it), and one can point to many highly accomplished musicians in every generation. Obviously, there is nothing a scientist could tell Paganini about a violin, or Liszt about a piano, that would have given them any better technique than they already had; and for 'Paganini' and 'Liszt' the reader may substitute the names of his own favorite contemporary virtuoso performers. Some, noting this, even express the fear that scientific knowledge of what is happening might be actually harmful to musical values, because that would distract one's attention from the music.

The truth is just the opposite. It is the musician whose technical control is shaky who is obliged to worry constantly about the mechanical details of what is being done. Before one can think about how a difficult passage should be played from a musical standpoint, it is necessary to get the technical control that enables one to play it at all – hitting the right notes at the right speed. The more complete one's technical mastery, the more automatic the correct technique becomes; this mechanical knowledge becomes, so to speak, transferred from the brain to the fingers. Then the musician, instead of being preoccupied with those mechanical details, is at last free to *concentrate conscious attention entirely on the music.*

It is perfectly true, as all the evidence of history tells us, that with enough musical perceptiveness (so that one knows whether some change in technique has made things better or worse) and enough persistence, one can by trial–and–error, without any conscious understanding, acquire both great musical and technical facility on an instrument. But we raise three points, which apply equally well to all instruments:

(A) How long did it take to acquire that technical facility? In the beginning stages – perhaps the first year of study – the pupil is hardly concerned with musical aesthetics. The immediate problem is simply mastering the mechanics of the instrument – how to handle it so as to get any acceptable musical sound at all out of it. At this stage, conscious understanding of the mechanics involved can speed up one's progress. A beginning violinist might require a long period of trial–and–error to happen on the right bowing technique (combination of bowing point, velocity, and pressure on the string needed to produce the desired loudness, duration, and tone), because that correct technique seems at first wrong and counter to what one would have expected.

But will not the teacher supply that information? Not necessarily! A violin teacher might know perfectly well how it feels *subjectively* to play correctly; and yet not be consciously aware of what is being done *objectively*. But subjective sensations cannot be communicated† accurately to another person, so such a teacher could never explain proper violin technique to a pupil, only demonstrate it by example. But a little understanding of exactly how the string moves under the bow (too fast for the eye to see) would have made the correct rules of technique obvious; and most important, would make it easy for a teacher to explain it so the pupil understands *why* this is the correct technique and what are the predictable and inevitable consequences of *failing* to obey it.

(B) How many musical talents have been lost for this reason? That is, how many students, who had fine musical perceptiveness and might have become excellent musicians, abandoned the field because their undirected trial–and–error just never happened to hit upon the right mechanical technique, and so they never reached the level of technical skill that permitted them to concentrate on the music? How many others stayed in music but never developed their full musical capabilities? Put differently, how many music teachers failed to train their students adequately because, lacking this mechanical understanding, they were unable to explain proper technique to them?

(C) Even after one has acquired good mechanical facility on an instrument, a conscious understanding of what is happening will almost surely enable one to get those results with less effort and therefore greater control and less fatigue – and therefore achieve a better overall musical effect. The human anatomy is equipped with various different sets of muscles, any of which can produce, after a fashion, the correct movements. But they differ greatly in strength, fineness of control, and endurance. The coaches of athletes who win Olympic Gold Medals have long since taken full advantage of this knowledge. A musician who is consciously aware of it can take equally good advantage of it, for a higher purpose, as we shall see in Chapter 6.

A Case History

A good example of these points is provided by the most famous of all pianists, Franz Liszt (1811–1886). His contemporaries have testified about his playing in some detail. Charles Hallé remarked about the perfect articulation and clarity of his playing, while his pupils remarked at the *smoothness* of his playing; however well they had prepared a work, Liszt would, immediately, play the same work in a way that made their own execution seem rough and jerky. Put more specifically, among his many accomplishments Liszt had the most perfectly smooth, uniform legato execution, at any speed, of passages such as scales and arpeggios that require repositioning of the hand (usually, passing the thumb under the palm of the hand). At the same time, he managed this with the most perfect clarity, every note being heard.

But Liszt did not come by this facility naturally; even after he had been famous for ten years – first as a boy wonder, then as one of the greatest virtuosos – he had not yet perfected this touch. But the shock of hearing Paganini, and suddenly realizing the

† For example, try to explain *in words*, to a person with no musical experience, the difference in sensation between a minor third and a major third.

difference between being a very good performer and having *total technical control* over an instrument, made him resolve to do for the piano what Paganini had done for the violin. He retired from public life for a year, to achieve that control by intensely hard practice, mostly scales and arpeggios. After this, he returned to concertizing and his greatest triumphs, with a totally new level of accomplishment – what has come to be called his "years of transcendental execution".

Then the secret of this technique was nearly lost. Having achieved this touch for himself by trial–and–error, Liszt was unable to teach it to his pupils. He knew perfectly well what it felt like *subjectively* to play correctly, but he was not consciously aware of what he was doing *objectively*; so again he could not explain it, only demonstrate it. His pupils were trying desperately to acquire his technique; yet in his lessons he said nothing about technique, instead offering only comments about interpretation.

While Liszt inspired his pupils by giving them incontrovertible proof that this technical control was *possible*, it was left up to them to discover for themselves what specific mechanical actions of the hand are required to *actually do it*. Accordingly, some of his pupils (d'Albert, Tausig) managed to acquire that touch reasonably well by their own efforts, but most of them never did. And those who did acquire it were in turn unable to pass it on to their pupils.

As it turned out, one who observed Liszt's hands very closely could have learned what he was doing (he was bending his wrists sideways in a way that feels wrong and unnatural at first, but which moves the fingers smoothly and automatically into the correct position for the next note, making quick jerky changes of hand position unnecessary – and, incidentally, promoting high accuracy). The first person to realize this was his American pupil Amy Fay (1844–1928), about whom we shall have a great deal to say in Chapter 6. It is pleasant to record that Liszt himself appreciated her written account of this so much that, in almost the last year of his life, he sponsored its translation into German and publication in Germany; so for those who knew where to look and had the wit to understand her message, the secret was not lost after all.

Retraining

We have already noted that in the beginning phase of study, conscious knowledge of what is happening mechanically, far from destroying musical values, helps to make the correct technique automatic, so that one can arrive more quickly at the level where one *can* concentrate on the music. But now we add that real instruments always have individual imperfections, and when even the most accomplished musician is obliged to use a different instrument, a new short learning period, calling again on this conscious mechanical knowledge, is necessary before one is able to compensate for its shortcomings in an automatic way.

No two pianos have exactly the same feel of the keys, the same variation of stiffness and loudness across the bass–treble range, or the same variation of tone with loudness on any one key; and so when one changes instruments one must adjust to this. A person who is obliged to practice on an upright piano will tend to produce a muffled sound – booming bass and weak treble – on a grand piano until this re–training is done to compensate for their different dynamics. Indeed, after every tuning your own piano responds differently than it did before, and a short re–training period is necessary before you can again produce the sound you want.

The writer's own experience is with the piano; but the same phenomenon is undoubtedly even more true of the violin and its relatives. We conjecture that it must be true also of woodwinds and brasses, but have no direct experience of it; therefore we must refer interested readers to the treatise of Arthur Benade (1976) for this kind of information.

These general observations are, of course, not limited to the playing of musical instruments; they apply equally well to any athletic or other coordinated activity. An automobile driver who understands consciously what the brake and accelerator pedals are doing, can learn the correct way of handling them far better and more quickly than one who finds their mode of operation mysterious and bewildering. Therefore one arrives more quickly at that expert phase in which one's attention is concentrated on the road conditions and the right things are done automatically – even in an emergency – without conscious thinking about mechanical details. But when one is obliged to drive a different automobile, it will surely respond differently to the controls, and that conscious mechanical understanding needs to be called upon again, to become aware of the difference quickly and adapt to it so that it becomes automatic. Every time the writer rents an automobile at a distant airport, he is obliged to go through a half–hour of this retraining before being able to drive it in a confident, automatic way.

In addition to understanding the mechanics of particular instruments, one of our secondary goals is to share a common cultural background that both musicians and scientists ought to have, concerning the origins of musical instruments, how much conscious technical knowledge went into their design, and what defines our scales, whether tonality and the diatonic scale are forced on us as a prerequisite for harmony. Accordingly, the next three Chapters supply a bare minimum of this and guide to the literature, after which we turn to what science has to tell us about proper playing and adjustment of the violin and piano, speculations on future musical instruments (in particular, is there any hope that we may have a truly satisfactory piano in the next Century?), and comments on musical aesthetics. However, the following Chapters may be read in any order; although there are many cross–references, the early ones are not prerequisites for the later ones.

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CHAPTER 2

ORIGINS OF MUSICAL INSTRUMENTS

It is curious that more is known about the rather vague quasi–mystical, quasi–aesthetic, quasi–mathematical course of music theory than about the definite facts concerning how the physical instruments were developed. The history of music theory is well recorded, from Pythagorus (about 580 B.C.) to the present.

From India there is the *Nātya–Shāstra*, perhaps as old as 200 B. C., in which instruments were classified in four categories: the stringed, wind, membranous percussion, and metal percussion. Evidently, by then there must have been already a long period of development. This continues in the *Sangita Makarandah* of the 8th or 9th Century, the *Sangita–Ratnākare* of the 13'th Century, and the *Rāga–Vibodha* and *Chaturdandi Prakāshika* of the 17'th Century, down to the *Hindusthani Sangita Paddhati* of V. N. Bhatkande, in the 20'th Century.

Arab theoreticians include Al–Kindi ($\simeq$ 873), Al–Farabi (950), Avicenna (1037), and Safe al–Din (13th Century). They discourse on mystical properties, then proceed to more mundane matters of calculation of intervals, definition of modes, rhythm, principles of composition, and properties of instruments that composers need to know.

Early European works after Pythagorus are rare but not entirely unknown; for example the *De Musica* of St. Augustine (late 4'th Century), and another *De Musica* by Aurelian (c. 850). But starting in the 16'th Century, we have a veritable flood of European works on music theory: Tartaglia (1543), Gioseffo Zarlino (1558, 1588), G. Benedetti (1563, 1585), Vincenzo Galilei [father of Galileo], (1589), Simon Stevin (1605), Father Marin Mersenne (1636), Jean Philippe Rameau (1722 *et. seq.*).

In contrast, the process by which one evolved the actual design and mechanical construction of the instruments was often not recorded. In early times this knowledge was handed down verbally from master craftsman to apprentice – no doubt, often secretively – and is now lost. We shall be concerned mostly with the violin, about which quite a bit is known, and the piano, for which we know in detail just how its present form was developed. But before turning to them, let us survey a little of what is known about other instruments.

The Migration Theory

Historical scholars tell us that lutes, fiddles, flutes, oboes, trumpets and drums did not originate in Europe, but were brought there from the Orient and the Near East, mostly before medieval times. At first hearing, this seems so implausible – or at least so unflattering to our Western ego – that one will demand to know the specific evidence for it. Quite independently of the blow to our pride, what the migration theory makes so hard to explain is this: if such instruments were already well developed and used for Centuries in the East before coming to Europe, why did oriental music never develop any sense of tonality and harmony?

Without going into a lengthy historical analysis, we can indicate the general nature of the evidence for the migration theory (for many more details, see Schaeffner, 1968). In the first place, the works on music theory just cited show a preponderance of oriental activity before the 16'th Century. The earlier European works are concerned mostly with vocal Church music. Secondly, evidence still in the East and near East (stone statues, temple carvings, tombs) shows many familiar looking instruments, already in ancient times.

Thirdly, the main routes by which such migration could have occurred seem to be; the movement of Arabs into Spain starting in the year 711,† the returning Crusaders, the Marco Polo type explorers and traders of the 13'th and 14'th Centuries, and the invasions of the Ottoman Turks into Anatolia and then into central Europe in the 15'th to 17'th Centuries. Now in each case we have historical proof that musical instruments *were* carried westward in these migrations.

The evidence for this is particularly complete and detailed in the case of Spain. The photographer Bradley Smith has taken beautiful color photographs of paintings and parchments found in various museums, churches, and public buildings all over Spain, that convey historical information about the period in which they were painted, and presented them in a magnificent volume (Smith, 1966). They depict many musical instruments, in greater detail than most of the Egyptian illustrations. For example, two 13'th Century illustrated parchments show (p. 60) an elaborate seven–string lute of the classical shape, being played; and (p. 63) an equally elaborate harp, of entirely different basic design than the Egyptian ones. On pp. 84–85, we see citterns (which appear to be intermediate forms in the evolution of the lute into the modern Spanish guitar), flutes, and – surprisingly – bagpipes. Of course, early instruments had many and various names different from our present ones; but their basic kinship is evident from illustrations and surviving specimens. For example, the Arabian stringed instrument called *Al–Shaqira* is found in Spain in the 13'th Century, and it had migrated on to England by the 14'th Century.‡

Finally, nobody has been able to find any evidence for such well–developed instruments being in Europe before those times (there have always been primitive peasant inventions known only locally). The sudden appearance of many European works on music theory in the 16'th Century seems to indicate that instruments deserving of serious study suddenly appeared in Europe shortly before then. So the evidence for the migration theory is rather convincing, and it seems that we must look elsewhere for an explanation of why the elements of tonality and harmony should be peculiar to Europe. Here we can only conjecture.

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† The Moslems remained in Spain for nearly eight Centuries, during which they acquired, at one time or another, control over most portions of the Iberian peninsula. Thus not only some of their culture, but also some of their racial character, was absorbed by the native Spanish population, and is by now diffused throughout most of it. This is the reason why Spain still presents, to a traveler, a quite different appearance and culture than does any other European country.

‡ For much of this information we are indebted to Alfonso X (often called *El Sabio*), who ruled in Toledo from 1252–1284 and commissioned many paintings and translations of Arabic works into Latin. In particular, his *Cantigas* contains, according to Smith (1966), illustrations of over 50 types of musical instruments used in 13–th Century Spain and examples of the music. We understand that this is now in the magnificent library of *El Escorial*, the 16'th Century Royal Palace of Philip II near Madrid. How we would like to have a photographic reproduction of it!

There is a hint of a rudimentary tonality in the ancient Greek modes, and although 'consonant' and 'dissonant' intervals were recognized, they seem nearly arbitrary. It seems a plausible conjecture that to develop a sense of harmony in the modern sense required keyboard instruments, so that one person could play easily any combination of notes. Only after some rudimentary principles of harmony were recognized could one perceive the fundamental status of the major scale, which distinguishes it from the other modes, leading to tonality in the modern sense of the word.[†] Since keyboard instruments appear to be European products, this conjecture has at least some self–consistency, even if we are unable to cite a definitive proof of it. Perhaps others can suggest better conjectures.

How are Musical Instruments Developed?

Every musical instrument, needless to say, requires a long period of development – usually trial–and–error experimentation by generations of craftsmen – before arriving at its final perfected form. An instrument such as the clarinet or French horn, whose development took place in Europe in the 18'th or 19'th Centuries, has left a trail of historical record readily available. But even the harpsichord and violin, although European products, are too old to meet this condition.

For the many instruments that were imported from the East long ago, the details of this development are completely lost in unrecorded history, and only the evidence of archaeology can shed any light on them. Elaborate harps are found, already highly developed, in tombs in Asia minor dating back to 3500 B.C. Fancy harps, lyres, and instruments resembling guitars and oboes are depicted in numerous carvings on the walls of Egyptian tombs of about 2600 – 1000 B.C. An authentic specimen of an Egyptian harp of about 1400 B.C. may be examined in the Metropolitan Museum of Art in New York, well enough preserved so that one can see exactly how it worked. It is surprising to see the sounding board already there, built into the thick bottom. Evidently, practical knowledge of the properties of strings and the facts of acoustics did not begin with Pythagorus. Also, drums essentially identical with modern bongo drums were found in Egyptian tombs of about 1000 B. C.

Brasses. For wind instruments the early history is likewise lost. The straight trumpet was known in ancient times; four specimens were found in the tomb of Tutankhamen (about 1350 B. C.), whose photographs may be seen in Manniche (1991).[‡] A folded version was developed, in the 14'th or 15'th Century, to make it easier to carry. The slide trombone (Italian for "big trumpet") evolved out of the folded trumpet in the 15'th Century, before the invention of valves, as the easiest way to play a full scale. Sixteenth Century engravings

[†] Of course, it is easy to pluck two lute strings simultaneously, thus producing what to our ears is perceived as a simple harmony. The Elizabethan lute songs already demonstrate this, and we readily interpret them as parts of our modern tonic, dominant, and subdominant chords. But that is only because of our long familiarity with harmonic effects; it seems likely that to Elizabethan ears the sound of two simultaneous notes was perceived in contrapuntal rather than harmonic terms.

[‡] The greatest collection of ancient Egyptian instruments is, of course, in the Cairo museum; however, the Metropolitan museum in New York and the British museum in London also have interesting collections, accessible to more people.

show folded trumpets very much like modern ones except that they have no valves; and trombones that look identical with our modern instruments except for a narrower bell.

The major advance in brasses was the invention of valves in about 1815. These changed the length of tube, allowing the full chromatic scale to be played. The patent, by Heinrich Stölzel and Friedrich Bluhmel, is dated 1818 and pertains to improvements in horns; but once seen the idea spread rapidly to other brasses. By 1825 the modern cornet existed, and by 1835 the modern tuba had been invented (in Germany, of course – where else?)

The French horn was originally an 18'th Century hunting horn, without valves, and coiled up in circular form so that it could be carried about on the shoulder by sticking one's arm through it, and played by a hunter on horseback, the bell turned up rather than down as now. But the valves then filled the central space so it could no longer be held that way. It turned out to be notoriously difficult to play clear, burble–free tones on the French horn. We are used to hearing a French horn, not playing a clear melody, but *trying* to play a melody, with a little uncertainty at the start of each note as to whether we shall actually manage to get it. The trouble is that the total length of the coiled horn is very large for the pitch of the notes being played, so one has the same problem as a bugler trying to play very high notes. The slightest change in lip tension can cause it to jump from one note to another; it is like trying to play a long garden hose.*

Woodwinds. The flute has been known from antiquity; carvings on ancient temples in India show them just the same size, and held in the same way, as our modern instruments. Manniche (1991) gives several reproductions of drawings in Egyptian tombs of roughly 2600 – 1000 B. C., showing some kind of tubular instrument with the end apparently in the mouth. She classifies them confidently as clarinets, oboes, and end–blown flutes; but we are unable to see anything in the drawings that could justify such a distinction. Even given a surviving specimen, what is the distinction between an end–blown flute, and a clarinet missing its mouthpiece? Both are just tubes with holes in them.

What is the difference between a clarinet and an oboe? In ancient instruments, this is arbitrary, and more a matter of semantics than of fact. If the distinction is held to lie in the single or double reed, then one could convert an oboe into a clarinet and vice versa, merely by changing the mouthpiece. Manniche (1991) uses this classification in one place, and in another – in seeming contradiction – makes the distinction in terms of the bore diameter, an instrument with a hole less than 1 cm in diameter being called an oboe – with no mention of the shape of the bore.

But neither of these classifications recognizes the real distinction between our modern oboe and clarinet. This distinction is in their entirely different tone; and this is caused by the clarinet having a cylindrical bore (uniform diameter from one end to the other), the oboe a conical one, tapering from a small hole at the mouth end to a large one at the bell.†

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* Indeed, as the virtuoso French hornist Dennis Brain has demonstrated, one who has mastered that instrument can play a garden hose just as well.

† As a result, their body resonances are entirely different; the oboe has all harmonics, the natural frequency ratios 1:2:3 and so on, while clarinet has only the odd–numbered ones, frequency ratios 1:3:5 and so on. This accounts for the distinctive "hollow" tone of the clarinet in the low register. This same hollow tone is produced by plucking a string at its exact center, which makes all even–

It is easy to prove that this difference in tone has nothing to do with a single or double reed; clarinet–type single reed mouthpieces that fit onto an oboe body can be bought commercially, and the resulting instrument still has the tone and musical function of an oboe, not a clarinet. If one is used to playing a clarinet, but in an emergency situation is obliged to play an oboe instead (as once happened to the writer in a college orchestra when the regular oboist was taken sick and at the conductor's request I underwent a crash program to learn oboe fingering in one day), one can play the unfamiliar instrument with better control by keeping the familiar kind of mouthpiece. Conversely, by drilling a small hole in a cork you can fit an oboe double–reed mouthpiece onto a clarinet body. The resulting instrument is still functionally an authentic clarinet, not an oboe.

It seems to us incongruous and illogical to classify an ancient instrument as oboe or clarinet according to a criterion that would not be valid for our modern oboe and clarinet. More generally, we think it is a mistake to try to classify any ancient instruments in exact modern terms; it is enough to say that they were obvious forerunners of several modern instruments, sharing some of their features.‡

The Upper Register. Of course, these ancient instruments had no keys; only holes and generally only six of them. Then the musician could play seven distinct notes, in a mode that is built into (*i.e.*, determined by the construction of) the instrument. Now the ancient Egyptians used a peculiar arrangement, an oboe–like or clarinet–like instrument in which two tubes proceed either from a single mouthpiece, or from two mouthpieces held simultaneously in the mouth. But the very numerous tomb drawings give sufficient detail – all in agreement – so that we can understand their function. Both tubes had holes, covered by the fingertips; but each hand enclosed both tubes with the right hand generally above the left. So the upper notes were played by the right hand on the left tube, the lower notes with the left hand on the right tube. In other words, the appearance of a two–tube instrument simply tells us that the principle of the upper register had not yet been discovered. In fact, it was not discovered for at least a thousand years thereafter; numerous wall paintings found in Pompeii (Schefold, 1956) and in Etruscan tombs in Tarquinia (Pallottino, 1956) show the same two–tube arrangement, in much better detail than do the Egyptian sketches.

Eventually it was found – almost surely by a serendipitous accident like a cracked tube – that opening a very carefully placed small hole near the mouthpiece allows a single tube to play at a higher pitch called the upper register.⋆ On the clarinet, with its uniform

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numbered harmonics disappear. As noted below, this also accounts for the different effects of the register key in a clarinet and oboe.

‡ In exactly the same sense, the pterodactyl was a forerunner – perhaps an ancestor – of modern birds, sharing some of their features; yet it would be absurd to try to classify the pterodactyl as belonging to any particular modern bird species.

⋆ As a scientist would explain it today, this hole must be placed at or very near a "node", or point of minimum sound pressure, for the upper register vibration mode; then opening the hole drains sound energy from the lower mode but not the upper, causing the instrument to speak out in the upper mode. All this is explained in detail by Benade (1990). Exactly the same physical principle is used today in the multimode laser, in which the emitted light can be made to jump from one color to another by varying the loss in the different modes.

bore, opening the register hole causes the frequency to rise by a factor of 3, or the pitch to jump a twelfth, while with the conical bore of the oboe the natural modes are different, as noted above, which causes the jump to be an octave.

With discovery of the upper register, in principle up to seven more notes become available with six holes. To go beyond that and play intermediate notes (a pseudo–chromatic scale) would be possible but quite complicated, because as in the toy ocarina, this would require different combinations of open and closed holes, so generally more than one finger would have to be moved for each new note in the scale. It would require a real virtuoso to execute a chromatic scale smoothly.

Although they must exist, we have never seen an analysis of the hole positions on a surviving ancient instrument, to deduce the scale, or mode, that it used. It is possible that no two instruments were alike in this respect, in which case each instrument would play its own distinct mode. If so, this would help to explain why elements of harmony do not seem to have developed; each performer would be necessarily a melodic soloist unto himself. It is true that many drawings show several musicians in a group with several different instruments; but of course the drawings do not tell us whether they played simultaneously or in sequence.

Not only drums and trumpets, but also oboes which now seem to have upper registers, were used by the Turks in the 17'th Century, played by mounted bands accompanying their armies, who invaded Europe marching to music. In spite of our horrified disapproval of all the other antics of the Turks of that time, we did admire their music; it inspired Mozart's "Turkish March" rondo which young piano students must learn, and our modern military bands have evolved from them. For evolution of the modern keyed oboe from the ancient form, see Philip Bate (1956).

An instrument like our modern clarinet appeared in the 18'th Century (for details see Baines, 1963; Rendall, 1971), and Mozart was also the first composer to appreciate its possibilities (although it was Brahms who brought them out fully). Note the Mozart Trio in E♭, K. 498 of 1786, for the remarkable combination of piano, viola, and clarinet; the writer has played the piano part of it many times, but does not understand how it was possible to play the clarinet part on any clarinet that existed in 1786.

The advance from the ancient forms did not start until the late 18'th Century, when the idea of adding metal keys to do what human fingers could not reach started a gradual, but haphazard evolution. To cite only a few examples of the dozens that are known, Kusder of London was producing a 5 key bassoon in 1780. Likewise, in London Potter was making a 6 key flute in 1795, and Clementi & Nicholson an 8 key flute in 1820. G. Astor of London was producing a 5 key clarinet in 1785, which advanced to a 6 key instrument by Astor & Horwood in 1810. Then in the period 1810 – 1840 many kinds of different 10 to 13 key clarinet systems were made. Similar developments, different in details, proceeded simultaneously in France and Germany, so by 1835 there was a situation of total chaos: dozens of different key systems, each of which solved some particular problem but none of which was really satisfactory in all musical situations.

To bring order out of this required an exceptional individual. Theobald Böhm was a German trained in the family goldsmith business, who became also a virtuoso flautist, performing on concert tours. It required this unique combination of talents to understand the totality of what was needed musically; and at the same time to know how to make it in the metal. In 1832 he invented the key ring and a system of keys that accomplished a chromatic scale of a few octaves for the flute. He also wrote a book, recently translated and republished, explaining it. The modern Böhm flute reached essentially its present state of development by 1847; its key arrangement makes it easy to play passages that were difficult or impossible on earlier instruments. For details, see Philip Bate (1969), Nancy Toff (1979), Theobald Böhm (1992).

In about 1840, C. Sax and E. Albert of Brussels devised a key system for the clarinet which was standard for many years as the "Albert system" clarinet. In 1843 the clarinetist H. Klose and the instrument maker Auguste Buffet, in Paris, patented a still better design following the principles of Böhm for the flute, which became known as the "Böhm clarinet". The two systems were in competition for many years; when the writer was a child making unpleasant sounds on them, Albert clarinets were still to be found in school orchestra collections, and so was advertising to indoctrinate us into the advantages of the Böhm, giving examples of passages that are impossible to execute smoothly on the Albert, but easy on the Böhm. Today, other post–Böhm key systems are being made.

In this work we do not go deeply into the properties of wind instruments, because it is unnecessary; the greatest modern authority on wind instruments, Arthur Benade (1990) has written a fine and almost overwhelmingly complete exposition with far more details than we could give here. This is the first source to consult for properties of wind instruments; no other author has a fraction of his understanding of the physical principles or his experience with fine–tuning these instruments for optimum tone and responsiveness.

The Lute and the Minstrel's Fiddle. These instruments became, so to speak, the parents of the violin, which shares some features of both. The lute was imported from the East in very early times so we do not know its exact antiquity; primitive versions were present throughout the available historical record.

Ancient Egyptian tombs also have numerous drawings depicting familiar looking instruments, which Manniche (1991) again classifies confidently as lutes, mandolins, and guitars although we are unable to see anything in the drawings to justify such distinctions and relatively few specimens have survived. But we have hundreds – perhaps thousands – of tomb drawings depicting them in use. Invariably they are plucked; the principle of the bowed string was evidently not yet discovered although the archer's bow was well known in ancient Egypt. Once again, we think it is a mistake to try to force modern classifications, which did not exist in ancient times, onto ancient instruments; it is enough to say that they are obvious forerunners of several modern instruments.

In any event, later historical records show that in the Near East the lute was highly developed, and was the basis of Islamic music of the period of the Umayyad caliphate (661–750), where it reached its "classical" shape, and it was imported into Europe some time afterward; we have already noted its appearance in Spain in the 13'th Century. By the 16'th Century it had become a very popular instrument in Elizabethan England.

The principle of the bowed string does not seem to have originated in the East; it is conceivably a simpler and more satisfactory version of the hurdy–gurdy principle described below. A bow would be easier to make, more reliable, and under better control by the player. In any event, the minstrel's fiddle (or fiddel) was perhaps the most popular of all instruments in medieval Europe. Numerous old illustrations (see, for example, the Larousse Encyclopedia of Music, 1974) show it having a roughly oblong box about 18 inches long, 8 inches wide with rounded corners. The heavy box was hollowed out from a single block of wood, then the thin top sound board was attached. The bridge was placed in the center of the sound board and it usually carried four strings, which were bowed across the handle at the point where it joins the box. The bow was literally a true "bow", with a circular arc like an archer's bow.†

But because of the distance from the end of the box to the bowing point, this could not be played as a violin is today, held securely between the player's chin and left shoulder. The bowing point would be too far away for human arms to reach, if the bow is to remain perpendicular to the strings. In fourteenth Century illustrations showing it in the act of being played, it is held either vertically by a seated player, clamped between the knees like a cello, or if the player must stand and move about it is held awkwardly and precariously in a horizontal position across the shoulders; the left hand is on the strings, the bow is in the right hand moving vertically to the left of the left shoulder; but the box is so long that it extends a few inches beyond the right shoulder. One cannot tell what is supporting it; perhaps there was a hook on the back that rested on the right shoulder. It was just not a practical way to manage things.

One should be warned not to take these old artist's illustrations too literally; depictions of musical instruments being played are often inaccurate because the artist did not observe the musicians carefully in actual playing. Looking only at a musician holding a fixed pose, one would not understand what was important. Old illustrations often show instruments being held in ways that would make it impossible to play them; violins being bowed across the broad part of the instrument, fiddles held so the bow makes a 45 degree angle with the string, *etc.*

Early Instrumental Music

Of course the human voice, being the most available of all sound producers, would be prominent in the music of early times; but still we may be surprised at the degree of that prominence and how little purely instrumental music existed in those times, even though a wide variety of instruments was available for it. Thomas Morley (1557?–1602) introduced his *Fantasia* for five recorders with the comment: "*This is the most Principall and Chiefest Musick which is made without a ditty.*"

In early music, even where instruments are used prominently, there is what seems to us a curious reluctance to make use of their full capabilities. In the Elizabethan lute songs, where today we would expect the lutenist to break into a virtuoso passage, there is instead a peculiar halting quality, as if the composer or the performer were not quite sure what to do next.

On the other hand, music of the Elizabethan period already shows that full awareness of the capabilities of the human voice, that comes with long experience. An elaborate ballad with really creative passages for the voice, named "*My Lord Willoughby's Walkin'*

† Medieval fiddles can still be bought today; see the "Lark in the Morning" catalog in our bibliography.

Home" sings of the exploits of an English General against the Spanish Army – not a very promising topic for a popular song. But its musical quality was such that it spread all over Europe and became, so to speak, one of the Top Ten Hits of the 17'th Century.

Presumably, the explanation is that even after an instrument has reached a high state of technical perfection, it may require generations to become fully aware of its musical capabilities. Late in life, Johannes Brahms testified to his own slowness to appreciate the expressive capabilities of the cello – on hearing the Dvorak cello concerto he exclaimed: "Why on earth didn't I know that one could write a cello concerto like this? If I had known, I would have written one long ago." This from the man who had already written the double concerto and the cello parts for four symphonies and about two dozen chamber music works.[‡]

The Violin

It appears that the European lute and fiddle makers gradually evolved their instruments into the modern violin. But what accounts for the peculiar narrow–waisted shape of the violin, which neither the lute nor the fiddle have? A writer of pamphlets on early instruments for the Metropolitan Museum of Art supposed it to be only aesthetic: "··· they were given beautiful shapes by instrument makers who felt beautiful sounds should come from beautiful instruments." Let us point out, then, that the choice of that shape had nothing to do with aesthetics; it was forced on the makers by the need to make a very practical compromise.

The main necessity was to get the bowing point closer to the end of the box, so human arms could reach it. But on the one hand, to get a good volume of sound a large, broad box was required for the same reason that a piano needs a large sounding–board. On the other hand, to move the bow from one string to another, it was necessary to tilt the bow without colliding with the box.

One solution was to move the bridge and bow up nearly to the end of the box opposite to the handle, but separate the strings so widely at that point that a very small tilt would move the bow from one string to the next. Indeed, some early illustrations show this solution, a modified minstrel's fiddle held like a violin, with the bow passing across the broadest part of the instrument, where it could hardly be tilted at all. But the smaller the tilt from one string to the next, the harder it was to play on the right string reliably. To ensure reliability a strongly curved bridge was needed; but then a narrow box was required, to permit the bow to be tilted through large angles.

In the end, the reliability consideration prevailed, and the successful solution was to make the box narrow in the region where the bow moves across it, broad elsewhere. Then one can put the bowing point wherever one wishes; and the place finally chosen as most comfortable results in the bow passing about five inches from the tip of the player's nose. In the modern violin, the bow can be tilted nearly twenty degrees from one double stop position to the next; thus the performer has a wide margin of safety against inadvertently bowing the wrong string.

[‡] The Brahms F major cello sonata is a work so busy that the cello is never allowed to sustain a note long enough to bring out any expressive quality.

Presumably, the fact that it was possible to adopt this narrow–waisted box shape without disaster was discovered in many cautious small steps, by anonymous craftsmen in the early 16'th Century. Michael Praetorius (1619) gives illustrations of instruments with a transitional shape intermediate between fiddle and violin, a shallow waist beginning to form in approximately its present position, but the elongated shape of the rest of the box still retained. One of these, called the *lyra da braccio*, could be described equally well as a stretched violin or a pinched fiddle.

It appears that the violin shape settled down into its present one – deeply cut waist and wider but shorter broad parts – gradually, in a series of experiments by Andreas Amati, who came to Cremona about 1550. A surviving instrument by him dated 1574 is virtually indistinguishable, except by a trained eye, from the violins being made today (it is slightly smaller and therefore, for a reason we shall see presently, thin–toned). Some ninety years later, Antonius Stradivarius learned his trade as a young boy apprenticed to Andreas' grandson, Nicholas Amati.

It might be thought – and doubtless the early experimenters feared – that this shape of the violin would ruin the tone quality, by making it too "stiff". Fortunately, the opposite turned out to be true; in fact, the deep, rich tone on the g–string is assisted by that narrow waist. It is now well known (Benade, 1990, pp. 531–535) that the tone depends chiefly on the pitch of the various resonances of the instrument. For the moment, let us just say that a 'resonance' is a pitch at which something in the instrument (string, body, or enclosed air) vibrates of its own accord when the instrument is disturbed from rest.

You can hear the deepest resonances by damping the strings with your fingers (so their own resonances will not obscure matters) and snapping the back of the violin with your fingernail, noting how much the sound varies with the snapping point. The sound is a dull thud, but with a definitely recognizable pitch. The deepest tone thus heard is produced by snapping under the g–string end of the bridge. This is the "breathing mode" air resonance in which air flows alternately in through both f–holes, then out through both; in the modern violin it is near C$\sharp$ just above middle C, and this gives the violin its deep tone – and willingness to speak out loudly – on the g–string.

Mathematical analysis, performed by the great physicists Hermann von Helmholtz and Lord Rayleigh in the late nineteenth Century, shows that the pitch of this deepest air resonance depends almost entirely, not on its shape or stiffness but on the air volume of the box and the area of its f–holes; so the waist does no harm to it. The viola, with a slightly greater air volume, has this resonance about a whole tone lower; and this is the main reason for its different tone.*

But if you snap the back just under the sound post (approximately the e–string end of the bridge), you hear what at first seems to be a higher tone; but on careful listening

* This can be demonstrated rather dramatically by making a violin produce a viola tone; merely fill it with carbon dioxide gas instead of air, from a rubber tube inserted into an f–hole. The sound velocity in pure carbon dioxide is 21% slower than in air, and this lowers the pitch of all air vibration modes by about a minor third. With a mixture of 2/3 carbon dioxide and 1/3 air the lowering is about a whole tone (there is no danger to the violin from this; in fact, a violin could be preserved intact for centuries by storing it in carbon dioxide, because it is chemically inert; with no free oxygen present the wood could not rot. However, pure nitrogen would be an even better preservative than carbon dioxide).

one perceives that the lowest tone present is still that C♯ of the breathing mode; only now it is so much weaker that other resonances can be heard. Most important is the second deepest resonance, in which the air sloshes back and forth between the broad sections. The narrow waist affects this mode a great deal, by impeding the flow and lowering its pitch down almost to A 440, which helps to enhance that deep tone.

The third air resonance is the "sideways" mode, in which the air sloshes back and forth between the left and right sides of the violin, thus flowing out of one f–hole while flowing in the other. The narrow waist raises the pitch of this mode appreciably (over what a box with no waist would show), but it is so high (nearly two octaves above middle C) that it plays no role in the deep tone anyway.

The still higher resonances of air and wood, which give the violin its brilliant tone quality, depend for their fine details on fine details of its shape and the stiffness of the purfling; but these are many dozens of these, so numerous and close and overlapping that their effects average out and the net result depends very little on the exact size and shape. Thus the box shape and dimensions affect the violin's tone mostly through their effect on the lowest two air resonances. Of course, this is only one of many considerations that a violin maker has to take into account; others concern the rigidity of the glued joints, which affects those resonances in which they bend, the exact shape and thickness of the wood under the bridge and the position of the sound–post, which affect the efficiency of transfer of vibrations from bridge to body, *etc.*

The important acoustical function performed by the resonant modes, helped inadvertently by that narrow waist, can be appreciated by comparing the aforementioned sound of a snapped violin with that of a large (12 inch) skillet held loosely by its handle and snapped by your finger. The lowest resonance of the skillet turns out to be almost the same as that of the violin; but for the skillet the next higher resonance mode is not at A 440 but nearly two octaves higher; the absence of anything in between makes the difference in what you hear.

A little is known about details of the final stages of development of the violin, because Antonius Stradivarius is so recent that many of his records – particularly the drawings and templates from which he made his instruments – have survived and may be seen in the museum in Cremona. It appears that he kept experimenting all his life; having found a particularly good design he might stick to it for a few instruments, but then would try a new design, altering some dimension a little bit to see what effect this had on the quality. Among other things, he was moving those resonances about slightly, fine–tuning them. For a good (and loud) tone he had to get those two lowest air resonances down a bit lower than in previous instruments, but if they were too low he would start to get a viola tone instead.

Of course, Stradivarius was not successful in all his experiments; indeed, if he had been, he would have learned nothing from them. Over his long life ($\simeq$ 1644 – 1737) he made some 1200 violins, and in every period there were some good, some bad. This is not a reflection on his craftsmanship, but simply evidence that he was still experimenting; it was only from getting a bad instrument that he could learn that he had carried some change too far.

But now the scene shifts to 250 years later: which violins are still in existence? The best ones have been preserved lovingly and kept in good repair by generations of good musicians; the worst have been destroyed by little boys who did not want to practice on them. The reputation of any craftsman is helped if he can be judged merely from his works that are still around 250 years later.

Early Keyboard Instruments

The known history of the organ is given by Sumner (1952). The hydraulic organ of Ctesibus, developed at Alexandria (2nd. Century B. C.) is depicted on some Roman coins. Unfortunately, they show little detail and we are left in doubt about what kind of keyboard it had, although it seems almost impossible that it could have been played without one. But keyboards with pivoted keys like our modern ones are described in the *Hydraulicon* of Vitruvius (1st Century A. D.). Keyboards were applied also to stringed instruments of the hurdy–gurdy[†] type before the 11'th Century.

A small portable organ called the *Regal* is described by many writers in and before the 12'th Century. By the 12'th Century it had become a product so standardized that tables were available for builders, with the correct dimensions to make the pipes for proper tuning. We know this from early 12'th Century manuscripts by one *Theophilus*, which is believed to be the pseudonym of a famous metal–worker, the Benedictine Monk Roger of Helmarshausen who flourished about 1100 AD; some of his works have survived to our time.[‡] Theophilus describes in great detail the process of making these organs; the pipes were made of copper pounded into thin sheets, wrapped around a tapered iron mandrel and soldered along the seam. He also gives detailed instructions for casting sets of tuned bells; to justify all the special jigs, mandrels, and templates needed to make these instruments, they must have been in something like mass production. Indeed, another 12'th Century manuscript[⋆] has an illustration of a group of musicians playing such an organ, together with tuned bells, a lyre, and a trumpet. The organ encompassed only about one octave, and had keys rather like modern cash–register keys.

Although the oldest are long gone, fairly old organs are available for study in churches all over Europe, so there is no question about how they were built after they had become nearly perfected and reached their present size. The full chromatic scale appears to be already in existence in the great Halberstadt organ, built in 1361, although its tuning was doubtless different from those of today. On these grounds, and the absence of any evidence for keyboard instruments in the Orient in early times, we may suppose that keyboard instruments are European inventions, not migrations from the East. For many more details about the great variety of the earliest keyboard instruments, see Wier (1940).

[†] These were played by turning a crank, which caused an abrasive wheel to scrape against whatever strings were lowered to contact it. The aforementioned "Lark in the Morning" catalog has illustrations of ten different hurdy–gurdy instruments still available today.

[‡] An English translation of the Theophilus manuscripts, with historical commentary, is in Theophilus (1963), which also contains photographs of some works of Roger of Helmarshausen.

[⋆] This is in the library of St. John's College, Cambridge, England; Manuscript B 18, fol. I.

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CHAPTER 3

DEVELOPMENT OF THE PIANO

The making of other instruments (even the organ) can be done in the traditional way of the individual craftsman who makes each part himself and fits them together one by one, using only simple tools. But a piano involves many different technologies; the making of hammers, actions, wires, and frames requires several entirely different skills and facilities, which no one workman has. It is necessarily an industrial project with organized cooperation of many different specialities. If a modern piano was made by an individual craftsman in a small shop, it would be of greatly inferior quality, it would cost hundreds of times more than it does, and the number of pianos in the world would be a thousand times smaller than it is. For this same reason, the development of the piano was a vastly more complicated process than that of any other instrument, requiring many different people to contribute their special expertise to the solution of many different problems, and warranting a separate Chapter for it.

The Harpsichord

Although it took place in Europe, the early development of the harpsichord is slightly mysterious today. Some authors state that the principle of plucking strings with flexible crow quills started from the Spinet by Giovanni Spinetti of Venice (1503). However, others make the more plausible claim that the Italian name 'spinet' or French *épinette* comes from the Latin *spina* (thorn),[†] that spinets existed under that name for perhaps a hundred years before 1503, and Spinetti merely named himself for the instruments he made, a common custom then. An Italian instrument used by Queen Elizabeth I (1533–1603) may be seen in the South Kensington Museum, London; she was an accomplished performer on it.

The first spinets produced feeble sound, with a different quality for different keys. Much more experimentation with size and shape of bridge and soundboard, and string length and tension, was needed to develop a satisfactory instrument. Larger, louder, and more uniform sounding instruments called harpsichords appeared in the middle 16'th Century, and were well developed over the next 100 years, as the Belgian Ruckers instruments of 1590 – 1659 show. By the time of Alessandro Scarlatti (1659 – 1725) the harpsichord had settled down into a more or less perfected standard product, present in considerable numbers throughout Europe.

Metamorphosis Into The Piano

A harpsichord string can produce only one sound however you press the key, because the quill always breaks free at the same point – where it is placing the same force on the string. Thus there is no dynamic variation *on any one key*. However, this can be overcome in three ways. Firstly, install a second manual, which controls another set of strings and gives the player the option of plucking two or three strings on a note, making a variation

[†] The English words 'pin' and 'porcupine' – literally, 'pig with thorns' have the same Latin origin.

of loudness and tone. This was tried about the middle of the 17'th Century, but it was expensive and never really satisfactory.

Easier, and much better, one can recognize that in most music the dynamics is quite simple: "expression" consists mostly of emphasizing the highest notes in a phrase (in imitation of a human singer, who must work harder to produce higher notes). So the builder needs only to make the quills progressively stiffer, so they pluck the higher notes harder. In the best harpsichords, this slight automatic gradation of loudness is carried out so smoothly that it does not call attention to itself; yet in the playing one is seldom aware of any dynamical limitation compared to what can be done on the piano.‡ Nevertheless, if one wants to emphasize any note strongly in a phrase or chord, or give prominence to a bass figure over the treble, it cannot be done on a harpsichord.

But neither of these solutions deals with another major problem of the harpsichord, the harsh, twanging sound that the builders tried unsuccessfully to soften (although today many scientists could tell them how to do it). Apparently, this sound is offensive only to Western ears; the Sitar of India has it to a far greater degree than does the harpsichord, due to what we would consider inappropriate scaling (length, density, tension) of the strings; but nobody seems to complain about this. Note that "tone" is concerned with the distribution of pitch in the many vibrations produced by a single string; not the variation of overall loudness over different strings, as discussed in the last paragraph.

Actually some progress was made in this respect; the Italian harpsichords, following their early spinet tradition, were small and light (the string for C above middle C only about 10 inches long) with a shrill, penetrating tone. The Flemish instruments evolved from them achieved a darker tone, generally regarded as more sophisticated, by making the instruments bigger (the aforementioned string is now about 14 inches long; this length is still used on our modern grand pianos).

The third solution solves both of these problems; and actually it had been well known for centuries before Spinetti. The dulcimer is an ancient instrument, which is essentially a long zither played like a xylophone, with the strings struck by little soft–headed hammers held in the hand. Its pleasant tone and great possibilities of musical expression were well known, so it is very hard to understand why over 200 years passed, during which time makers of spinets and harpsichords were struggling to improve the sound, before this principle was applied to the harpsichord. Actually, we know that several people did suggest this; but they were not listened to, for reasons that we cannot comprehend today (but of course, the phenomenon of a person in deep trouble, who indignantly rejects the only thing that can help him, is observed in every field of endeavor).

Finally, in the early 18'th Century, the decisive step was made. In Florence, the Prince Ferdinand de Medici kept in his palace forty harpsichords and spinets. To maintain them all in working order required an in–house master mechanic, so he hired a young harpsichord maker from Padua named Bartolomeo Cristofori (1683–1731). Fortunately for us, it seems that maintaining the Prince's instruments was not quite a full–time job, for Cristofori found there both the time and the facilities to try out the dulcimer idea,

‡ This is not to say that the actual physical sound *energy* generated is greater in the treble; measurements show the opposite to be true. However, what matters is the loudness as perceived by human ears. Our ears are more sensitive to high pitches than to low; and this more than compensates the greater bass energy.

completing his first instrument in 1707. It was, of course, far from satisfactory on the first try, and he continued to experiment, producing a fancier looking one in 1711, and his first *real* piano in 1720. We do not know how many more he made.

The Cristofori Piano of 1721

This is believed to be the oldest piano still in existence, and it can be examined in the Metropolitan Museum of Art, New York.* The writer spent a long afternoon studying it from every possible angle and recording measurements on it (the guard became suspicious when I crawled under it, but I managed to convince him that I meant no harm, and was merely very interested in knowing how Cristofori did things; particularly the things that are usually out of sight). Here are some of the notes that I made on it:

The case has the standard harpsichord shape (like a thin grand piano, except that the back is cut off square instead of rounded). The "white" keys are of light–colored wood, the "black" keys and key blocks are apparently of ebony. It has no pedals. It was discouraging to see that there were loose strings and broken parts; no effort had been made to restore it to playable condition or even its original appearance, although the latter could have been done easily.†

This piano encompasses 4.5 octaves, ($C_2 \rightarrow F_6$).‡ Most of the notes are double strung with thin brass wires, although the lowest four are single thick brass wires. The top treble string is 5" long, and is struck 0.5" from the end; the bottom bass string is 5.5 feet long and is struck 0.5 foot from the end. The key dampers function in the same way as the modern ones, with the peculiarity that they rise on wires that go *between* the strings damped; one is working at dangerously close quarters here.

Today we would consider it an error, making a shrill, tinny tone, to strike a middle range string only one tenth of its length from the end. Probably he was only copying Italian harpsichord practice here, not realizing the importance of the striking point. For the top few notes the striking point does not matter very much as far as tone is concerned (this affects only high overtones beyond the range of human ears), but it would increase the efficiency of sound production to move the striking point further from the end of the string; this opportunity is still missed on modern pianos.

The bridge and sound board also copy harpsichord practice, but are not very different from those on a modern piano. The slanted pegs that press the strings to the bridge are identical with those on a modern piano, except that the bottom seven strings have only one peg, while a modern piano has two pegs on every string. The bridge is not undercut

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* Another Cristofori piano, dated 1726, is in the Museum of Leipzig University.

† Restoring it to playable condition would be a major undertaking, since the action had no bearings. Their function was served by leather hinges, which after 250 years would probably disintegrate on any attempt to bend them; so every one would need to be removed and replaced.

‡ By C_3 we mean the third C from the bottom on a modern piano, by A_5 the next A above C_5, etc. Thus C_4 is middle C, A_4 is the A 440 tuning base, C_2 is the "Cello low C", C_6 is the "Soprano high C", and G_3 is the lowest note of a violin. On a modern piano the lowest note is A_0, the highest C_8. Note that before 1960 some writers used an index one lower; C_3 stood for middle C. Our notation agrees with Benade (1976) and other recent writers. Also, some writers from Helmholtz (1877) to the present use small letters and primes to denote notes measured *from* middle C; thus f''' would mean the third F above middle C, what we call F_6.

on the bass end as it is for about the bottom octave on a modern piano (to give more flexibility to the sound board).

The action of the piano is shown in Fig. 3.1:

cristex6.pcl2.54

Figure 3.1. The Cristofori Piano Action

One can recognize several features of the modern piano action; the key K which turns on a pivot so that its back end rises when a key is depressed, the hammer H with a familiar shape but unsatisfactory material (wood covered with leather), the vertical jack J which conveys the key motion to the hammer, the escapement E, which disconnects the hammer from the jack just before it strikes the string, the back check B which catches the hammer on the first rebound from the string and prevents it from striking the string a second time, the damper D which stops the string from sounding when the key is released. He surely worked long and hard to get that far. This action was successful enough to survive for some time in the works of other piano makers; it was easy to play (requiring less force than does a modern piano), but lacked the rapid repeated action that we are accustomed to today; after playing a note one must release the key all the way up and allow the hammer to settle back down to its original position before the note can be repeated.

All in all, it is astonishing how many features of the modern piano were worked out already by Cristofori, in only about fifteen years of part–time experimentation. But it required 150 more years to complete the development, up to the stable design that was reached about 1870.[†] There were several obvious things still needed; a sustaining pedal (although this is a triviality that Cristofori could have added at any time); better materials for strings, which were not available then, better materials for hammers (this required a major research effort with results that are not yet 100% satisfactory), a stronger and more stable frame, so that it could stand a higher tension on the strings and stay in tune when the weather changes; but most of all, a faster, more reliable repeating action.

Silbermann, Stein, and Broadwood

Gottfried Silbermann (1683–1753) of Freiberg, Saxony, was an organ builder who became interested in the dulcimer principle and started experimenting with a simple action invented by Cristoph Schröter, a German organist. In 1728 Silbermann made a pianoforte with the Schröter action; but then learned about the Cristofori action and switched to it. The action of Fig. 3.1 is found unchanged in the pianofortes [said by Forkel (1802) to number originally 15] made by Silbermann for the various palaces of Frederick the Great. His *Sanssouci* palace at Potsdam was completed in 1747, and in that same year Johann Sebastian Bach visited it and, as narrated by Forkel, played on several of them.[‡] He had tried previously

[†] We do not mean to imply that the modern piano is now perfect; only stable. As noted later, it still has many serious imperfections that could be corrected easily without any increase in cost.

[‡] In December 1991 the writer visited *Sanssouci* and saw one of these pianos, still there in Frederick's magnificent music room [depicted very accurately – even to fine details of the rococo wall decorations – in the painting by von Menzel, reproduced on the inside covers of the Larousse Encyclopedia of Music (1974), which shows a concert in progress with Frederick himself at the flute]. The piano is fancier than Cristofori's, with four trumpet–turned front legs and a cover that

one of Silbermann's first efforts and complained that it was weak in the treble – which Silbermann tried to correct, without success.* This would be particularly bothersome to one who was used to good harpsichords which, as noted, become progressively louder in the treble. But Bach was too polite to repeat that complaint to Frederick, and instead he improvised grandly on a theme that Frederick gave him, which later expanded into his *Musical Offering.*

In spite of their defects, the Silbermann pianos remained in use for many years and played an important role in piano pedagogy. Carl Philipp Emanuel Bach spent several years at Frederick's court starting in 1740; and while there, with Silbermann pianos available for his use, he wrote his famous "The True Art of Playing the Clavier" which, 50 years later, Beethoven required his piano pupils to read. In 1772 C. P. E. Bach was living in Hamburg and the English writer Charles Burney visited him. He reported (Burney, 1773) that Bach had a Silbermann piano in his music room, and played it beautifully for hours.

Silbermann had four apprentices who learned the craft and, about the time of his death, went out into the world to seek their own fortunes. Johann Andreas Stein went to Augsburg with the Schröter idea, and developed it into the light "German action" which he manufactured with great success, as we shall see. The characteristic feature of the Schröter action is that the hammer butt is not fixed, but moves up and down on the key. Christian Friederici went to Gera in West Saxony and started the development and production of vertical and square pianos, in particular some square art pianos which found their way into the finest palaces, although more as beautiful furniture than as viable musical instruments; for over 100 years square pianos continued to use the Cristofori mechanism. Johannes Zumpe and Americus Backers took the Cristofori idea to England, where Zumpe made several square pianos, also not very successful as musical instruments. Far more important, they interacted with the just forming Broadwood company.

John Broadwood (1732–1812) was a Scotsman who as a young man, according to plausible legend, walked penniless all the way to London and found employment as a workman in the Schudi harpsichord factory. Zumpe, Backers, and Broadwood developed the Cristofori mechanism into the stiffer but more powerful one that came to be called the "English action" and added the sustaining pedal. The energetic Broadwood rose in the company to become a partner of Schudi, married Schudi's daughter; and thus came eventually into possession of the company. It went through some complicated name changes, but became *de facto* the Broadwood company in 1783 and turned to piano manufacture. Their last harpsichord was made in 1784; by 1984 Broadwood had produced some 270,000 pianos. For many further details, see Wainwright (1984).

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closes over the keyboard. Unfortunately, the public was not allowed within touching distance of it and the cover was closed (with Frederick's plain black flute lying on it as if to hold it closed), so the keyboard could not be seen.

* This remains one of the major defects of our modern grand pianos and the cause of bad, muffled sound by inexperienced pianists; to achieve any kind of balance between bass and treble, we are still obliged to work the right hand much harder than the left. This is particularly exasperating, because it would be so easy to correct today; yet no piano maker appears to be doing it, and modern piano actions seem designed specifically to make the problem worse. See further comments below and in Chapter 5.

The Roles of Mozart and Beethoven

In October 1777, Mozart passed through Augsburg on his way from Salzburg to Paris, encountered his first Stein piano, and wrote back enthusiastically to his father in words that have been quoted so many times that we must apologize for quoting them still another time:

> "Before I had seen any of Stein's make, Späth's claviers had always been my favorites. But now I much prefer Stein's ···. His instruments have this splendid advantage over others, that they are made with an escape action.† Without an escapement it is impossible for a piano to continue vibrating after the note is struck. When you touch the keys, the hammers fall back again the moment after they have struck the strings, whether you hold down the keys or release them."

This gives very important – but rather shocking – testimony about the kind of instruments Mozart was obliged to use before then. A sharp staccato touch on the key would be necessary in order to play anything at all on the primitive non–piano made by Franz Jakob Späth of Regensburg; but this is presumably the instrument on which Mozart practiced, and developed his habits of playing. It is startling to realize that the Mozart piano works composed before October 1777 (the six sonatas K. 279–284, which contain some of his most familiar themes) were written for such an instrument.

Since the Stein piano made such an impression on Mozart, we might expect that it would have an influence on his later piano music; some of his biographers take this for granted, although none seems ready to tell us exactly what that influence was.‡ Evidently, however, the appearance of a *legato* marking would tell us that the work was for a Stein instrument rather than a Späth; such works could not have been composed before October 1777. But for the next four years in his travels he would have difficulty in locating a piano with *legato* capability and the inspiration must have faded. Only after he made Vienna his home in 1781 would he have a piano of his own with a Stein action, so we might expect to find *legato* markings used freely in his piano works composed after about 1783 or 1784.

So we checked through the Second Schirmer Edition, revised by Richard Epstein (1918) of the nineteen Mozart piano sonatas believed to be authentic. In view of the criticisms by Saint–Saens⋆ of those early Editors who took liberties with *legato* markings in Mozart's scores, it is very hard to believe that Epstein would have inserted any spurious *legato* markings, much less removed any put there by the hand of Mozart. But we find a surprise; none of these sonatas – early or late – have any *legato* markings, with two exceptions; *sempre legato* occurs in the opening *allegro* of the Sonata in C, K. 309 known to have been composed in Mannheim – the next leg of his journey after Augsberg – in

† If the hammer does not "escape"; that is, if it is not disconnected from the key just before it strikes the string, it cannot bounce away freely from the string. As Mozart notes, although not very clearly, continuing to press the key would then keep the hammer pressed against the string and prevent it from sounding.

‡ Some have supposed that his early works were written for the harpsichord rather than the piano. But the appearance of *forte* or *piano* or *crescendo* is a sure indication that it was not for the harpsichord; and virtually all his scores are full of these marks. The only exceptions are a few very early works (K. 37–41 and 107); all of Mozart's other clavier works must have been written for an instrument with at least touch–sensitive dynamics, with or without an escapement.

⋆ Quoted in Chapter 7 below.

November 1777 (where he would have had a Stein piano available), and in the *andante* of the familiar "easy" Sonata in C, K. 545, published in Vienna in June 1788. Mozart enjoyed considerable success with his concerts in Mannheim, which at the time had the finest orchestra in Europe under the conductor Christian Cannabich,† and he stayed there over four months, composing several works before resuming the journey to Paris. So the Stein influence must have been rather transitory; we can point convincingly to such an influence on only those two sonatas. But why are they so far (11 years) apart?

There is a very plausible explanation: we suggest that the K. 545 was actually composed in Mannheim in November 1777, but not touched up for publication until 11 years later. The Mozart biography by W. J. Turner (1938, p. 231) sheds light on this. In Mannheim, Mozart gave lessons to Cannabich's young daughter Rosa on a Stein piano. In a letter of November 4, he reports that "I am working now on a sonata for his daughter, which is already complete up to the Rondo." Elsewhere he states that the *andante* is intended to be a tone picture of Rosa. Turner supposes that he is referring to the K. 309; but its *andante* seems to us too clumsy and uninspired for that purpose, and its *rondo* is long, difficult, and not very interesting; not what one would expect a young piano pupil to want to – or be able to – play. In contrast, the K. 545 has always been recognized as pedagogical music to serve just such a purpose; not only technically easy, but attractive to the pupil. Its *andante* is smooth and easy–flowing, with Schubertian simplicity and piquant but unobtrusive little harmonic embellishments, making an effect much like Beethoven's *Für Elise* and eminently suited to be a tone portrait of a young girl; its *rondo* is bright and easy to play, also eminently suited for this pedagogical purpose, yet with (we think) superior musical content to the K. 309 *rondo*.

This theory makes the 11 year delay in publication easy to understand also; in Mannheim, Mozart was preoccupied with turning out major works in hope of securing a good position; that was the whole purpose of his Paris trip. His efforts with Rosa were made only to ingratiate himself with her father, in hope of securing such a position in Mannheim. That having failed, the K. 545 was not, in his mind, a big enough work to advance this purpose with others, and any further time spent on it would have been counter–productive. Later in Vienna, when he again had a Stein action piano available and pupils to write for, he would finally have good reason to dust it off and put it back to use.

But whether our theory is right or wrong, the surprising thing is that, even after he had a Stein action piano of his own, it appears that (with this one possible excepton) Mozart never again indicated the *legato* in a piano work. After his initial excitement at discovering the Stein possibilities, he must have reverted back to his previous mind–set (a common phenomenon) and did not think of piano music in terms of finger legato. He would still prefer the Stein action because of its other virtues noted in his letter; this agrees with the later testimony of Czerny and other contemporaries about the status of staccato

† As an amusing circle of coincidences, the reason why Mannheim had the finest orchestra in Europe was that the local Elector, Karl Theodor, had inherited immense wealth from his grandmother, who was the sister of none other than that Prince Ferdinand de Medici who had supported Cristofori in the development of the first pianos! And Karl Theodor was bound by her will, which stipulated that it could be used for support of musical activities but not for raising of armies; the musical tastes of the Medici continued to have a good influence long after their time.

and legato piano playing before Beethoven.

The Stein action that Mozart praised but failed to exploit very much is shown in Fig. 3.2.[‡] In all the following piano action drawings, the letters K, H, J, E, B, D denote the homologous parts of key, hammer, jack, escapement, back–check, and damper. They perform basically the same functions in all actions, with varying degrees of efficiency and reliability.

Fig. 3.2. The Stein Piano Action, Sometimes called 'the Mozart piano'

Stein's pianos became so popular that he was unable to produce them fast enough, and several competitors went into business making copies of them; in the 1780's both Mozart and Haydn bought copies made in Vienna. But throughout Mozart's lifetime, Stein action pianos were still far from ubiquitous, and Mozart had his own piano carried all over Germany for his concerts. The Stein pianos had a five octave range [that is, five full octaves, 61 keys, $(F_1 \rightarrow F_6)$], and all of Mozart's piano works are of course confined to that range (since no more advanced piano existed until some years after his death).

Nannette and Beethoven: While Mozart had high praise for Stein's pianos, it was otherwise for Stein's little daughter Nannette, then 8 years old and playing the piano as

[‡] These illustrations are the best we are able to offer and they are sufficient to make the important points; but we do not claim absolute accuracy for them. They started from drawings made perhaps 100–150 years ago, with some draughtsman's conception of the action but without any indication of whether he actually had it before him as a model. Predictably, different draughtsmen produced different renditions of what was presumably the same action; so these were computer processed to combine additional information, graphical and verbal, from several different sources including White (1906), Fischer (1907), Dolge (1911), Schauffler (1937), and White (1946). No single source can be regarded as entirely trustworthy on these details, and our Stein and Streicher drawings still appear to us lacking in something; the escapements seem too crude to serve their function reliably. Of course, it is also possible that Stein or Streicher changed their actions more than once without making any public announcement of this. As in all historical research, more information would be needed to resolve puzzling questions. Today, absolute accuracy about every detail of an old action could be obtained only by examining an actual specimen of the piano, known to be still in its original condition. This would be a major undertaking, requiring years of study and travel throughout Europe; yet we wish that somebody would do it.

best she could. In a letter he makes sarcastic criticisms of everything she does, in effect condemning her for not being a fully mature musician. This tells us more about Mozart than about Nannette; it is hard to imagine any other musician becoming incensed over how an eight–year–old child plays. [Of course, Mozart himself was, at age 8, famous all over Europe for his keyboard feats.] But if not a prodigy, Nannette grew up to be an accomplished pianist who performed in public concerts and had, in most areas, a good deal more sense than Mozart had.

Stein died in 1792, and Nannette, then 23 years old, and her brothers moved the Stein piano factory to Vienna. But soon Nannette married a musician named Johann Andreas Streicher and set up the Streicher piano factory. She had thorough knowledge of every detail of piano construction and action, and managed the company herself. It was long the largest piano factory in Germany, and so Streicher pianos became familiar everywhere. In addition, she took a motherly interest in Beethoven (who was only one year younger than herself, and had also moved to Vienna in 1792) and saw to it that he had what he needed to do his work.

Beethoven was presented with a Stein piano. We have found no record of the exact date at which he received it, but several sources state that his early piano sonatas, starting with Op. 2 (1796) were composed on it. But five octaves were not enough for his needs; this is seen in many places.[‡] Beethoven complained to Nannette about the 5 octave range, and she had a special Streicher piano made for him, with 5.5 octaves ($F_1 \rightarrow C_7$); several sources state that Beethoven composed many works on it.

The Streicher action of 1794 is shown in Fig. 3.3; it has evolved somewhat from its Stein forerunner.

Fig. 3.3 The Streicher Action of 1794 used by Beethoven

[‡] For example, the first movement of the Sonata Op. 10 #3 has a rising figure that Beethoven obviously wanted to carry up to A_6; but he was out of piano keys at F_6, and had to truncate it with a clearly contrived alternative (bars 104–105). A player on a modern piano may complete the passage as Beethoven wanted; particularly since he repeats the same passage a fifth lower and then terminates it as expected without the contrived ending (bars 285–286). On a modern piano he could have gone on up to C_8.

We have found no record of the exact date on which he received the Streicher either (the Beethoven biographers seem curiously uninterested in such matters), but the internal evidence of his sonatas is suggestive. The sonata Op 54, published in 1806 uses the exact range ($F_1 \to F_6$) of the Stein, and all those before it are also within this range. His third piano concerto, Op. 37, believed to have been completed 1803 and the next sonata in opus numbers, Op. 57, published in 1807 but thought to have been composed in 1804, suddenly use the full range ($F_1 \to C_7$), and so could not have been played on the Stein piano.

On one occasion Nannette Streicher discovered that Beethoven did not have any good coat, a single whole shirt, or a decent pair of shoes. When he was asleep, friends would tiptoe into his rooms, and replace the old clothes with new ones. In the morning he would put them on and never notice the difference; he simply did not think about such things when engaged in the 'throes of creation', which was most of the time. But he did express his appreciation to Nannette Streicher in many sincere letters. And Beethoven did return value for what he received; the Streicher firm got the benefit of his practical suggestions about improvements in piano action, took them seriously, and markedly improved their product. By 1824 the Streicher action had evolved on to that shown in Fig. 3.4.

Fig. 3.4 The Streicher Action of 1824

This came to be called the 'Viennese action' or 'German action' with a light touch and mellow tone. Perhaps unfortunately, this seems to be the limit of development of the piano action embodying the Schröter idea; our modern pianos have evolved from a different line involving the ideas of Cristofori, Broadwood, and Érard.

In 1817 Beethoven complained to Nannette that he needed a louder piano, due to advancing deafness. This time he did not get another Streicher piano, but his plea was heard by another. Thomas Broadwood, who with his brother James had inherited their father's piano manufacturing business in England, visited Vienna and met Beethoven about this time. On his return to London he had a Broadwood grand made with special stringing, four strings to the note, which Beethoven received in March 1818.

A Broadwood action is shown in Fig. 3.5. We see that it has the same basic simplicity as the Streicher action, although with a stationary hammer butt and moving jack where Streicher used a moving hammer butt and stationary jack. This has the consequence that when a Streicher hammer contacts the string, it "brushes" along it slightly, contributing to a mellow tone; while the Broadwood hammer bounces off the string in a purely percussive way. But there is no really fundamental difference in mechanical efficiency; the Broadwood had no great advantage in key repetition, and it need not have been any stiffer than the Streicher. It appears that it was stiffer only because it was made of heavier parts, which made the Broadwood more rugged; one had a wider dynamic range before something broke.

Fig. 3.5 A Broadwood Action

But there is an ominous sign in those three holes in the back end of the key. These are a pure invention of the devil; they were filled with varying weights of lead slugs for the specific purpose of making the action as stiff for the treble notes as the bass ones.* As we go toward the treble, the weight of the lead slugs is increased progressively to 'compensate' for the smaller weight of the hammers. One is deliberately wasting the strength of the player in just the region where the piano was already weak, without contributing anything to its musical function; something which would receive the unqualified condemnation of all pianists, if they knew it was being done to them.

Beethoven's Broadwood had a range of 6.5 octaves, ($C_1 \to A_7$) and we see its effects immediately in Beethoven's output. The 'Hammerklavier' sonata Op. 106, published in 1819, not only has a much heavier 'feel' than the earlier ones; it breaks out of the Streicher confines and uses ($D_1 \to A_7$). The remaining three sonatas, Op. 109, 110, 111, use respectively ($D_1 \to C_7$), ($G_1 \to C_7$), ($C_1 \to E_7$). Thus the evidence of Beethoven's scores tells us that his last four sonatas were composed on the Broadwood; and this checks with the known dates.

* Unfortunately, this practice still persists today; we shall return to it in Chapter 5 and see that it makes the action cheaper to build because it enables the maker to use identical mechanisms on all keys. But the musical purpose would be far better served by progressively changing the lever ratios so that in the treble notes the exertion of the player's fingers goes into useful motion of the hammers instead of useless motion of lead slugs. This, plus changing the striking point on the treble strings, would surely correct the defect that Johann Sebastian Bach complained about to Silbermann.

Of course, we do not suggest that these "baseball–type" statistics about his sonatas are of any musical significance; he would have written equally good works whatever range he was confined to. They are noted because they provide evidence on the kind of piano (and therefore the kind of piano mechanism) Beethoven had available at different times. Indeed, in the end he was totally deaf and it did not matter to him that by then he had reduced the insides of the Broadwood to a tangle of broken wires; the keys still had the same feel to him.

But how do we know that the range of Beethoven's published scores corresponded to the range of the instrument on which he composed them? Might he not have anticipated what type of piano they would be played on by others, and written the score with their needs in mind? The cogent argument against this theory is that the discrepancies go in the wrong direction; it would have defeated his purpose. His own piano had, almost always, a *greater* range than would be available to most who tried to play his works. Then, had he tried to accommodate the needs of others he would have had to ignore the extra range of his own instrument; but then that range would have been useless. The evidence of his scores is that, whenever he acquired a wider range piano, he took full advantage of it immediately, leaving others to figure out as best they could what to do about it. But what else *could* he do, if that extra range was to serve any purpose? Instead of coming down to existing instruments, he quite properly stimulated the development of better instruments that came up to him.

Our tentative conclusion from all this is that the sonatas through Op. 54 were composed on the very light Stein piano, not essentially different from what Mozart had in the last seven or eight years of his life, Op 57 – 101 were probably composed on the Streicher, and Op 106 – 111 were composed on the stiffer and more powerful 'English action' Broadwood, with dynamic capabilities more like those of a modern piano; and Beethoven was keenly aware of the difference.[†] But Beethoven never knew a piano with felt hammers or the modern fast repeating action.

We think that an artist performing his works today might like to have this information. By all means, use legato on all Beethoven's works just as his pupil Czerny recommended; when Beethoven did not wish the *legato*, he so indicated. But the booming dynamics sometimes heard – straining the resources of both finger and instrument – is appropriate only in the last four works (and not very often there). We think that it is utterly wrong to pound those *ff* chords in the first movement of the Op. 57 sonata to the point where the piano makes a harsh, offensive sound, as so many pianists do today; Beethoven may have been vigorous, but he never exaggerated things to the point of bad taste.

On Beethoven's death in 1827 the Broadwood was bought at auction by a dealer who later presented it to Franz Liszt, and it is now in the National Museum in Budapest. Nannette Streicher and her husband both died in 1833 but the Streicher business continued under their son and grandson until 1871 and Streicher pianos became familiar throughout Germany. But during this period the tradition passed gradually into other hands.

[†] Another difference, of which Beethoven may or may not have been aware in view of his hearing problem, is that the Broadwood had a much more shrill, penetrating tone than the Viennese pianos. In 1788 Broadwood instituted the design in which all strings are struck at 1/9 of their length from the agraffe, which has acoustical consequences that we shall study later.

In 1828 a new Viennese piano maker, Ignaz Bösendorfer, appears on the scene. He was also a pianist, born in 1795, who grew up in the Vienna of Beethoven and the Stein and Streicher pianos. He and his son Ludwig continued to make notable improvements in the Viennese piano, readily taking advantage of later technical advances such as faster repeating actions and cast iron frames; but always insisting on retaining the mellow "Viennese tone". However, it was found that the mellow tone could be produced just as well with a stationary hammer butt, by using a softer hammer and by moving the striking point further from the agraffe, perhaps as much as 1/6 of the length of the string. Today the Bösendorfer company is still active and continues that policy. Many – including this writer – consider the Bösendorfer piano better suited than any other for playing Beethoven.‡

Liszt and Erard: Chopin and Pleyel

Sebastian Erhardt (1752–1831) was a cabinet maker from Strasbourg who moved to Paris and changed his name to the French–like Sébastien Érard. There he learned harpsichord construction, made an experimental piano much like Cristofori's in 1777, and founded a piano factory in 1785. But he soon saw the imminence of the French Revolution (1789) and, because some of the aristocracy (including King Louis XVI himself) were his patrons, decided that it would be safer in England. There he waited out the Revolution and learned about the Broadwood piano mechanism. Then he returned to Paris with this knowledge and in 1796 resumed manufacture of pianos, becoming the dominant French piano maker (but now with Napoleon as a patron).⋆

Most important for our purposes, Érard also resumed experimentation on improvements in the piano mechanism, seeking to retain the good features of the English and German actions but to add the capability of rapid repetition of a note. This proved to be possible to an astonishing degree, although it required many years to perfect it. His "double escapement" mechanism finally reached a state of high performance and reliability in 1821, the date of his basic patent. While it was intermediate between the German and English actions in ease of playing, it was superior to both in reliability and range of controlled sounds, therefore in possibilities for musical expression. Its double escapement principle permits extremely rapid repetition of a note, beyond anything Mozart or Beethoven ever knew, and limited more by human fingers than by the mechanism.† Since 1821 the appearance of the action has changed (nearly every manufacturer has made some small

‡ My own instrument is a 6' 4" Bösendorfer made in 1953. During a year (1983–1984) at Cambridge University, England, I used a new English piano which had a much stiffer action and was much harder to play with good control; it felt as if a strong spring was opposing any effort to depress a key. With the Bösendorfer you feel that the work you are doing is going directly into the useful accelerating of a hammer – exactly what it should be doing (in the treble, however, this is an illusion, as we have just seen). The Steinway has a feel intermediate between these.

⋆ Incidentally, Érard also manufactured harps and invented the double action key–change mechanism of the modern harp. It is illustrated in the *Larousse Encyclopedia of Music* (1974); p. 262.

† This is possible because, when the hammer is only about half way down to its bed and the key about half way back up, a spring slips the jack back under the hammer, so that pressing the key back down repeats the note. At this point one can feel the tension on the key increase. Those who are used to this are dismayed upon trying to play a modern electronic piano; even though the note always sounds at the same point in key descent however high the key started above that point; and thus it might seem to realize the purpose of the escapement perfectly, one loses the

alteration), but this involved only unimportant, nonfunctional details; our present grand piano action, shown in Fig. 3.6, still operates on the same principles and so is still properly called the Érard action.

Figure 3.6. The Modern Érard Double Escapement Action

Érard became wealthy and a princely entertainer; his home, the *Salon Érard*, was one of the centers of the cultural and intellectual life of Paris. He built a concert hall, the *Salle Érard*, an enormous four–story high room encircled by a balcony at the second floor level, much like our present, even larger, Boston Symphony Hall. Here Liszt and nearly all the great virtuosi except Chopin held concerts. But Sébastien died a little too soon to see the full fruit of this, and his nephew Pierre Érard carried on the enterprise in its greatest days.

One can get some idea of the repetition capabilities of the early pianos by examining tempo markings on the music that was written for them. Franz Schubert (1797–1828) had a predilection for rapid repeated notes. Living in or near Vienna all his life, he probably never laid hands on any kind of piano except a Streicher or an old, worn–out Stein (he never had the money to buy, or even rent, a piano of his own). Then the pace of the last movement of his piano trio in $E\flat$ Op. 100 written in late 1827, in which fourfold sixteenth notes occur many times, probably indicates the limit of the Streicher's repetition capability; Schubert marked it *Allégro Moderáto*. In a recent videotape recording (a concert at Indiana University) of this work with a modern piano, the Beaux Arts Trio takes it at a pace that we would call *Prestíssimo*. The pianist, Menahem Pressler, playing at what must be close to the limit of possibility of human fingers, uses the finger sequence 4-3-2-1 for each quartet of repeated notes. This must be considerably faster than was possible on a Streicher piano; further evidence for this is given by the Viennese pianist Adolph Baller, performing the same work 40 years earlier with the Alma trio[‡] at a considerably slower tempo and

tactile sense of when this happens, and so cannot judge how high to let the key rise before trying to repeat it. The result is that, although in general things can be done electronically thousands of times faster than mechanically, one cannot execute trills on the electronic piano as rapidly as on the acoustic one; an unexpected bonus from the Érard action.

[‡] Allegro Records, AL 1, ca. 1950.

managing the repeated notes with one finger 2-2-2-2, as the writer observed at a recital in 1953. This must be closer to what Schubert's contemporaries heard, although we can well imagine that Schubert would have preferred the Beaux Arts tempo if it had been possible then.

A half–Century later the rapid repetition that Schubert would have liked was available, and in the Liszt *Hungarian Fantasy for Piano and Orchestra* can hear repeated notes at the limit of possibility of the Érard action. But on listening to the effect we understand why, after another Century, no faster action than the Érard has been developed. Anything still faster would not be perceived as repeated notes at all; they would blend into a continuous buzzing sound. In the matter of speed, the Érard action reaches the limit of possibility of both human fingers and human ears.†

Another example is Louis Moreau Gottschalk's *Grand Tarantella*, with its chords repeated so rapidly that the human ear is barely able to detect this. It could not be played at all at the pace we are used to hearing it, on a piano without the Érard action. On the other hand, if successive notes are different, the piano mechanism places no limitation on velocity; only the capability of human fingers matters then. The Mendelssohn G minor Piano Concerto – a youthful show–off which says, in effect, "Look how fast I can play!" has no repeated notes, so perhaps Mendelssohn could play it just as fast on a Streicher as Liszt could on an Érard.

Érard pianos became ubiquitous in Paris and Hector Berlioz, in his role as music critic, gave them the strangest testimonial a piano make ever received (Barzun, 1956). At the *Conservatoire*, he had been obliged to hear a piano competition at which all the contestants played that Mendelssohn concerto on an Érard piano. After thirty performances, he reports, the Érard starts playing the concerto by itself. Nobody can stop it, so they send for the manufacturer; but Érard himself cannot stop it. He sprinkles it with holy water, with no effect. They remove the keyboard but it continues to play; Érard has it chopped up with an axe, but each piece still dances about playing Mendelssohn's Concerto. Finally they are obliged to throw them all into a fire. Berlioz concludes: "*There was no other way to loosen its grip. But, after all, how can a piano play a concerto thirty times in one day without contracting the habit of it? M. Mendelssohn won't be able to complain that his music isn't being played. But think of the damage!*"

Enter Pleyel: Érard had one important competitor in France. Ignaz Pleyel (1757–1831) was born near Vienna, a child prodigy who studied harpsichord and piano with Haydn for five years. He became a successful composer and, in 1783, Kappellmeister of Strasbourg Cathedral. But he too needed to escape the French Revolution; after some

† It is also coming up against an even more fundamental limit, arising from the nature of sound itself. Each note has a definite number of vibrations per second, and it must last long enough for several cycles before it is perceived as having a definite pitch. For example, the note A440 vibrates at 440 cycles per second. If it sounds only for 1/40 second, only 11 cycles are present; this would be perceived by the ear only as a sharp click with hardly any definite pitch. Every time we go up an octave, the vibrations are twice as fast, and the note need be held only half as long in order to have a definite perceived pitch. Thus the superfast treble tinklings of Liszt's *Gnomenreigen* cannot be perceived as musiucal sounds at all by the ear if played on bass notes, even though the Érard action itself is just as fast there.

time concertizing in London he moved to Paris and started a music publishing business in 1797. Several years later his son Camille Pleyel (1792–1855), also a talented pianist, was sent to England to study piano making with Broadwood, and by 1813 the Pleyels were manufacturing English model pianos in France.

As far as we know, the Pleyels, musically well–educated but not craftsmen, made no contribution to the mechanical development of the piano.[‡] But they prospered financially nearly as well as Érard, and perhaps appealed to a more refined taste. The *Salle Pleyel*, opened in 1830, was smaller (only about 1.5 stories tall with no balcony) and much more intimate than the *Salle Érard*. It also became a musical and cultural center of Paris; Chopin, Rubinstein, Gottschalk, and Saint–Saëns made their Paris debuts there and Chopin used it in public concerts.

The Mystery of Chopin: It seems a curious twist that would lead the weak and sickly Chopin to prefer the stiff English action which must have hampered his performance; while the powerful Liszt – breaker of hammers and strings – used the easier Érard action, which he did not need. How can we understand this?

One might be tempted to see in these relationships a crass commercial arrangement; indeed, in the cases of Clementi and Kalkbrenner the commercial possibilities were never out of sight, as the historical record shows abundantly. Loesser (1954) suggests this also in the cases of Liszt, Chopin, and several other prominent artists.[†] Of course, Érard and Pleyel would perceive that associations with great artists would raise their prestige and help to sell their pianos; that is why they built their halls, and nobody would suppose otherwise. But in passing judgment on anybody's behavior, it is essential to consider what alternatives were available to him and the consequences had he behaved differently. Also, we need to ask: what was the alternative from the standpoint of the artist?

Chopin and Liszt necessarily used concert halls and pianos built by *somebody* and whatever choice they made, it would appear inevitably to be an endorsement. Of course, it really was a weak endorsement in the sense that a great artist cannot afford to appear in public with an instrument that he knows is inferior for his purpose. The fact that he chooses a particular kind of piano does not by any means indicate that he considers it the finest in existence; but it does indicate that he has found no defects in it serious enough to hinder his performance. But Chopin and Liszt had no need, musically or financially, to enter into exclusive commercial arrangements with anybody and were free to choose whatever facilities they wished. Indeed, Liszt also spoke just as highly of several other piano makes, and we have the well–known painting of a Liszt recital in which the name *Bösendorfer* is clearly legible on the piano.

[‡] However, the introduction of felt hammers instead of the original leather was done in 1826 by a former worker in the Pleyel factory, Jean–Henri Pape.

[†] But Loesser had, like many social ideologues, a morbid preoccupation with the subject of money, and took a stance of high moral indignation over *every* commercial activity. What he finds intolerable is that the successful business man is making money; but never does he recognize that, in return for this he is contributing something that society wants, at a price that people are willing to pay voluntarily. And what was the alternative? If those despised 'money barons' had not been successful at supplying society's needs, and everyone had to supply them for himself, Loesser himself would have lived out his life at the material level of a medieval peasant, without ever seeing a piano.

Any difference in the piano actions would be more important to Chopin than to Liszt; but Chopin disliked the Érard action, which he called "too insistent". This seems incredible to us today; indeed, once one is used to the Érard action, it seems remarkable that Chopin's music could be played at all with an early Pleyel or Broadwood action. This suggests a different line of inquiry.

Long Distance Piano Moving: What kind of pianos did Chopin learn on in Warsaw in the 1820's? At first we say, "Surely, Steins, Streichers, or their imitators; the difficulty of transportation before the days of railroads would have made it impractical to transport Broadwoods or Pleyels there." But a glance at a map shows that the situation is just the opposite. In 1818 Beethoven's Broadwood had to go by sea through the strait of Gibraltar to the port of Trieste, then by horsecart 350 miles over the alps to Vienna, over roads worse than any we can imagine today. It is a wonder that it arrived in a repairable condition at all.

To transport a Broadwood to Warsaw would be trivial by comparison: first by sea to the port of Danzig, then by barge up the Vistula, right into the center of Warsaw. A horsecart would be required only for a few blocks, over city streets. We conclude that, in the 1820's, Broadwood pianos were far more likely to be found in Warsaw than in Vienna. In fact, it would be far easier to transport a Broadwood from London to Warsaw or a Pleyel from Paris to Warsaw, than to transport a Streicher from Vienna to Warsaw (the latter requiring some 400 miles of horsecart over bad roads). Loesser (1954, p. 332) confirms this, noting that the German musician Johann Friedrich Reichardt visited the Érard factory in 1802 – eight years before Chopin was born – and reported that already then, they were exporting their pianos "to all countries of Europe, wherever water transport favors it." Therefore it seems highly likely that Chopin had been used to stiff action English or French pianos all his life; and just never outgrew his early training.[‡]

But perhaps the piano actions were not the only consideration. A glance at the two halls makes it clear that for public concerts Liszt would prefer the ostentatious *Salle Érard*; and Chopin would prefer the more tasteful *Salle Pleyel*, whatever brand of pianos came with them. Dolge (1911) gives pictures of both of these Paris halls (as well as the much plainer *Saal Bösendorfer* of Vienna, which opened in 1872 with a recital by Hans von Bülow, and really looks like a University classroom). In any event, the piano and hall considerations reinforced each other for Chopin.

On the other hand, both the Érard and Pleyel pianos were much stiffer than the easy German Streicher pianos; we have evidence about this from the first concert tour of Paris by Clara Wieck (later Clara Schumann) in 1832. She was an outstanding performer on the Streicher pianos of her native Leipzig; but her efforts in Paris were a rather dismal failure due in part to the unaccustomed hard action French pianos which her father cursed as "tough bones."[⋆]

[‡] This sounds very much like the case of Mozart, who as we have noted, probably learned to play on primitive instruments on which a legato touch was mechanically impossible and, even after he had a Stein action instrument of his own on which it was possible, he did not outgrow his early mindset and made no appreciable use of this capability.

[⋆] But Clara had started adjusting to this; on her return to Leipzig her future husband, Robert Schumann, was shocked at the change in her playing, and recorded in his diary that she now attacked the Streicher pianos "like a hussar." The German and French pianos were indeed different!

We have seen that the four most famous pianists – Mozart, Beethoven, Chopin, Liszt – all had interesting connections with the development of the piano. Nevertheless Hector Berlioz (1803–1869), himself no pianist at all, gets the last word in the Pleyel story also. A beautiful and accomplished woman pianist, Marie Moke (1811–1875), had a romantic involvement with Berlioz, who expected to marry her. But while Berlioz was safely away on a visit to Rome in 1831, the practical Marie, perceiving that Berlioz was penniless and would remain so, suddenly married the much older Camille Pleyel instead, opting for a life of luxury and high society; whereupon Berlioz came close to assassinating both of them. He did not realize how fortunate he had been until some years later.†

The Iron Frame: Babcock, Chickering, Steinway

Up to this point the pianos were all of wooden construction, and with the development of the Érard action, this became the main remaining bottleneck. Wooden frames were barely able to sustain the total tension of all the strings (amounting to a few tons) and prevented any further increase. Furthermore, wood absorbs moisture and expands, so changes in temperature and humidity could throw the instrument out of tune; every serious pianist was obliged to be also his own tuner, touching it up again every few days (as harpsichordists still do). Broadwood started by replacing the main structural members by iron bars, but this solved only a small part of the problem. Several other European piano makers tried similar things, but nothing permanent came of them.

Then an American inventor, Alpheus Babcock, made a one–piece cast iron frame for a square piano in 1825. But the idea was not quick to catch on; there was a prejudice against the use of a metal frame, due to a quite mistaken but persistent belief that this would make a "metallic" or "tinny" tone. However the Chickering piano Company of Boston then studied the possibility and in 1843 developed a similar frame for a grand piano. It was successful enough to be produced, but not really great; it tended to have a weak tone not because of the iron, but because the scaling (combination of length, density, and tension) of the strings was not right.

This introduces us to the Steinways (no relation to Stein), a family of like–minded men as numerous and energetic as the Bachs and the Strausses combined. Henry Engelhardt Steinweg was born at Wolfshagen, Germany in 1797 and, thanks to Napoleon, found himself a homeless orphan at the age of 15. He apprenticed himself to an organ builder at Seesen, and started experimenting on the side with building pianos, completing his first good instrument in 1825. In 1839 he exhibited three of his instruments at the fair of Brunswick, for which he received the top prize gold medal and sold one of them to the Duke of Brunswick for a high price. His reputation thus established, he received so many orders that he was obliged to set up a factory, hire and train workmen, and bring his sons Theodore, Charles and Henry Jr. into the business as soon as they were old enough.

Then disaster struck again with the attempted revolution of 1848, which paralyzed all nonessential business. Charles, having been an active revolutionist, was obliged to flee to Switzerland and made his way to New York. He sent back such glowing reports of the possibilities in the New World that the entire Steinweg family (except Theodore, who stayed behind to pursue scientific study related to acoustics and continue the piano business) arrived in New York in 1851 and changed their name to Steinway.

† For the details, see Berlioz' memoirs (Cairns, 1975), Chapters 28, 34; pp. 553–554.

Instead of starting a business at once, they decided to acquire first a knowledge of the current American business methods and customs. Henry, Charles, and Henry Jr. found employment in three different piano factories, and observed closely the good practices and the errors being made. After two years they had absorbed enough information to see what was needed to start their own factory in 1853.⋆ With their better knowledge of scaling, they proceeded to develop a better cast iron frame design with cross–stringing, heavier strings under greater tension (about 20 tons, which increased eventually to over 30 tons in the Steinway concert grand), producing a stronger sound. One of their early pianos created a sensation at the American Institute Fair of 1855, and their business prospered so rapidly that they constructed an enormous six–story, block–long factory in 1859, at what is now Park Avenue and 53'rd Street. Soon it was producing 2,000 pianos per year, about a quarter of the total United States output. All other piano makers were obliged to adopt the iron frame quickly; or perish.

A third disaster was the sudden death of Charles and Henry Jr. in 1865, just at the peak of their powers. But the prolific Henry Sr. had two more sons, William and Albert, who were now old enough to help, and Theodore sold his German factory to his workers and joined them in New York. For almost the first time some real scientific knowledge entered into piano building as the well–educated Theodore took over technical aspects of their piano design. Having done this he returned to Germany to continue studying acoustics with Helmholtz, then the most authoritative scientist in the world on such matters. He returned to New York periodically to superintend Steinway's technical operations.

Steinway Hall, seating 2,500 persons,† was built in 1866 and was the main New York concert facility for a quarter–Century, until the opening of Carnegie Hall in 1891. It was the home base of the conductor Theodore Thomas and his orchestra, and most of the famous pianists of the time performed there.

With the death of Henry Sr. in 1871, William took over management of the Company, which now prospered more than ever. He started a branch house in London in 1875 followed with a London Steinway Hall in 1876, and another factory in Hamburg in 1880. He bought 400 acres of land on Long Island (now a part of Astoria, Queens), and made it the village of Steinway. The youngest son, Albert, took over its development, and by 1910 all of the American manufacturing operations had been moved there. In 1972 the Steinway company became a subsidiary of CBS, but it continued to be managed by descendants of the founders.

There were many other American piano manufacturers [Knabe, Chickering, Mason & Hamlin, Baldwin, Weber, Aeolian, American Piano, Cable, Kimball, *etc*]; but the sheer magnitude of the Steinway operations – only a small part of which we have noted here – has guaranteed that in the twentieth Century it would be the most familiar piano name in the United States, used more than any others for concerts and recordings. They were just as active in their relations with artists as in business [for details see Loesser (1954)].

⋆ It would be quite wrong to condemn this behavior as 'industrial espionage'. The Steinways already had the superior knowledge of how to design and build pianos. What they needed to learn were the social customs of conducting business in a strange new land – very different from those in Germany, but common knowledge among American businessmen.

† By contrast, *Salle Pleyel* accommodated only 300.

Steinway pianos are characterized generally by a louder and more brilliant tone and longer sustained sound (but at a price of a somewhat stiffer action), than most others. In the early days of recording this did indeed make them preferred, resulting in a cleaner final sound (but today, with sensitive directional microphones, it no longer matters, because very little of the reverberation of the recording studio is picked up by the microphone anyway). In recent years there has been a movement back in favor of the more mellow Viennese tone of the increasingly popular Bösendorfer.

The Yamaha piano is a relatively new name outside of Japan; but it is hardly a new company. Torakuso Konan Yamaha started his business in 1880, concerned with musical instruments in general. By 1910 his factory at Hamamatsu was producing annually about 13,000 violins and 8,000 organs; but only 600 pianos; by 1932 this rose to 4,000 pianos per year. They were patterned after the Viennese models, and today Yamaha grand pianos are often thought to be copies of the Bösendorfer; indeed, their design is similar in may ways due to a common ancestry. Therefore, as Bösendorfer pianos became popular in the United States in the 1950's and 1960's,[‡] the fact that Yamahas were almost identical in appearance and sound and could be bought considerably cheaper, guaranteed Yamaha a good ready–made market here.[⋆]

Many other piano manufacturers are or were in existence, even in the mid–18'th Century. Wier (1940) gives a list of over 200 of them, mostly German and American (but in the 19'th Century there were a dozen piano factories in Barcelona). Most contributed nothing to the actual development of the piano and had no interesting dealings with famous musicians, so we have not considered them here. A number of other technical problems called for creative solutions; in particular the making of uniform piano wire and durable hammers, and the seasoning and planing of soundboards. For the many somewhat tedious details of these developments, we refer the reader to Dolge (1911).

Suggestions for Further Study

Many readers will want to know more than we have given here. In trying to understand the development of other musical instruments, the problem is the scarcity of material. In understanding the development of the piano we faced the opposite problem; so much material is available, scattered in so many different places, that nobody could possibly locate and read it all. And, as in all historical research, different sources give contradictory accounts of details.

We have consulted about a dozen sources, but found that almost all of the material unearthed is contained in two of them: (1) the book of Alfred Dolge (1911), a German craftsman who emigrated to the United States in the 1860's and became the main developer of our present felt hammers and soundboards; and (2) The less technical account by Arthur Loesser (1954), a professional pianist and teacher at the Cleveland Institute of Music. Also, the *Larousse Encyclopedia of Music* (1974) has lavish illustrations of many things discussed

[‡] Thanks largely to Adolph Baller, a former prodigy who had performed as soloist with the Vienna Philharmonic Orchestra at the age of eight, and who migrated to California after WWII.

[⋆] In 1981, American prices for the Bösendorfer ranged from $29,000 for the 5' 8" grand to $60,000 for the 9' 6" concert grand; the corresponding Yamaha prices were $6,300 to $18,000. A 9' Steinway concert grand cost about $26,000. By 1992 these had roughly doubled; a 7' 4" Bösendorfer had a $78,000, and the 9' 6" Bösendorfer a $125,000 list price (doubtless subject to negotiation).

here. The interested reader should consult these works for far more details than we can give here; but should be forewarned about their shortcomings.

Dolge gives a vast amount of technical information about piano making, with detailed drawings of almost every piano action ever made. He also gives biographical sketches and likenesses of dozens of the great piano makers and players. His section "Literature on the Pianoforte" describes an astonishing number of other works on the history of the piano. Unfortunately, he also reveals inadvertently some appalling things about the level of scientific understanding in 1911; the most elementary facts about vibrating strings and acoustics of soundboards, clearly demonstrated and explained by Helmholtz fifty years earlier – just the things that Theodore Steinway had returned to Germany to learn from Helmholtz forty years earlier – were not yet comprehended by Dolge.

Dolge developed some incredibly ingenious machinery for mass production of felt hammers, which could turn out an entire 88–key set, of 88 different sizes, as a single mass of felt with 88 wooden hammer heads imbedded in it. This was then sliced like a loaf of bread into the separate hammers. He also developed the planing machinery for mass production of sound boards (with which two workmen could turn out 30 sound boards per hour), but he had no comprehension of what sound boards actually do acoustically in a piano; or indeed, what a sound wave is.

It has to be said that the thinking of uneducated craftsmen is all right on things like hammers and boards that they can see and feel directly for themselves. But in trying to reason about unseen things like vibrations and sound waves, Dolge's thinking was dominated by the ignorant folklore of his peers, quite unrelated to the real facts and the laws of physics. The low point of Dolge's work is on p. 426 where he actually *endorses* some completely false, incompetent attacks on Helmholtz.

But this makes it easy to understand why the development of the piano required so long. The most eager, energetic craftsman would require many years to discover by laborious, uneducated trial–and–error what a scientist of the caliber of Helmholtz could have told him in five minutes. Of course, a sufficiently persistent craftsman will arrive eventually at a usable solution – after all, he cannot violate the laws of physics, even if he does not comprehend them – but he is unlikely to live long enough to finish the job properly.

Since 1911 there have been many small technical improvements which do not seem to have been written up in any common place. In particular, the replacement of some parts by modern high–quality plastics is not in any sense a "cheapening" of the instrument. Plastic is a far better material than ivory for piano keys; it is not only tougher, longer wearing, and free from that dirty yellow stain and brittle cracking of old ivory keys; but also easier to work (and, of course, it requires no killing of elephants). Likewise, the replacement of felt bearings by teflon has made piano actions far more reliable and trouble–free, virtually frictionless and impervious to moisture and moth. Where a felt bearing will wear out in fifty years, a teflon bearing should remain dimensionally stable and fully functional for Centuries. If Cristofori had had such materials, we could still play his pianos today.

Looking to the future, if the wood parts of the action were replaced by the tough plastic now available, or by die–cast metal, all glued joints would be eliminated and it would become practically indestructible.† We still need a better material than felt for

† To appreciate the strength and toughness of plastics now available, we note that protective

hammers; presumably, some future soft plastic will make hammers impervious to wear, moisture, and moth; and actually improve the range of tone quality available. Cracking of dried–out sound boards would become a thing of the past if we replaced the wood by modern laminated plastic, which can be made to duplicate every acoustical property of wood, including its grain structure if that should prove to be important (we think that it will not). Going out of tune by slipping of tuning pins could be eliminated, while at the same time making it much easier to tune a piano accurately using only a small screwdriver, by mechanisms along the lines of the fine–tuner for the violin E–string, or the geared mechanism for tuning guitar strings.

But far more important, we could now redesign the lever–ratios in the action for the treble notes and revise the striking points for the treble strings, to correct the defects that were noted already by Johann Sebastian Bach, and are made even worse today by those lead slugs. We examine the possibilities here and "redesign" a treble key piano action to exploit them, in Chapter 5. There is still plenty to do in improved mechanical design of the piano; and the manufacturer who has the initiative to do it, will reap the same kind of rewards as did Érard and the Steinways, while becoming a benefactor to music and musicians. Of course, many minds are still filled with ignorant folklore and superstition about these things, and they would oppose all the changes we have suggested; but when faced with the accomplished fact all such opposition would melt away as fast as did superstitious opposition to the cast iron frame.

But is it likely that electronic pianos will soon make all these suggestions irrelevant by making the acoustical piano obsolete anyway? We discuss electronic musical instruments briefly in Chapter 8, and conclude that, while this is certainly a technical possibility – and even a very promising and attractive one – there is no present sign of its actually happening. Electronic pianos produced to date have been such abysmal failures musically that manufacturers appear to be moving away from trying to imitate a piano. There seem to be no electronic engineers who have any comprehension of what is needed musically, so while the low–end 'spinet' piano is headed for swift obsolescence from this competition, we think that the high quality acoustical grand piano is still safe for many years to come, and it is very much worth while to continue improving it.

Loesser (1954) also gives many interesting names, dates, places, and details about the successes and failures of those who tried to build better pianos; but is more concerned with the experiences of the composers and performers who were obliged to use those pianos at various stages of their development. But he too is, just as much as Dolge, a victim of the folklore and mythology of his peer culture; the reader of today quickly perceives that his unceasing social commentaries really tell us more about the conventional social ideology of American academics in the 1950's than about the actual social conditions of the earlier times being discussed.† Someone writing 40 years earlier or 40 years later than Loesser would often draw quite different sociological conclusions from the same historical facts.

Also, Loesser tends to get his musical judgment and his social moralizing scrambled

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goggles and bullet–proof windows are made of Lexan polycarbonate plastic; bullets fired directly at them merely bounce off, leaving behind only a slight scratch on the otherwise intact plastic.

† The characteristic identifying feature of this ideology is the constant jumping to instant, absolute value judgments of what other people do on ostensibly moral grounds – but without ever considering the alternatives available to them, or the consequences had they behaved differently.

up, to the confusion and bewilderment of the reader. For example, on p. 340 he compares the tone of the harpsichord and the piano thus:

> "A gulf lies between these two ideals of sound. The former belongs to a philosophy that values logic, that wants to control the world by dividing it into neat, tight, inviolable categories, order, and ranks. The latter is characteristic of a fluid, pietist, libertarian cast of thought, which has little respect for what it regards as contrived boundaries or limits – a frame of mind harboring the mystical suspicion that anything might merge into everything."

The prospective reader is warned that, in order to extract from Loesser a few wanted hard facts about the history of pianos and their users, it may be necessary to plow through pages of this kind of drivel. In spite of this, we recommend reading Loesser; it still has a more compact collection of interesting and useful historical facts – on a higher intellectual level than Dolge's – than one can find elsewhere. By this we mean that, however bizarre his social views and motivations may be, Loesser's academic training still enables him to recognize – unlike Dolge – what is and what is not a real historical fact, and to report the facts with scholarly standards of documentation.

Loesser (a professional pianist and piano teacher) reveals, just as much as Dolge, an appalling lack of understanding of what is actually happening mechanically in a piano. For example, (p. 339) he explains the function of felt hammers thus:

> "· · · it was found that impact by a larger, softer–striking surface at the hammer's end allowed the string to develop its vibration more slowly along its entire length, thus encouraging the formation of stronger lower harmonics–on which a richer quality of sound depends."

This is a comedy of errors. The softness of the felt does not make the lower harmonics stronger; it makes the upper harmonics weaker because the hammer remains in contact with the string for several cycles of a high harmonic, cancelling out its effect. The string does not develop its vibration 'more slowly' along its entire length; the wave of string displacement moves away from the hammer always at the same velocity determined by the tension and density of the string, as Newton's laws of mechanics require, and as we describe in detail in Chapter 5. If this were not true, the string would not generate any definite pitch at all.

In the 1920's these mechanical actions of piano hammers and strings were analyzed and explained in detail by the great Indian scientist Sir C. V. Raman, and published in several articles; yet by 1954 this knowledge had not yet reached Loesser, who had the need for it.*

The greatest pianists have just as serious misconceptions as Dolge and Loesser about the unseen happenings in their instruments. For example, we noted that Adolph Baller was largely responsible for the introduction of Bösendorfer pianos into the United States in the 1950's. The present writer admired him more than any other contemporary artist and never missed an opportunity to see and hear him in action and watch his hands closely. Yet in conversation with him, it developed that he believed that the mellow tone of the Bösendorfer was due to sympathetic vibrations in the small segments of the strings

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* Similarly, the basic facts about vibrations of piano strings were established in the last Century by the German scientist Hermann von Helmholtz, and the English scientist Lord Rayleigh, and were understood correctly by Theodore Steinway in the 1870's; yet forty years later, as we noted, this knowledge had not yet reached Dolge.

between the agraffe and the tuning pins! He thought that some deep secret of the design was amplifying those vibrations in the Bösendorfer but not in other pianos. In fact, those segments are hardly vibrating at all in any piano because they are not being struck or plucked, and whatever vibrations they have are communicated through the agraffe by the bending of the string and are at the same pitch as the main segment of the string. But these neglibly small vibrations produce no sound because they are not connected to any bridge or sound board.

The real reason for the Bösendorfer tone lies in the different position of the striking point on the strings – as one can verify at once by converting it back into a dulcimer by striking the strings at a different point, with felt or soft rubber hammers held in the hand (with, of course, the dampers up). One can make the Bösendorfer sound like a Broadwood, a Steinway, or even (by striking at the exact center of the string) a clarinet. Just as easily, one can make a Steinway sound like a Bósendorfer in this way.

Dolge and Loesser give conflicting accounts of many historical facts. In particular their descriptions of the details of Nannette Streicher's efforts with regard to Beethoven are totally at variance with each other. Dolge has Nannette giving him a specially built 6.5 octave Streicher in 1816, which would make nonsense of the story of the Broadwood. Yet the Broadwood is a tangible fact, supported by many contemporary eyewitnesses and records, and still in existence, so we concluded that Dolge is completely wrong here. Dolge also gives impossible sequences of dates, having Albert Steinway dying three years before acquisition of the land for Steinway village which he developed – but we have found equally bad factual errors in every source we have consulted. For example the *Larousse Encyclopedia* states (p. 260) that the Pleyel company was established in 1809; then (p. 264) gives a photograph of a square piano with 5.5 octaves, ($F_1 \to C_7$), described as a Pleyel dated 1800, owned by Beethoven. This not only contradicts itself; it contradicts all other sources both about Pleyel and about Beethoven. Other sources give 1797 for the date of Pleyel's establishment, and 1807 or 1813 for the date of Pleyel's first French pianos. It is conceivable that in 1800 Pleyel smuggled[‡] some English pianos into France and put Pleyel labels on them; and that over the next twenty years one of these found its way to Beethoven. But there is no hint of this in any other source we have seen.

Only further independent historical study – presumably requiring access to archives in Bonn, Vienna and Paris and to authentic specimens of old pianos – can resolve our puzzlement over many of the issues raised here.

‡ Anti–British feeling was so strong after the Revolution that a French law of 1796 made it illegal to import – or even own – any British goods.

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CHAPTER 4

BACKGROUND OF OUR STUDY

Having had a glimpse at the historical background of our material, we now note briefly the general background of the studies we propose to carry out. Our agenda includes: Relations between musical sounds and mathematics, and their implications for scale construction and tuning; Physical properties of modern musical instruments and their implications on how those instruments should be played and constructed; Physiological facts about the machinery of fingers, wrists, and arms, and their implications for achieving control and endurance; Summary of the techniques and pedagogical principles of the great musicians of the past; The writer's personal comments on musical performance and composition. They need not be read in this order.

Before turning to the specific details of this program, we set forth our general aims, the general attitude toward them, and the general state of knowledge that we have available to bear on them.

What Do Scientists Really Know?

The writer of a book like this faces a small dilemma. On the one hand scientists know, with a degree of certainty virtually unknown in any other field, what physical laws govern the behavior of musical instruments; and we know that this information could be of great help to a musician learning how to play the instrument, or a craftsman trying to make a better instrument. A person who persists in believing what is not true or disbelieving what is true, can waste a lifetime of effort on something that is without hope of success.

On the other hand, musicians and craftsmen with no scientific training often do not believe us, or even fear that scientific knowledge would be in some way harmful to their musical goals. How do you help a person who does not want to be helped?

Our major problem is not in convincing others that something is possible; but in convincing them that something is impossible. Therefore let us emphasize: when a scientist makes a statement that something is or is not possible in a musical instrument, he is not merely expressing a personal opinion. He is stating the result of a great deal of experience, supported by thousands of quantitative experiments, carried out over Centuries. It is this continual *recording and accumulation* of evidence that makes us so confident.

But our evidence does not pertain only to the case at hand. The same law of composition of forces that determines whether the body of a violin can stand the 50 pound stress, applied to it by tightening the strings, without breaking, also determines whether a steel railroad bridge can carry its thousand ton load without collapsing; or whether a spider web can support the one-tenth ounce weight of a beetle without tearing. The same (Newton's) law of motion that determines the vibration frequency, and thus the pitch, of a violin string playing the note A 440, also determines the thousands of times longer vibration period of a mile long suspension bridge, and the ten thousand times shorter vibration period of the quartz crystal that regulates the speed of a wristwatch.

In other words, the laws of physics that are relevant to the behavior of musical instruments have all been verified accurately, innumerable times, over ranges of size, time, and forces from thousands of times greater to thousands of times smaller, than those occurring in musical instruments. Therefore, scientists have become very confident about the correctness of those laws, and we have no hesitation in pronouncing certain beliefs about musical instruments to be false superstitions or folklore.

Among these are the very persistently held beliefs that a musician can change the tone quality of a piano, without any accompanying change in loudness, by pressing the keys in different ways, that a certain microscopic structure of wood cells is essential for a good sounding–board, that the tone quality of a Stradivarius violin is due to details of the grain of the wood or a secret varnish known only to him, that a soloist can, by a conscious effort of the will, "throw" his tone to the rear of an auditorium, etc. I have heard every one of these claims, and many others equally false, expounded in full seriousness by competent musicians or instrument repairmen; and been laughed at when I tried to explain why it could not be.

Often, for people without scientific training, it has simply never occurred to them that a cause–effect relationship requires a physical mechanism to bring it about. Like an oboist we knew who believed, with absolutely unshakable certainty, that he could project his sound by an act of will in any direction, they tend to be so sure in their own minds that they brusquely dismiss all attempts of scientists to explain to them why the relation could not exist. He was, in effect, claiming for himself a power of psychokinesis that transcends all physical law (although he would have laughed at anyone who made pretension of such powers in a non–musical context).

Sometimes when we try to explain the impossibility of something, we get the response, "They laughed at Edison, too." Indeed, it is true that clever inventors have made fools of people who were too quick to claim that something cannot be done. But note the difference: those who laughed at Edison were, far from being scientists, quite ignorant of physical law. If what you believe or want to accomplish does not actually stand in violation of known laws of physics, then a prudent scientist will refrain from claiming that it is impossible (although in the heat of argument anyone may blurt out something that he regrets later).

Persons without scientific training have no comprehension of the amount of evidence we have supporting our claims; and tend to dismiss them as being mere opinions of someone who lacks *their* experience. To anyone who holds that attitude, let me point out this: if you can prove the incorrectness of any of our present laws of physics, by definite experiments described in sufficient detail that others can reproduce them and verify them independently, you will not be scorned by scientists (like the whistle–blower in a Government agency, who is ostracized for pointing out the defects of the system). On the contrary, you will be admired, will undoubtedly receive a Nobel Prize in physics, and your name will go down in history as a great discoverer. That is how scientists operate, and how confident we are of our present laws.

A Two–Way Street

But our communication problems are not only for a scientist trying to explain something to a musician; they may be even worse for a musician trying to explain something to a scientist, even when both are trying their friendly best to accomplish that communication.

For example (a real example, in which the writer has participated several times), consider a musician trying to explain to a scientist what property of a violin is most important to him. A musician without scientific training just does not have the vocabulary to do this, and is unable to communicate any definite facts to the scientist, because he does not distinguish between what is a real property of the violin, and his own feelings while playing it. Almost always, his own private sensations are believed to be a real property of the violin. The violin will be described as having a "good tone" or a "bad tone" but the scientist does not have the slightest idea what is meant by that because it is not an objective statement of fact.

The only way to break this communication block is to have a person who is an experienced, sensitive musician *and at the same time* is a trained scientist, able to judge from his knowledge of physical law what is a real property of the violin and what is his own sensation.

Finally I had the opportunity to talk with a very good violinist, who was also a scientist and had thought about these problems. He was able to communicate to me things about a violin that no musician could. What a violin player really wants, it turned out, is an instrument that speaks out, immediately, reliably, loudly, and above all *uniformly* on all notes. An instrument that does this will probably be described subjectively as having a 'good tone', because it sounds good to the player to get an immediate, predictable response to what he does.

Of course, an extremely harsh tone will be noticed eventually; but it is surprising how much musicians will tolerate it. The writer once heard a string quartet performance in which the cello had such a harsh, scratchy tone that it was physically painful to listen to; yet the famous cellist was perfectly happy with it, because the instrument responded well to his commands.

We realize, then, that what a violinist reports as a 'good tone' could be as much a matter of the condition of the bow, or the smoothness or roughness of the strings at the bowing point, as anything in the mechanical construction of the instrument.

Beware of Illusions!

But even a trained scientist can confuse his own sensations with reality if unchecked. The writer can understand how this happens, because he has had the experience several times. For example, in playing the first movement of the Beethoven piano sonata Op 26, a musician told me that I was overemphasizing a certain chord, destroying the musical sense. I simply did not believe him, because it did not sound that way to me. But later I listened to the objective evidence of a tape recording of my playing, and it was obvious that he was right; I *was* playing that chord much too loudly, but the fact that I was pressing the keys at the same time had changed my perception of its loudness.

After that experience, I made a habit of checking everything I played with tape recordings, so I could compare my subjective experience while playing with the objective fact of the sound it was producing. But after a few years of this, I had myself 'calibrated' well enough that the tape recorder was no longer needed; thanks to this training I now know, at the moment of playing, what effect I am producing in the ear of the listener.

From this experience there emerges the following advice. There is a certain stage in the training of a musician (the mechanics of playing under fair control, attention turning to interpretation), when listening to tape recordings of your playing will help more than can any teacher or long hours of practice. This is the only way you can know objectively what sound you are producing; therefore the only way you can know what needs to be changed. Without this experience you could practice forever – as I would have – perhaps improving your technical facility, but without improving your actual musical performance.

Illusions are notoriously easy to produce in all areas of perception. A famous example concerns blind people, who when questioned how they detect and avoid obstacles, report almost unanimously and with total confidence, that they feel a pressure on their faces that warns them of the obstacle ahead. A scientist, seeing at once that there is no physical mechanism that could possibly do this, then conducted carefully controlled experiments to determine the true means in use. It was found that when a mask was placed before the face, unknown to the subject, he still found the obstacles just as well; but when his ears were plugged up he lost the ability to navigate around obstacles.

So, just as the scientist suspected from the start, blind persons are actually using *sound* echoing off those obstacles, to orient themselves (just as bats do, skillfully avoiding obstacles and catching insects, while flying about in the dark).

Our point is this: it certainly does not help a blind man to be in ignorance of the means by which he gets around – indeed, the necessary first step toward improving his ability to do this is a conscious understanding of what he is really doing.

It is exactly the same in music. However much a musician may cherish the illusion that he has a "singing touch" that can alter the tone of a piano at will, or project his sound at will to wherever he wants it to go, the holding of such illusions cannot possibly help him to perform music more effectively. On the contrary, he will be wasting effort on nonproductive things; indeed, to carry a false mental picture of what he is doing, could very well prevent him from doing what is necessary to improve his musical performance.

The first step toward improving his effectiveness is a conscious understanding of the real facts concerning what is and what is not happening in a musical performance.

But may not some illusions be harmless? Sometimes they are. There is plenty of evidence of people who cherish illusions and are nevertheless perfectly good musicians – that oboist was an example. But he was a good musician not *because* of his illusions, but *in spite* of them. How many musicians remain mediocre performers or unsuccessful teachers, because their illusions prevent them from learning, or explaining to pupils, what is really essential in musical performance?

It is not really exaggerating to way that a musician's life, in its physical aspects, is one of *total immersion* in evidence for the correctness of our understanding of physical laws. His comfort and safety depend on the fact that the known laws of physics are valid over ranges of conditions vastly beyond anything in his direct experience. And yet, he may doubt, and teach his pupils to doubt, that those same laws apply to his piano!

A view which we have heard several times runs like this: "Your scientific theories and instruments reveal part of the truth, but not all of it. My trained ear is far more sensitive than your cold, unfeeling instruments, and I can hear differences in tone quality which are far too subtle for your instruments to detect."

To this, the proper reply is: "Our instruments are vastly more sensitive than your ear. Can you, after hearing a piano note, tell me just what happened in the first thousandth of a second after the hammer first touched the string, what happened in the next thousandth of a second; and the next? Our theories predict, and our measuring instruments verify in minute detail, exactly what happens in every thousandth of a second throughout the process of hammer rise, striking the string, and tone production. Without the slightest difficulty they can reveal differences in sounds that are totally beyond the ability of your ear, or anybody else's, to detect. Our instruments are indeed cold and unfeeling; and it is just for that reason that they can reveal the truth. They are never confused by the illusions and emotional factors that are distorting your personal judgments."

The whole success of science is due to the fact that scientists have learned to recognize frankly the *unreliability* of our own personal judgments. While no scientist can – or should – disregard such feelings entirely, he knows that major reliance must be placed on evidence obtained by completely objective means.

Many other fields of inquiry would benefit if there were more widespread recognition of the unreliability of personal judgments. For example, an economist who is emotionally committed to upholding one particular political philosophy, and insists on interpreting everything in terms of his own political value judgments instead of the real facts, is thereby automatically prevented from learning the true laws governing economic activity, and from making any real contribution to economic knowledge.

The scientist must, however, concede at least this much: knowledge of the objective facts concerning tone production in a piano will not necessarily make one a better musician (otherwise every physicist could become a superb pianist!); conversely, a lack of such knowledge does not necessarily prevent one from becoming a good musician, as the evidence demonstrates abundantly. But the valid and important point to be made is this: a dogged belief in demonstrably false ideas concerning a piano cannot possibly *help* anyone to master the instrument; it can only delay this mastery by misdirecting our efforts. It is for this reason that a musician ought to be aware of the objective facts concerning the piano's operation.

Furthermore, as scientists we must always admit a small possibility that we might be wrong. Certainly, if some utterly unexpected and startling new evidence were found, we would not cling doggedly to past beliefs, but would change the way we state the laws of physics so as to accommodate the new facts. How greatly civilization would benefit if some others, who have far more need of it, were willing to make the same concession!

CHAPTER 5

MECHANICAL FACTS OF PIANO PLAYING

The writer witnessed an interesting demonstration of contrasting piano techniques at a concert at the University of Minnesota in November 1959, at which Robert and Gaby Casadesus played the Mozart Concerto for two pianos, K 365. He, with presumably greater native strength, wasted it with unnecessary motions; when a crescendo was called for, he worked visibly harder, raising his hands higher and striking the keys more percussively; but this strategy met with very little success.

She produced just as loud crescendos without any such exertion. The reason was visible only because she wore a sleeveless gown. In the loud passages one could see no difference at all in the motions of her hands, but the muscles on the back of her arm stood out; she had learned to keep her hands on the keys, but simply to press harder using the strength of the large arm muscles to do the work.

A physicist or physiologist could have told them that this is not only the most efficient from the standpoint of muscular effort and fatigue, but also the best controlled, way to produce piano sound. In the present Chapter we support this observation by studying what is happening in the piano mechanism; and in Chapter 6 we examine what is happening at the same time in the hand and arm. Both areas reveal surprising, and little known, things that can be important to a pianist trying to improve control and endurance.

How Should A Piano be Played?

It is a basic fact of Nature that no mechanism – from a mosquito wing to a human hand to a bulldozer – can be under full control when it is being strained to the utmost; some reserve strength is necessary. One observes this constantly in any athletic activity, from basketball to skiing to swimming; the athlete who has learned to move in the most efficient way, using each muscle only to do what needs to be done and in proportion to its strength, so that it is accomplished with minimum exertion, has a great advantage in accuracy and endurance over one who wastes energy with unnecessary motions or who uses weak muscles, easily fatigued, to do what strong muscles would have done better without fatigue.

When in the 1930's José Iturbi raised his hands high above his head to come crashing down upon the keys, when in the 1960's Glenn Gould was tossing his trembling hands high after a staccato, and when in the 1980's André Watts was snapping his hands away from the keys and downward as if they were red hot, none of these gestures had the slightest effect on the actual sound produced – except that all were wasting muscular reserves and therefore inevitably losing a little bit of the precise control that they might have had otherwise. Of course, the loss was not serious and for most pianists it would hardly matter; but it was nonetheless real, and at the peak of the virtuoso performance scale it becomes crucially important.†

† In exactly the same sense, for a mediocre pole vaulter a small change in efficiency hardly matters; but for the champion pole vaulter, winning or losing can depend on being able to squeeze just one more inch out his clearance.

The pianists with the most perfect control over dynamics and timing are the ones who have learned to keep their hands on the keys, relaxed, never moving a finger except when it serves the musical purpose. For rather obvious reasons, this habit is also necessary to achieve the greatest accuracy (put bluntly: hitting the right notes), and to produce the smooth legato phrasing without which it is impossible to play Beethoven and Chopin properly.

But this efficient use of one's hands at the keyboard does not come naturally, any more than does the proper handling of a violin bow or the proper plucking of a harp string; all require careful explanation from teachers and then conscious effort and practice, to achieve. When there are many ways of being wrong, and only one way of being right, a beginner is very unlikely to happen onto the right habits by lucky chance – and practicing the wrong habits does more harm than good, very rapidly. This has been very well established in many different athletic activities.

Athletic Performance

Scientific study of athletic performance and the best way of achieving it, has been underway for some sixty years. The principles are the same as those involved in pressing a piano key but the scenarios, involving longer distances and times, are easier to visualize.

In the 1930's Claude Jerome Lapp, a Professor of Physics at the University of Iowa, studied the design of archery bows with the aim of finding how to achieve the greatest arrow velocity with the least muscular strength. Ordinarily, one would expect that the force required to draw the string a certain distance would be proportional to that distance, as we find for ordinary springs; this rule is called "Hooke's law" by scientists. But with a Hooke's law bow the muscular strength required would be the *maximum* force, which is actually exerted on the arrow for a miniscule fraction of the time it is being pushed by the string.

Obviously, it would be far more efficient if one could design a bow which required, as nearly as possible, a *constant* force, independent of distance, to draw the string; for then that same force would be exerted on the arrow throughout its acceleration by the string. This ideal bow would enable one to achieve a given arrow velocity with just half the muscular strength required by a Hooke's law bow – and consequently greater control and endurance. Lapp succeeded in finding a way of tapering and curving the bow (back–curved at the ends) so that this ideal was rather well approximated; and this enabled his daughter to win many prizes in archery. The Lapp bow design, or one based on it, is now more or less standard for tournament archers.

The same principle was then found in a study of efficient performance of members of rowing teams, a popular sport in England and Australia. Physicists measured the force exerted on the oar at different points of its travel, by various crew members, and Fig. (5.1) illustrates what was found. Here we plot the distance moved by the oar horizontally, the center of the diagram being the point where the oar is perpendicular to the boat (or rowing shell). The corresponding force exerted on the oar is plotted vertically. Curve A represents the instinctive performance of almost all rowers; they start out gradually, increasing to a maximum force at the middle of the stroke, then taper off gradually. The area under the curve is the total energy that has gone into propulsion of the shell.[‡]

But one crew member was smaller and presumably not as strong as the others, and there was some concern about whether he was able to "pull his fair load." However, his force – distance curve turned out to be the B curve; he started out vigorously at the beginning of the stroke, exerted nearly a constant force for most of it (although less than the maximum force exerted by his teammates), and continued this nearly to the end of the stroke. But the areas under the B and A curves were the same; he was actually contributing just as much propulsion as anyone else, *and he was doing it while contributing less to the total weight of the shell and using about half the muscular strength.* A crew of rowers like him would win easily over a conventional crew. Needless to say, this discovery resulted in some changes in the selection and training of rowing crews.

The same kind of effort analysis has been applied to pole vaulting, and it has resulted in adding about two feet to the recent Olympic records. Active studies of this kind continue at many places; Colorado Springs, Calgary, Spain, and Australia among others. They have studied in detail the efficient ways in broad jumping, swimming, bicycling, and practically every other such activity; today an Olympic Gold Medal is very unlikely to be won unless the athlete has had the benefit of training by a coach who understands these things.

The Pressing of a Piano Key

The problem of finding the efficient way of pressing a piano key is almost identical with the above ones, and attention to it will produce the same kind of results – as Gaby Casadesus demonstrated (perhaps unwittingly). Now let us justify these general remarks by a closer examination of the process, both mechanical and physiological, of pressing a piano key.

Here it is much harder to be consciously aware of what one is doing, because it is all done in a fraction of a second, and the maximum travel of a piano key is only about 3/8 inch (and the useful pushing of the hammer occupies only about 1/4 inch of that key motion, compared to about 6 inches for the archer, and 3 feet for the rower). None of us has naturally the perceptiveness to know what kind of force–distance curve we are producing, and no teacher can tell this merely by watching us play; so we need conscious practice guided by understanding of the physical facts.

************************** MUCH MORE HERE! *****************************

‡ More technically, it is the increase in the kinetic energy of forward motion of the shell, contributed by that oar stroke.

CHAPTER 6

PHYSIOLOGY OF PIANO PLAYING

The writer once had a startling experience with piano–playing muscles. In the back yard was a shipping crate with good quality lumber (in which a new Bösendorfer piano had just been delivered from Vienna), and I decided to make a big garden gate out of it. After a great deal of prying, sawing, drilling, pounding and hoisting, the new gate was in place, and I was exhausted; forearm muscles were sore and hands, unaccustomed to it, that had been grasping tools tightly for hours were almost inoperative. Somehow, at that most inopportune time, I decided to cool off by trying to play the new piano, but expecting not to be able to do anything. As expected, the rapid or *forte* passages just would not come forth; but to my astonishment, I was playing slow *pianissimo* passages with better control over dynamics and phrasing than I had ever been able to manage before.

It required some study to understand this. The muscles which I had used habitually until then in piano playing (the forearm muscles which produce a grasping motion of the fingers and are most natural to us because that grasping is already an automatic reflex of every newborn infant) were fatigued to the point of refusing to function. But, unknown to me, Nature had given us a second set, which then came to the rescue and controlled finger motion far more precisely because they were not a foot away, connected to the fingers by long elastic tendons; they were right at the scene of action, in the hand and fingers.

Muscles of the Hand

These "new" muscles which I had discovered by accident, are called the Lumbrical and Interossei muscles. They are not naturally strong, being so little used by most of us; but like all muscles they are strengthened by exercise.† Fig. 6.1 is a stylized and simplified view of the hand and arm in piano–playing position, revealing the mechanical arrangement that is built into all of us by Nature; we therefore have no choice but to learn how to use this as best we can. The strong deep and superficial flexor muscles in the forearm are the ones that you feel thicken a great deal if you grasp your forearm while clenching your fist. They pull upon the finger bones (or *phalanges*, as the anatomists call them) in two different places.

The lumbricales are also depicted in Fig. 6.1, and both lumbrical and interossei muscles appear in Fig. 6.2, which shows the back of the hand. The arrangement is more or less the same for all fingers, although on closer inspection one finds that no two fingers are exactly alike.‡

† However, in discussion with an anatomist, we learned that the lumbrical muscles are subject to great individual variations; and some people do not have them at all. So our conclusion is: "If you have them, use them! If you don't have them, then consider taking up some other instrument than the piano."

‡ In particular, the fourth and fifth fingers are anatomically quite different from the second and third. Even their blood supply is arranged differently; as countless seamstresses have discovered, the fourth and fifth fingers bleed more profusely from a pin–prick than do the others.

Medical books have all this information in far more detail than we need here; for example, the book *Surgical Anatomy of the Hand* by Sterling Bunnell has the information needed by a surgeon doing reconstructive surgery on injured hands. Some may find all this a bit gory, as did Hector Berlioz, who started as a medical student. But in his memoirs written in his old age he is finally able to describe, with great humor, the horrors he experienced many years before, dissecting human corpses to acquire this kind of knowledge directly. The experience turned him to music, much against his father's wishes. Nevertheless, since anyone may have an injury or deformity of the hand, we are fortunate that at least a few people are willing to dedicate their lives to acquiring and applying this intricate anatomical knowledge.

The lumbricales are sometimes called the harp muscles, because as we see from the Figures, when a lumbrical muscle contracts it moves the finger in that combination of straightening and forward motions that is used in plucking a harp string. Using this fact, you can learn how to call upon the lumbricales consciously. We do not have naturally the ability to call consciously upon one particular muscle rather than another; we learn only to will a particular motion of the hand. By trial–and–error practice not unlike a musician's first year of practice on a violin, infants are busily learning how to bring about that controlled motion, without knowing consciously exactly how they are doing it.

But you can know easily when your fingers are being moved by the lumbricals; just will that harp–plucking motion of your finger. Generally, the lumbricals, flexors, and extensors will all be involved at once, in a way not under conscious control. But change the finger movement – that is, change the relative amount of straightening and forward motion – while pressing a piano key down and feeling your forearm with your other hand. If the flexor and/or extensor muscles are contracting, you feel that easily because they grow thicker and slide under the skin. When you are moving your finger forward in such a way that all muscular action in the forearm ceases, then the lumbrical muscle is doing all the work.

Then if you develop the habit of moving your fingers in that way while playing the piano, you have learned how to call consciously upon the lumbricals; with much practice this becomes automatic and you can switch back and forth at will between the two sets of muscles. Both control and endurance will be improved, because you can use the arm muscles for loud passages; then let them rest while you switch over to the lumbricals when fine control is needed; then let the lumbricals rest when fine control is no longer needed, *etc.* Of course, this ability is not acquired overnight; a year of conscious practice will be needed.

Reaching for octaves, ninths, and tenths requires the thumb and fifth finger to move out away from the hand, far beyond what a normal person needs in almost any other activity. Then the interossei muscles that move the fifth finger outward become large and strong in all experienced pianists – Sherlock Holmes could spot a pianist instantly by noting how thick the palm of the hand is at the outside edge just below the fifth finger. You can see it very clearly in videotapes of Alicia de la Rocha and Vladimir Horowitz performing (interestingly, her hand was more developed there than his, suggesting that he, with longer fingers, did not need to work the interossei so hard to achieve his span).

Has Anyone Else Noticed This? At this point in the reasoning it occurred to me that such a striking experience must surely have been reported by others, so I undertook a literature search to find some mention of it. This turned out not to be easy; but three years later, browsing in Schirmer's music store in New York, I found what I was looking for. It had all been reported twenty years earlier, just as I had experienced it, in the book *The Riddle of the Pianist's Finger* (1936) by Arnold Schultz, a piano teacher in Chicago; and he tried to understand it in much the same way I had. Strangely, his account of the discovery does not appear in his book, but only in some supplementary notes that he wrote for its dust cover; so we quote them here:

> "Throughout all of my musical life, I have been aware of variations in my technical relation to the keyboard which made enormous difference to my pleasure and skill in playing. One of the chief characteristics of a 'good' period was a sensation of tension and work in the palm of the hand, amounting in a long session of playing to actual muscular pain. But the sensation was on the knee of the gods. I was quite powerless to induce it voluntarily and I did not know what caused it. The whole problem of technique, so far as I was concerned, hinged on the explanation of that sensation."

Then he recounts some long frustrating attempts to understand it, and finally concludes:

> "I saw suddenly that a good technique must depend upon a dominant use of the small muscles in all the technical touch–forms. It required almost another year of experiment, however, to learn how they might be voluntarily controlled. I then began to write the book."

Looking back at that work with 60 years of hindsight, we can say that it contains some very important truth that cannot, as far as we are aware, be found anywhere else.

But then the value of all this is nearly destroyed when Schultz – with no training in physics and so without giving any consideration to what is known about the mechanics of piano and finger – proceeds to invent an elaborate and fanciful mechanical theory of his own, concerning many imagined "touch–forms" by which a finger acts on a key, and inventing a new name for each – {*contra–fixation, contra–weight, trans–fixation, trans–pressure, trans–weight, trans–movement* } – each of which can be used with a {*fixed–base, moving–base, prepared stroke, or unprepared stroke* }.

Thus Schultz tries to define $6 \times 4 = 24$ different ways of pressing a key down – all without asking whether the principles of mechanics recognize any such fine distinctions. As a result, the picture of piano technique that he presents to us is grotesquely confusing, and many times more complicated than the real facts.[†] We doubt whether any reader has ever been able to hold in his mind all these new, arbitrary definitions long enough to follow his exposition. So here our aim is to recover a valuable nugget of truth, cleansed of the mud in which it has been buried for 60 years.

What are the Conclusions for Piano Technique? Once aware of the availability of the small muscles in the hand, and the possibility of controlling them voluntarily, we can draw several conclusions important for present piano technique – and even for future piano design. The most effective piano technique involves perhaps 100 little details of hand motion, taking advantage of every little detail of the anatomy of hand and arm. We need not dwell on those that are so obvious that everybody discovers them at once without any help; but we want to explain in some depth the ones that are so subtle that without

[†] This is not to say that every point Schultz makes is wrong, only that they are unreliable, and the average reader has no way of judging which are right and which are wrong. To his credit, he does recognize the essential role of the lumbrical muscles.

informed help one can practice diligently for years – as I did – without ever discovering them.

********************** MUCH MORE HERE ! ****************************

So what does the future hold here? We think it is hopeless to try to change the thinking and teaching of any musician who has managed to reach the virtuoso level without conscious attention to these physical facts; his attitude would be, inevitably: "The methods I used have *worked*, with results so precious and fragile that it would be stupid to make any change in them in favor of something unknown." We agree that *from his standpoint* this would indeed be stupid; but a mediocre player is free to try out anything because he has nothing to lose. Innovations in thinking and teaching must take place not at the summit, where too much is at stake; but at the most humble elementary level. Then a process of Darwinian Natural Selection must take place. If the ideas we suggest here are actually taken seriously and prove to be successful in practice, then within a generation there will appear many virtuoso musicians who understand and teach them. If they do not produce superior musicians, then our ideas will die out of their own accord, whether or not they are true.

The Schumann Slips.

Another aspect of the anatomy of the hand played a famous role in the history of piano music, and gives us an instructive case history of how folklore grows to fill up the vacuum created by lack of hard facts. Referring to Fig. 6.3 showing the muscles and tendons in the back of the right hand, one sees that the tendon which lifts the fourth finger is tied by two small cartilage "slips" so–called, with the tendons on either side, which lift the third and fifth fingers. As a result of the angle they make, third and fifth fingers can be raised independently while keeping the fourth down; but the slips prevent one from raising the fourth finger unless the third and fifth are also raised at the same time.

Putting your fingers on a table in piano–playing position, you can experiment with finger raising and verify that you can easily raise the third or fifth finger while keeping all the others on the table; but – unless you are an extremely well–practised pianist – you are hardly able to raise the fourth finger off the table at all unless the third and fifth are raised at the same time. You can easily feel these slips directly; just press a fingertip lightly to the back of your hand between two finger tendons near the knuckle, and open and close your fist. You feel the slips moving under your finger and may verify that the one between the third and fourth finger tendons is wider and flatter. Pressing between the second and third finger tendons, you feel nothing sliding under your finger, verifying that there is no slip connecting them.

Nature has seemingly made a foolish and wasteful error here; while we are equipped with individual muscles and tendons for the individual fingers – and they are under our individual conscious control to move any one finger at a time – yet the ability to do it is frustrated by these slips which, as far as we can see, perform no useful function for us, although they might for a duck or a tree–climbing monkey. Perhaps this is the unfinished business of evolution, from an animal without separate control of the phalanges to man, in which full independent control is not yet quite achieved. But if so, then it seems unlikely that the job will ever be finished if left to the devices of Nature.‡

This strange anatomical peculiarity causes no inconvenience to most people – the vast majority of us are not even aware of it. But it is a great inconvenience to a pianist, who learns quickly that the fourth finger is harder to control than any other. Awkward fingering is forced upon us by the refusal of the fourth finger to do the same things that the others do. By long practice and exercise specifically designed to stretch them, these slips can be loosened to the point where the fourth finger achieves a little more autonomy; but the amount of exercise needed is appalling.

Conceivably, if they cause too much trouble, these slips could mean the difference between becoming and not becoming an accomplished pianist. Robert Schumann (1810–1856), as a young man, was greatly troubled by this, and he tried to correct it himself. Exactly what he did to his hand is a matter of great mystery; there are many vague accounts of the story, but it seems that none of his biographers knew any authentic hard facts. Most have it that he invented some kind of mechanical contraption, which went wrong and permanently damaged his right fourth finger. But different sources disagree as to the purpose of the contraption and none gives any details about its construction or how it worked – which would be easy to understand if that contraption were a figment of the imagination, conjured up by someone who, unaware of the anatomical facts just noted, did not understand what the real problem was. There are many Schumann biographies; but we have found no writer on Schumann who showed any awareness of these slips as the cause of the pianist's fourth finger problems. Yet, as we shall see, medical people have been well aware of this all the time those biographies were being written.

For example, Schonberg (1970, p. 153) gives it only one sentence: "*Trying to achieve a short cut to finger independence, the impetuous Schumann invented a contraption that permanently ruined one of his fingers.*" We think, from the weight of other evidence, that he is correct in saying that finger *independence* was the goal; but we fail to see how any contraption could help to achieve that, much less how any contraption could *permanently*

‡ Because anyone who happened to have a mutation making these slips smaller or absent, would get thereby no particular survival or reproductive advantage, so even if such mutations are happening today, there is no reason why the percentage of the population having them should be increasing; the Natural Selection mechanism of Darwinian evolution is absent. But as soon as sufficient intelligence is achieved, the Darwinian mechanism becomes inoperative anyway, to be replaced by a much more efficient one; conscious intervention of biologists of the distant future – with the knowledge and power to rebuild DNA molecules as a carpenter rebuilds a damaged house – might solve this problem and a thousand others.

ruin a finger. Sufficiently violent externally applied stresses and twists might cause a temporary finger sprain – but that would heal of its own accord in a week. Indeed, Nature can heal even a broken bone.

Brockway & Weinstock (1939, p. 295) tell a different story: "*He even invented a device for keeping the fourth finger of his right hand inactive while he practiced, evidently hoping that this curious procedure would overcome the laws of nature, and make the fourth finger as strong as the others. To his horror, the favored finger tended to retain this artificial position when free.*" Again, we can grant that the goal was stated almost correctly: to make that finger as 'strong' as the others (that is, as *functional* as the others). But again, that contraption is obvious nonsense; how could anyone believe that holding the finger inactive would help to make it stronger? The ones who perform any muscular activity best are the ones who have practised it most diligently; a runner does not train for the big race by spending a week lying in bed. Even more senseless; how could holding a finger inactive for the short period of a practice session cause permanent ruin to it? Surely, we have again the attempt of someone who does not understand the real problem, to visualize how things might have been. However, the statement that he lost the ability to raise his fourth finger at all would make excellent sense on the theory we suggest below; that is exactly one of the dangers that it would risk.

The Schumann biographer R. H. Schauffler (1945) devotes all of Chapter 5, entitled *The Crippled Hand* to this incident but again without giving a single hard fact about that contraption; only another conjecture of the same kind. He imagines Schumann's right fourth finger in a kind of sling while practicing, which "*resulted in laming for life the right ring finger, thereby shattering all his shining hopes of a virtuoso's career.*" Again we find this fabulous, not only because putting the finger in a sling could only defeat his purpose, not help it; but also because, while a mechanical contraption might cause a temporary strain, we are unable to imagine how it could cause *permanent* damage, that would not heal of its own accord without any need for medical treatment. Permanent loss of a part of finger function would require some kind of *internal* damage, so severe that Nature could not heal it.

The Chiroplast. Then what accounts for the invention of the contraption theory, and the seemingly universal credence it received from later writers? This was explained, inadvertently, by Arthur Loesser (1954), pp. 297–300. There actually was such an infernal contraption, called the *Chiroplast*, which was sold by the thousands in the period just before this, 1814–1830, mostly in England and Germany. First the wrist of the player was clamped between horizontal bars, preventing any vertical motion; then the thumb and fingers were inserted into holes in brass plates called 'finger guides'; finally wires were connected between the wrists and the finger guides to prevent the wrist from moving outward. This was supposed to force correct hand position in piano playing; but in fact it did exactly the opposite.†

The accursed inventor of this was one Johann Bernhard Logier, who also wrote a book on his weird, disastrously wrong theory of piano pedagogy.‡ His contraption was

† As was realized later, vertical motion of the wrist is essential in playing chords with best control, and outward motion of the wrist was the secret of Liszt's perfectly smooth legato touch.

‡ It is startling to learn that Friederich Wieck, Schumann's piano teacher, owned a copy of Logier's

manufactured in England by Muzio Clementi and it was promoted profitably by Logier, Clementi, and the pianist Friedrich Kalkbrenner. The latter proceeded to market in France another contraption called the *Dactylion*, in which the fingers were inserted into ten rings hanging from springs, supposed to train the fingers to lift off a key more quickly after playing a note (again it would, of course, do just the opposite by denying the lifting muscles the exercise they needed). We have no record of these horrors actually injuring anyone, but with the example in everybody's mind and the claims by well known musicians (with a financial interest) that such things could actually help one's piano technique, it is easy to see why, hearing of Schumann's injury but not being able to learn any details, a biographer might jump to the conclusion that he had also made use of some kind of contraption.

Furthermore, in the fifty years following the Schumann incident, various other contraptions of this sort were promoted, under names like *Chirogymnast, Manumoneon, Technicon, Digitorium, $\cdots$ etc.* The idea was much in the air throughout the 19'th Century; for more details, see Loesser (1954, pp. 383–4, 541–3). So, of course, once one biographer had invented the contraption theory, it had an instant plausibility for anyone without detailed anatomical knowledge of the hand. Later biographers would tend to assume that he knew whereof he spoke, so they would repeat the story with embellishments; that is how folklore grows.* But this ignores some far more cogent evidence pointing to a quite different theory.

So What Actually Happened? A theory which makes much better sense in view of the facts of physiology, some letters that Schumann wrote about it, and some more direct evidence to be noted, is that some time in early 1831 he tried to perform surgery on his own hand, to sever the slips; and bungled it. Firstly by not realizing the need for antiseptic conditions,† he incurred a horrible infection that required over two years to heal. He tried many treatments and reported that his rooms were like a chemist's shop. His doctor recommended constant application of raw meat and brandy! At least, the brandy would prevent further infection; but this treatment would also nearly prevent natural healing. In such conditions, it is remarkable that he recovered at all, but understandable that he then turned to full–time composition (in fact, the incident hardly affected his productivity; his first six Paganini caprices and the two books of Intermezzi for Piano were written while the injury was healing).

Secondly, under these unsanitary conditions (and before the days of anaesthetics), the knife probably slipped, severing something else like the main tendon of the fourth finger.

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book, but fortunately had too much good sense to believe it. To add still another coincidence we learn that Wieck's copy of that book was borrowed just at this time by a young man of 18 named Richard Wagner, who had enrolled as a music student in Leipzig University the year before – and Wagner too never became an accomplished pianist.

* The *Larousse Encyclopedia of Music* (1974, p. 278) advances this process another step by repeating the contraption story, but moving the scene of action from the right fourth finger to the left third finger, undeterred by the fact that, of all ten fingers, this is the one in least need of any help.

† Recall that, at this time Louis Pasteur was eight years old and Joseph Lister was four years old; fifty years later, thanks to Pasteur and Lister, physicians were just beginning to comprehend the need for antiseptic conditions, and a large fraction of surgical patients still died of the inevitable infections.

This would, indeed, cause a lifelong disability, which Nature could not heal. Two years later, in 1833, Schumann was still writing letters indicating that the hand was not yet fully healed; a mere sprain from a finger sling could hardly do all that to him.

But the clinching evidence for this theory is supplied by a footnote in Schauffler's Chapter five, which we quote in full:

> "The venerable Dr. Alfred Meyer of New York tells me that in 1878, while a post–graduate student of medicine in Leipzig University, he was told by a German doctor that Schumann had cut the tissue between his fingers with the object of increasing his span."

Here Schauffler is recalling as best he can what the doctor told him; but unaware of the anatomical fact of the slips, he perceives the scene of operation to be between the fingers rather than between the tendons, and so imagines that if surgery was attempted, the problem must have been insufficient span. But again, as you can see at once on examining your own hand, cutting the tissues between the fingers would not help the span (and would cause other troubles far worse than a mere crippled finger); you can already extend your thumb and fifth finger out in opposite directions, achieving all the span which the length of the phalanges permits. The problem was not span; but the *independence* of the fourth finger.

But the truly important part of this quote – that Schumann *did* attempt self–surgery – was quite missed by Schauffler. We cannot understand why he gave this only enough credence to rate a passing remark in a footnote; it seems to us vastly more likely to be true than the fanciful story of a 'sling' with two physically impossible properties, which he puts into the main text. This is a good example of how a little attention to the facts of physics and physiology can change our appraisal of historical testimony.

If the bungled surgery theory is true, then since the incident occurred in Leipzig, it would of course be well known among medical people there for many years afterward; conceivably, some record of this may still be in the medical school archives. Indeed, Schauffler also quotes from some of Schumann's letters of the time referring to the injury, which provide further evidence for the bungled surgery theory and against the sling theory. But Schauffler does not seem to realize that Schumann is describing a serious broken–skin infection, not merely a soothing ointment.

In view of all this, we suggest that the truth is more like the following: in Leipzig with its medical school – many of whose faculty and students would have been then, as now, amateur musicians – Schumann would have no difficulty in meeting people who could explain to him the anatomical facts about the slips, which prevented independent control of the fourth finger.[‡] But the medical people, aware of the constant danger of serious infection, would naturally refuse to perform any operation if the patient's life were not in immediate danger; so the headstrong Schumann, perhaps while drunk, tried it himself. This theory violates no principles of physics or physiology, is not inherently implausible, and it explains very easily all the known facts.

The suggestion of drunkenness is not essential to this theory, but it has some plausibility in its own right. It is known that, at this age (21), Schumann had a strong predilection for alcohol which alarmed his mother and friends, who tried to urge moderation on him.

[‡] Of course, Schumann also knew his way around Leipzig University and its library facilities independently, having been a law student there briefly three years before.

And we all know that when persons get very drunk, just at the point where they nearly lose all muscular coordination, they also acquire a bravado that makes them try all kinds of difficult and dangerous feats, which they would never attempt to do when sober.*

Furthermore, the drunkenness theory helps to explain two other facts; it greatly increases the probability of the knife slipping and doing permanent damage; and it would account for Schumann's own reluctance to enter into details of the injury later, confining his remarks to the progress of the treatment. Surely, had the injury been inflicted in a less stupid way, he would have become a crusader, describing what he did in great detail in order to warn everybody else against it.

In any event, the main known fact is that Schumann never became a virtuoso pianist, because of some kind of self–inflicted crippling of his right fourth finger that occurred in early 1831. This shows in his piano music; he makes less demands on the right fourth finger than do other composers. Schauffler (*loc cit*, p. 494) quotes a letter from Morton Krouse, a good amateur pianist who broke his right fourth finger and never fully recovered its use:

> "Long before I met you, I noticed that Schumann's piano works were much easier to play with my crippled finger than those of any other composer. For example, in most parts the Schumann Piano Concerto is easier for me than many passages in Bach's *Two–Part Inventions*, just because the fingering seems to suit my right hand much better. Whereas *Papillons*, written before his accident, is just as difficult for me as any other composer's works of approximately the same technical caliber. Any pianist who broke his ring–finger would notice how much more easily he could play Schumann than anybody else."

By the end of the 19'th Century, surgical technique had advanced to the point where the Schumann operation could have been performed safely. Professor Wm. S. Forbes, writing in the Philadelphia Medical Journal for January 15, 1898, recommended that it was proper to try this if a pianist was having great difficulty from the slips. We do not know whether the operation was ever actually tried, but a search of old medical journals of this time might shed some further light on it.

Today, there are competent surgeons specializing in reconstructive surgery of the hand, for whom this operation would be trivial; if anyone believed that these slips were the main factor preventing him from becoming a first–rate pianist, the Schumann operation could be performed under proper antiseptic and anaesthetic conditions. The procedure would be very simple – even more so than the plastic surgery which many people undergo for merely cosmetic reasons – since the slips are very small and directly under the skin. With modern antibiotics to prevent infection the hand ought to heal in a matter of days. Although we do not advocate this operation for anyone, if it *were* done, it would be of great interest to follow the patient's subsequent fate and see whether it did indeed make a noticeable difference in his piano technique (but we suspect that failure to become a good pianist has other causes, far more important and not surgically correctible).

Robert Schumann was a medical phenomenon in more ways than one. He suffered from having been born 130 years too soon, when medical knowledge and technology were

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* The writer knows this very well from his own personal experiences at the same age; it is in retrospect remarkable that I survived to the age of 25.

hopelessly short of what he needed. The cause of his mental breakdown, leading to his death in an insane asylum in 1856, could be neither diagnosed nor treated.† The symptoms appeared gradually in several different brain functions; auditory hallucinations, difficulty in speaking, inability to reason coherently and consequent preoccupation with trivia, at the end inability to recognize old friends. Only post–mortem examination was able to reveal a large osseous growth in his skull, which had been exerting increasing pressure on his brain. Today, NMR–imaging‡ could reveal its exact location, size, and shape in a few minutes, and surgical correction would be a more–or–less routine procedure, although hardly a trivial one. From the available information it seems highly likely that, with modern medical facilities, Robert Schumann could have had another thirty years of normal, healthy, productive life, more than doubling his total musical output. Perhaps his musical horizons would have expanded over the years, as did Beethoven's.

If there were an abnormality within the brain, such as a tumor, this would be revealed by NMR equally well, in minute detail, although it might or might not be operable. But this would cause dysfunction of just one localized area of the brain, which does not check with Schumann's symptoms.

An example of such a localized dysfunction is given by the case of Maurice Ravel (1875–1937), who also died of an undiagnosed brain disorder, but a very localized, specific one. He lost the ability to speak and write, but retained his full intelligence and musical skills for at least a year longer. Other cases have been observed, in which a musician lost the ability to speak but could still play the piano as well as ever. Evidently, the verbal and musical functions are carried out in different areas of the brain.*

The Schumann story is so interesting as an historical incident – and also possibly important for others today – that we have described it in some detail and taken pains to demystify it, even though it might seem a digression from the main purpose of this Chapter. Now let us return to the business at hand.

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† From time to time we still hear a dark rumor, that his mental deterioration was really the result of a venereal disease; and that Friedrich Wieck, aware of this, was quite right to raise strenuous opposition to Schumann's marriage to his daughter Clara. Anyone who wants us to believe that, must also explain to us how Clara then managed to bear him eight children without contracting the disease herself. In her late 60's – more than 40 years after their marriage – she was still healthy and engaged in active concertizing.

‡ This stands for "Nuclear Magnetic Resonance", in which a strong magnetic field causes the hydrogen nuclei in various tissues to emit radio waves revealing their location and chemical surroundings. The latter yields extremely detailed pictures of tissues, with no ill effects on the patient. The present writer, in the 1950's, participated in some of the early theoretical study of NMR as a physical phenomenon; but NMR imaging became possible only some twenty years later, with the development of the computers to process the enormous amounts of data and convert them into meaningful images.

* But only in 1992 was the brain area involved in piano playing finally identified by NMR imaging. Justine Sergent, a neurologist at McGill University, Montreal and also a pianist herself, recorded NMR images of the brain as ten professional pianists sight–read and played, and found that the active area of the brain during this was a kind of network adjacent to, but distinct from, the areas used for verbal skills. This knowledge, reported in *Science* magazine, July 1992, will doubtless be valuable in the future, for treating musicians who may incur some kind of brain injury or dysfunction.

But How did the Great Pianists Actually Play and Teach?

Having propounded a theory of correct piano playing based on the facts of physics and physiology, we need to confront it with the facts of actual experience at the keyboard. The great pianists learned their craft in many different ways. The first were of necessity self–taught; then a formal piano pedagogy (Czerny, Clementi, Leschetizky, Kullak) appeared, producing many of the best known concert artists, and advocating various 'teaching methods' which became fashionable in the late 19'th and early 20'th Centuries.

But the effectiveness of this pedagogy is unclear when we note that different teachers, although all apparently successful in the sense that a few of their pupils achieved worldly fame, used very different 'methods'. And only a few of their pupils had that success; might they have been just the ones with exceptional drive who would have become just as great without the pedagogy? Indeed, some of the greatest masters of all, such as Leopold Godowsky, continued to be almost entirely self–taught.

In a sense, all the pupils of Liszt were self–taught, since he said nothing about technique. It seems that he could only demonstrate it, not explain it. The pupils of Chopin complained about the same thing; as one put it, his teaching method was "to play like an angel, then tell us to do likewise." But that is equally true of every virtuoso, it is not confined to the piano, and once started it is self–perpetuating for reasons that we note next.

Violin Pedagogy. Leopold Auer (1845–1930) was one of the mainstream violin teachers (he was a pupil of Joachim, and among his pupils were Jascha Heifetz, Efrem Zimbalist, and Mischa Elman). He wrote a small book (Auer, 1921) on violin pedagogy, in which he reports on the teaching methods of Joachim:

> "Anything which had to do with the technique of the two hands we were supposed to attend to at home. Joachim very rarely entered into technical details, and never made suggestions to his pupils as to what they were to do to gain technical facility ··· He rarely made his meaning clear in detail, and the only remark which he would utter at times, after having demonstrated a point would be: '*SO müssen Sie es spielen!*' (*That* is how you must play it!), accompanied by an encouraging smile. Those among us who were able to understand him, who could follow his inarticulate indications, benefited enormously by them, and tried as far as possible to imitate him; the others, less fortunate, stood with wide–open mouth, uncomprehending, and fixed their attention on one of another of the great virtuoso's purely exterior habits of playing – and there they remained."

The similarity to what the pupils of Liszt and Chopin reported is remarkable. But then Auer in turn follows this same policy in the rest of the book; he goes in great detail into the gross matters that one can see directly, such as how many fingers should be used in holding the bow; but there is not a word on how the bowing point, bow velocity, and pressure of bow on string determine the tone produced. Yet the mechanical facts of how the string moves under the bow – and thus determines the necessary manner of handling the bow – had long been well known, thanks to the work of Helmholtz (1862).†

† And to add to the mystery, Joachim was a friend of Helmholtz, who in addition to being the greatest German scientist of that time, was also a competent pianist. Joachim played Schumann's *Abendlied* at the memorial service for Helmholtz in December 1894. Still, the fundamental knowledge that Helmholtz had given thirty years earlier to help violinists quickly master the rules of

Nowhere does Auer mention such essential facts as that to play louder, one must move the bow more rapidly rather than pressing harder on the string; or to produce a long sustained note, one must move the bowing point closer to the bridge, press a little harder on the string, and move the bow more slowly. For a beginning student, these completely counter–intuitive facts are the ones in most need of being pointed out and explained (and they can be not only understood at once, but *predicted*, from the physical principles given by Helmholtz). But each violin student had to discover them for himself as best he could; those who failed to do so simply abandoned the violin at an early stage. The more persistent ones learned them unconsciously, remained unaware of just what they were doing – and were therefore unable to pass it on to their pupils. The situation is self–perpetuating because those who manage to reach the virtuoso level in spite of their incomplete understanding of it can, like Liszt, Chopin, and Joachim, only demonstrate it, not explain it. Doubtless, the same thing can be said of the pedagogy of every other instrument.

Back to the Piano. Piano technique is more subtle than violin technique in at least one respect. In both, the crucial things happen too fast to see, but the laws of physics dominate violin playing so completely that unless one handles the bow in something like the correct way, it will be impossible to produce any musical sound at all. With the piano, any kitten can press a key and make a musical sound; but what is important about just how it is pressed is much less visible than is the motion of a violin bow. Not only does everything happen too fast to see; the crucial things happen out of sight. Needless to say, most pianists remained not consciously aware of these things; but all musicians readily noticed that there was no discernible connection between the 'methods' of piano teaching and the success of that teaching, and by the 1930's the notion of piano 'methods' was in disrepute.

Looking back today, we can say that the 'methods' undoubtedly did have some important bits of truth in them; but without any attempt at objective, scientific validation they were all scrambled up with a great deal of superstitious nonsense which did more harm than good. Then the methods were greatly oversold by eager promoters. But can we now salvage the useful bits of truth and dispose of the superstitious nonsense and the promotional hype?

Put differently, in spite of the varied backgrounds of the great artists, is there any common factor in the final result? Regardless of how they learned to do it, does the actual performance of the great pianists provide evidence for or against our theorizing? There is plenty of evidence, if we will open our eyes to it; let us examine what is known about the early pianists (those who lived before the days of recording); and then turn to the much more detailed information available about recent and contemporary pianists.

Imagine what it would be like today to have videotape recordings of Mozart, Beethoven, Chopin, Liszt in their greatest performances. What we can only speculate on would become evident facts, and perhaps we might learn some important things from them. As it is, we would like to form the best judgments possible about how the great pianists who lived before the days of recording dealt with the keyboard; in particular, whether it was

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proper technique, was ignored by those who had the most to gain from understanding it. Perhaps, 100 years later, it may finally be appreciated.

importantly different from the way pianists perform today, as many believe (however, the controlling principles of physics and physiology were the same in 1790 as in 1990, so they could not have been very different; given the same problem and the same resources, one is forced inexorably to nearly the same solution, whether or not one understands the real reasons for it). However, we should be aware that many pitfalls face those who try to form judgments on this today.

Difficulties of Historical Interpretation. In 1963 the Music Critic of the New York Times, Harold C. Schonberg, published a book, *The Great Pianists*, in which he made some interesting attempts in this direction. But we think that his conclusions can be improved on greatly – in some cases reversed. This is not a problem of *logical deduction* because the necessary information is lacking. It is a problem of *inference* (*i.e.*, how to reason consistently and honestly from incomplete information, so that we take fully into account what is known, but avoid assuming what is not known) in which it is important to take into account all the evidence available, of whatever kind. The principles of inference, being needed constantly in science, are rather well understood (Jaynes, 1994); and a person familiar with them can see that Schonberg did not avail himself of some cogent evidence that would have changed his conclusions. Let us point out the nature of some of this.

The testimony of eyewitnesses is obviously very important, but it can also be distorted and biased due to faulty memory and ulterior motives. For example, when Carl Czerny (a Beethoven piano pupil) and Anton Schindler (a violinist who acted as Beethoven's private secretary) give conflicting testimony about him, whom are we to believe? This is a relatively easy decision, because Schindler is drawing upon recollections forty years after the fact, with some obvious personal animosity toward Czerny[‡] in a work full of provable factual errors on almost everything; we believe Czerny.

In addition, the further back we go, the more inclined are witnesses to believe in the supernatural and the miraculous, and the less likely to comprehend the simple facts about mechanics, acoustics, and physiology that are familiar to educated persons today. Even today, the notion that a cause–effect relationship requires a physical mechanism to bring it about, is quite foreign to the thinking of many persons without scientific training.[⋆] Therefore, the further back we go, the more essential it is to have and use the relevant scientific knowledge of today. If a witness, writing in 1830, claims to have seen something that we know to be physically impossible because of scientific knowledge that was not discovered until later, that needs to be taken into account. We have seen this in the fabulous Schumann stories.

Likewise, if today an historian (out of ignorance of scientific facts or failure to perceive their relevance) takes for granted things that scientists now know to be impossible, or disbelieves what is known to be true, his interpretations of old testimony can be thrown far off the truth. We think that Schonberg's conclusions suffer greatly from this, and particularly so in the case of Beethoven.

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‡ Waiting just until Czerny was dead, Schindler proceeds to disparage both his playing and his teaching, with criticisms that we can find from no other source. He even tries to blame the theatrical mannerisms of Liszt on Czerny's faulty teaching!

⋆ And this ignorance is also self–perpetuating; because of course, those who never look for the real causes of things never find them.

Beethoven was famous for breaking hammers and strings on the fragile pianos of his day. Modern commentators such as Loesser and Schonberg draw what we think are two erroneous conclusions from this. Firstly, they suppose that he demanded far greater dynamic range than other composers; but let us observe that those pianos were not capable of very much sound volume before the strings snapped, and he was also going deaf. Most of us have observed that people who are only slightly hard of hearing habitually talk much louder than the rest of us.

Secondly, Schonberg (1963) states several times that all early pianists except Beethoven kept their hands close to the keys, but Beethoven raised them high. He even entitles his Chapter on Beethoven: "*String–Snapper, Hands on High*". But this contradicts the testimony of many independent eyewitnesses, all of whom stated the opposite; how could Schonberg have got such an idea? On closer examination, we find that whenever Schonberg states this in the text, the *fact* that he is trying to interpret for us is simply that Beethoven played *loudly*. Not understanding the physics of it, he merely *imagines* that this requires highly raised hands; but as Robert and Gaby Casadesus demonstrated so nicely, the opposite is true.

Schonberg displays his lack of comprehension of this point in several other places; for example, in discussing Clara Schumann's performance, he notes that her father had drilled into her that the finger must never strike a key percussively. Then he states (p. 229), "*Apparently, even with this hands–close–to–the–keys technique, she was able to draw a full, colorful tone. All her hearers are united in this.*" He need not have been so surprised; it was, of course, just her correct hands–close–to–the–keys touch that *enabled* her to draw a full, colorful tone with minimum effort – as it did also for Gaby Casadesus 100 years later. Friedrich Wieck was indeed a very good piano teacher for technique.[†]

It was Liszt who raised his hands high at the beginning of a loud passage, as attested by many eyewitnesses; but he knew perfectly well that this was showmanship that had no effect on the sound. The ladies, not comprehending the physics of a piano action any better than Schonberg (that the effective mass of a piano key is many times greater than that of a finger) expected it of him; and he obliged.

You can snap a string (or with the steel strings of today, more likely break a hammer) most easily by holding the second and third fingers vertical and rigid on the key and suddenly bearing down with the full muscular strength of your arm, without raising your hand at all. This is the point about mechanical efficiency that Tobias Matthay did not understand either, when he warned his readers that the "forward dig" produces a harsh tone.[‡]

Keeping in mind these examples of how easily wrong conclusions can be drawn, we find scattered through an immense literature the reports of many eyewitnesses concerning the keyboard performances of all the aforementioned greats, and much auxiliary evidence

[†] Yet he failed to teach Clara even the rudiments of harmony, as Robert Schumann discovered after their marriage, leading him to give her some much needed remedial instruction in music theory.

[‡] It does so only because it is so much more efficient mechanically that it produces a much *louder* tone for the same muscular effort. Had he relaxed that effort sufficiently, the forward dig would have given him just the tone he wanted, with far less muscular effort than flat–handing was costing him.

concerning the credibility of the witnesses. We have their compositions indicating their style and technical level. This is enough to draw some reasonably sure conclusions about the keyboard methods and powers of the first great pianists.

The First Pianists. In the first place, what do we know, from credible sources, about the keyboard techniques of Mozart and Beethoven? We have the most valuable testimony about this from Carl Czerny (1791–1857), the Beethoven pupil who went on to become perhaps the first professional piano pedagogue, and surely knew whereof he spoke concerning both the musical and technical sides of Beethoven's keyboard performances. His pupils included Liszt and many of the next generation of piano teachers such as Theodor Kullak (1818–1882) who founded the Berlin *Neue Akadamie der Tonkunst*, and Theodor Leschetizky (1830–1915) who taught in St. Petersburg and Vienna, and probably had more famous pupils than any other teacher. Czerny was already a highly accomplished prodigy when he came to Beethoven in 1800 at the age of nine; he played the just published *Pathétique* sonata Op. 13 in a way that impressed even Beethoven, and for the next few years Beethoven was his teacher. Beethoven appreciated his talent so much that he then entrusted Czerny with the proofreading of his new works from 1805 on (that is, starting at about Op. 47).

With such credentials, we trust Czerny's testimony. In his reminiscences of Beethoven's teaching, Czerny reports that Beethoven first made him read C.P.E. Bach's *On the true manner of performing upon the clavier*, and for the first few weeks put him back to practicing scales, showing him the right positions of the hands. Then in Czerny's words,

> "After this, he - - - drew my attention to the *legato*, which he himself mastered in so incomparable a manner and which at that time all other pianists considered impracticable, as it was still the fashion (dating from Mozart's time) to play in a clipped, abrupt manner."

We would need no more evidence than this to infer than Beethoven did play in the manner we have recommended, hands on the keys; and that he was the first, or one of the first, to do so (it may be that Clementi – the master of smooth, lightning–fast, parallel thirds – had also discovered this technique).

We infer also that Mozart did not play in that way; but as we noted in Chapter 3, the *legato* was in any event mechanically impossible on the early Späth claviers on which he learned to play. Then on discovering and praising the more advanced Stein piano, he failed to make use of its *legato* capabilities in his later piano sonatas. Apparently, as soon as he settled in Vienna and acquired a Stein action piano of his own, he reverted to his previous mindset and did not think in terms of finger legato. So Mozart's performance was always limited by the mechanics of the old Späth instrument rather than by the capability of his fingers; in Beethoven we see finally the limit of capability of human fingers. There is much additional evidence of this kind, but it all supports the same conclusions.

On the piano techniques of Liszt and Chopin we have already made several comments in our Preface and in Chapter 3. There is a vast amount of eyewitness testimony, of which we note particularly the recollections of Charles Hallé (1896), those quoted in the Liszt biography by Sacheverell Sitwell (1955); and most importantly in the testimony of Amy Fay, described below. It seems that Chopin had a delicacy unsurpassed before or since, while Liszt started as a mere technical powerhouse, capable of breaking strings on much stronger pianos than Beethoven's. But Liszt learned precise control from the example of Paganini and delicacy through his association with Chopin. Outliving Chopin by many years, in his old age Liszt's string breaking days were over, but he was still the master of all other pianists in the matter of smooth, expressive *legato* execution at any speed. His superior control showed itself even on the simplest compositions, well within the technical grasp of any beginner. One witness to both Anton Rubinstein and Liszt, in quick succession, playing the famous first movement of Beethoven's "Moonlight" Sonata Op. 27–2, reported that Liszt's performance made Rubinstein's seem clumsy and amateurish. Our own ideal of pianism is some kind of blend of middle Beethoven (before deafness) and late Liszt (after string–breaking).

The More Recent Pianists. The level of technical proficiency and musical perceptiveness of the great pianists of the past 100 years is not in doubt. Since about 1910 we have had the advantage of audio recordings, so that we can know exactly what sounds Camille Saint–Saëns, Ferrucio Busoni, Leopold Godowsky, Moritz Rosenthal, Josef Hofmann, Sergei Rachmaninoff, Josef Lhevinne, Ignaz Paderewski, Artur Schnabel, Wilhelm Backhaus, Rudolph Serkin, Artur Rubinstein, Vladimir Horowitz, and so many others, actually produced (although some of the earliest ones were already past their prime when recorded), what degree of precision they achieved, and what liberties in phrasing and dynamics they allowed themselves.[⋆]

The results are surprisingly uniform; hearing these pianists, we are at first shocked to realize that their standards were not as high as we expected. Their reputations were considerably better than their actual performances (at least, their performances in recording studios; they might well have been nervous and apprehensive of the experience). Their technical apparatus was doubtless impressive to untrained audiences of their time; but it was inferior to that of most young pianists today. However, great technique is not really necessary for a successful concertizing career, as we see next.

Artur Rubinstein was far from a great technician – and perhaps not even a great interpreter – but he was always popular with the concert–going public because of his basically healthy attitude in an age when so many of his contemporaries had serious problems. He never took his music or himself too seriously, and his music was the better for it. If he did not have the technique of Godowsky[†] he was also free of the annoying, distracting mannerisms and psychiatric hangups of most of his contemporaries. He would raise his hands high in the air occasionally for dramatic effect or perhaps out of sheer exuberance; but unlike some of the others he understood that this contributed nothing to the actual music, and when a difficult passage was called for, his hands went right back close to the keyboard and he accomplished it without any unnecessary hand or finger motions.

⋆ The making of recordings can also defeat a musician's purpose. Artur Schnabel (1935) published a highly edited version of the Beethoven sonatas, full of detailed instructions on their execution; then it was startling to hear Schnabel's actual recorded performance of those works, showing little regard for his own instructions. The reaction of many (including the present writer) was to ignore both his practice and his precept, go back to the *Urtext* edition of Beethoven; and rely on our own judgment.

† One pianist remarked of Leopold Godowsky (1870–1938) that his ten digits were "ten independent voices." But Rubinstein remarked instead: "Look at Godowsky! It would take me 500 years to acquire his mechanism, but what does it get him? He is uptight and miserable, while I am happy!"

In the early 1950's Rubinstein was a regular performer at concerts in San Francisco and the present writer, then at Stanford University, knew his piano tuner. Gustav Gulmert was an old friend of Rubinstein's who had settled in the San Francisco Bay area, and whenever Artur Rubinstein came to town, Gulmert was called in to tune the pianos he would use. He reported back to me some of their conversations; on one of his visits, Rubinstein said to him, wearily, "*Gustav, you don't know how lucky you are to be in your line of work instead of mine. You have only to be as good as you were last time; every time I come here I have to be better than I was last time, or the critics will know it.*" Rubinstein was then in his middle 60's; and in fact, he *was* better each time.

His playing actually improved markedly as he grew older; he was playing better at 75 than at 60. In his early performances the sound had a muffled quality, due to the combination of wrong or half–missed notes (*i.e.* accidentally striking two keys instead of one) and too much pedal and bass; but probably from listening to his own recordings and comparing with what others were doing, he learned to overcome it. He himself was very much aware of this, and in his old age he would give horrible examples of how he used to play when young, bringing back all the old muffled quality; then show how he could do it now, with crisp articulation when the music called for it. We suspect that many young pianists profited from this lesson in piano technique, which he gave on public television.[‡]

Videotape Recordings. Today, for studying piano technique mere audio recordings are obsolete; we have the great advantage of movie and now videotape recordings of piano performances, which we can slow down and replay as many times as we please and thus see exactly, in minute detail, what hand movements a pianist was using to produce those sounds. From studying these, we can learn things about a pianist's technique that the pianist is not consciously aware of. We can see Alicia de la Rocha, Aldo Ciccolini and André Previn obeying the rules of efficient sound production indicated by our theory, with the good results to be expected; and Glenn Gould violating them, also with the results to be expected (in addition, his annoying and distracting personal mannerisms intruded upon the music more than did those of any other contemporary pianist).

We can see Vladimir Horowitz (at least, in his old age) flat–handing the keyboard like Tobias Matthay; and thus using more muscular exertion than would be needed and achieving less control and endurance than would be possible. Of course, with enough musical perceptiveness and enough physical strength to spare, one may produce good results in spite of this; but might they have been even better? His last recordings, unlike those of Artur Rubinstein, lacked the clear, crisp quality of the ones[*] that he made in his prime.

Becoming clinically diagnostic, we can see Robert Taub's right fifth finger sticking up in the air where it has no business being (but somehow managing to get back down to the keyboard when it is needed); a mannerism that could be corrected quickly, were he to be persuaded that it is costing him some control over what is being played.

[‡] A few years before his death in 1982 at the age of 95, Rubinstein made a request that two works be played at his funeral: the slow movements of the Beethoven 'Archduke' trio, and of the Schubert C major cello quintet. It was interesting to hear him say this in a TV documentary, because those were just the movements that I had already decided, twenty years earlier, were the two most beautiful pieces of music ever written.

[*] We have in mind particularly his Moussorgsky *Pictures at an Exhibition* (RCA LM–1014).

****************************** MORE HERE! **************************

Amy Fay Gives Away the Secret

A remarkable American girl, Amy Fay (1844–1928) became the source of much of what we know about the state of music in general, and piano pedagogy in particular, just at its most formative time. She studied piano in Germany in the years 1869–1875, an ideal time to be there. The piano had just reached its present state of mechanical development, and its possibilities were being exploited furiously. This was the time of the great piano teachers of the next generation after Czerny – Liszt, Kullak, Deppe, and Tausig – all of whom she studied with. It was also the time when Clara Schumann, Joachim, Wagner, Hans von Bülow, Anton Rubinstein were in their prime, and she listened to, and met all of them. She had long private conversations with Liszt and Joachim, and spent an evening in the home of old Friedrich Wieck, Clara's father. About the only notable German musician of the time whom she, apparently, failed to meet was Brahms. On top of all this, she also met Bismarck and made friends with some of the German nobility.

How could a lone American girl manage all this, at a time when the European intelligentsia regarded America as a land of illiterate savages? Amy Fay was perhaps the only one who had the talent and connections to bring it off. Her family had German connections (her great–grandfather had been a prosperous Hamburg merchant), and her father was a Harvard–trained linguist who taught her Latin, Greek, German, and French. She received her first piano instruction from her mother (the daughter of an Episcopal Bishop and an accomplished pianist) and by the age of five Amy was performing with notable proficiency.

The American conductor Theodore Thomas (manager of New York's Steinway Hall) was her brother–in–law, and with him she had performed the first complete piano concerto heard in America. But she felt that she still lacked the polished style of a true artist, which could at the time be obtained only from the European masters. She knew exactly what she wanted to do, and had the means to do it.

To be sure, her success in Germany was not entirely due to her own talents. In Berlin, the American Ambassador Bancroft and his wife were enthusiastic music lovers, who took a parental interest in Amy and saw to it that she attended all the right concerts and social occasions and met all the right people. She had already acquired enough social graces and proficiency in piano playing to take full advantage of this (the fact that she had only to play once for Liszt, Tausig, Kullak, and Deppe in order to be accepted immediately as a pupil is ample testimony for that). After her return to America she embarked on a very successful career of concertizing and teaching.

What distinguishes Amy Fay from all other music students is that when in Germany, almost every week she wrote a long letter to her sister back home, telling in detail of all her adventures, and these were preserved. Somehow the letters came to the attention of Henry Wadsworth Longfellow, who saw their value as a social history of the times and urged that they be published – indeed, it was Longfellow who personally carried the manuscript to the publisher. The first edition appeared in 1880 under the title: *Music–Study in Germany*, and it has since been republished over thirty times in the United States and Europe. It was published by MacMillan in London at the request of Sir George Groves, who wrote a preface for it. A French translation was introduced by Vincent d'Indy, who had heard her play and was impressed; and a German translation was sponsored by Franz Liszt himself.

Amy Fay's letters provide the most interesting and detailed account we have of the teaching methods, performing skills, and personalities of the great musicians of the time. Indeed, they provide almost the only information we have about Carl Tausig, who might have surpassed Liszt as a pianist, but also had serious psychiatric problems (how familiar that sounds to us today, when half the great pianists of our Century were afflicted likewise!). Tausig died suddenly and unexpectedly at the age of 31, when Amy Fay was his pupil.

Of immediate importance for us is that Amy Fay discovered, quite by accident through Ludwig Deppe, a major secret of Liszt's technique, of which Liszt himself was not consciously aware. Deppe understood the hand movements required for automatic legato playing, but had never seen Liszt play; Amy had, many times, standing close beside him in his Weimar studio and observing his hands closely without realizing the significance of what she saw until she met Deppe. This understanding revolutionized her own playing, and she explained it clearly, for the first – and to the best of our knowledge, the only – time in print. At least, she explained enough of it so that anyone with the wit to recognize it and carry on the line of reasoning, can reconstruct it all, and extend it further.

In the writer's opinion, two pages of Amy Fay's Chapter 24 – the letter of December 11, 1873, where she explains how to play the E major scale – are of greater value for piano technique than all the dozens of books written by teachers who did not really understand the physical facts.[‡] Many, with ulterior commercial motives, proceeded to embroider their 'methods' with grand, arbitrary claims – unjustified and dangerously misleading. Amy, with no such motives, was trying to explain it privately, and as clearly as possible, for the benefit of her own sister, and she had the expository sense that almost all of the others lacked: state things not in aesthetic or subjective terms that mean different things to different people, but in *objective* terms that all of us understand in the same way. And her words were always written within a few days of observing the event.

In other words, in Amy Fay's writings, everything is at last going right to give us a document full of detailed, explicit, and reliable information. One such good document is worth a hundred bad ones.

The principle she explains here is that, in playing the ascending E major scale, when the time comes for a shift of hand position (third finger on $G\sharp$) one does not turn the thumb under, reaching hard for the A; but instead rotates the hand a little on the third finger as a pivot, until the thumb is brought automatically over the A. One prepares the way for the thumb, which is kept free from the hand and slightly curved. Then to continue with the second octave, she reports:

> "··· when I got my third finger on D sharp, I kept my hand slanting from left to right, but I prepared for the turning under of the thumb, and for getting my first finger on F sharp, by turning my wrist sharply out. That brought my thumb down on the note and prepared me instantly for the next step. In fact, my wrist carried my finger right on onto the sharp

[‡] One hundred twenty years later, reading those two pages accomplished for me in a day what 30 years of practice had failed to accomplish – the smooth legato touch that I had been striving for (or at least, the knowledge of how to practice so as to acquire that touch in any particular passage).

> without any change in position of the hand, thus giving the most perfect legato in the world, and I continued the whole scale in the same manner. $\cdots$ The direction of the hand in running passages is always a little oblique."

Then she recalls having watched Liszt play, as she had recounted some time earlier to her sister:

> "Don't you remember my telling you that Liszt has an inconceivable lightness, swiftness and smoothness of execution? $\cdots$ I suddenly remembered that when he was playing scales or passages, his fingers seemed to lie across the keys in a slanting sort of way, and to execute these rapid passages almost without any perceptible motion. Well, dear, *there* it was again! As Liszt is a great experimentalist, he probably does all these things by instinct, and without reasoning it out; but that is why nobody else's playing sounds like his. Some of his students had most dazzling techniques, and I used to rack my brains to find out how it was, that no matter how perfectly anybody else played, the minute Liszt sat down and played the same thing, the previous playing seemed rough in comparison."

Of course, it would be ridiculous to suppose that mastering this one little detail of hand motion is enough to make one a great pianist. It is only one of a hundred equally important little details; yet for nearly everybody it seems to be the least obvious, therefore the most difficult to discover. It feels wrong and unnatural at first, because one is bending the wrist joint in the "wrong" direction; not the one that Nature intended. But, having overcome every difficulty except this, it would indeed then become the remaining bottleneck, of overriding importance to a pianist, as it seems to have been for Amy Fay and her fellow pupils of Liszt. In a few months of conscious practice it becomes automatic; then one can go back to concentrating entirely on the music.*

But in order to appreciate this at first hearing, one needs to have a little knowledge of physics and physiology, and some experience at piano playing. Therefore, it seems a pity that Amy Fay did not also meet Hermann von Helmholtz, who just two years before had moved from the University of Heidelberg to become the Director of the new Physical – Technical Institute in Berlin. This man, the greatest scientist in Germany and as we have noted also a competent pianist and a personal friend of Joachim, would have understood instantly her discovery that this was the long missing fact behind Liszt's seemingly supernatural technique, seen its full implications, and extended it beyond what Amy Fay had seen. He could have used the facilities of his Institute to produce photographic proof of it (an early movie), by persuading Liszt to allow his hands to be thus photographed while playing; Liszt was vain enough to jump at the chance to leave this evidence for posterity. Helmholtz could have sponsored a public demonstration of it at his Institute; now that it was understood, talented young pianists who had just learned this could then exhibit the old wrong, and the new right way of playing in much the same way Artur Rubinstein had, showing that they too could now play like Liszt. Had this happened, this new understanding would have been a central part of the pianistic tradition from that time on.

* But we think that one can waste much time on endless practising of scales for this purpose only, as Amy Fay seems to have done. We were gratified to see the great pianist Josef Hofmann (1909) later expressing exactly our view: "*I do no technical work outside of the composition, for the reason that I find plenty of technic to work on in the piece itself.*" This has the further advantage that by concentrating on the actual music, no bad unmusical habits are formed.

As it is, this little detail has been so far from obvious to others that those whose minds were unprepared for it were unable to see the point even after Amy Fay had explained it; even today, it is not generally comprehended. For example, the statement is made, in the unfortunate Introduction to the 1965 Dover Edition of her book, that this method of achieving legato was the "weight–relaxation method" taken up by Tobias Matthay and others (that is, a method in which the arm muscles are relaxed, so that the keyboard supports the weight of hand and arm, and one plays successive notes by transferring that weight from one key to the next).† It seems to us that this is a calumny on Amy Fay; anyone who makes that claim has simply not taken the trouble to read and understand her words. She is not discussing weight–relaxation at all; she is concerned with lateral hand movements, which can be done with or without weight–relaxation. A glance at Matthay (1947), with his foggy confusion, facts all wrong, inconsistencies, fiercely argumentative over matters far above his head – is enough to dispel that idea; Amy Fay committed none of that foolishness. In any event, for mechanical and anatomical reasons, weight–relaxation is not possible except in slow *pianissimo* to *mezzo-forte* passages; and then it is done automatically by anyone who follows the general advice to avoid unnecessary motions and exertions.

Misreading of Amy Fay's clearly written remarks is surprisingly common, because her message was so unexpected. As another example, Schonberg (1963, p. 169) tells us that:

> "Liszt himself was no theorist of technique and must have played without thinking twice about how he accomplished his effects. It seems clear, though, that he employed a weight technique, playing with loose shoulders and a fairly high position of hands and fingers, with hands slightly out–turned so that they naturally covered the E major scale (Amy Fay is quite specific about this)."

Somehow, he has got her message completely fouled up; there is no one position of the hand which "naturally covers" the E major scale (as he might have discovered for himself in ten seconds at a keyboard); and Amy Fay said no such thing. She is discussing what happens at the turning points in an ascending passage with the right hand or a descending one with the left hand. There the hands must be turned *inward* (that is, wrists outward as Amy says) in order for the finger to be brought into the correct position for the next note after the turning point.‡ Again, we are unable to understand how he can see in her words any reference to a 'weight technique'; that is just not the topic. But psychologists

† As is evident from the considerations of the previous Chapter, by transferring the weight of hand and arm at different rates one can achieve a certain dynamic range. But even a ton of weight simply transferred instantaneously to a different key would not be enough to achieve the loudest sound, because a weight dropped does not start moving at high speed, as Galileo showed 400 years ago. Any weight released and falling freely requires 44 milliseconds to fall the first 3/8 inch, corresponding to the key travel; and this (representing the acceleration of the earth's gravity) determines the maximum key velocity that can be attained by pure weight transference. Dynamics from *pp* to *ff* corresponds, as we saw in Chapter 5, to about 120 to 12 milliseconds key depression time; 44 milliseconds stands somewhat below the middle of this range, and corresponds to a rather mild *mezzoforte*. If the loudness called for by the music is greater than this, then weight transference alone will not suffice; it must be supplemented by muscular exertion to increase the downward force on the key. Put differently, anyone who plays louder than a weak *mezzoforte* cannot be using pure weight transference, even though he may think that he is.

‡ Thus to an onlooker, the right hand seems to drag behind the wrist as it moves up the keyboard;

are well aware that people tend to see what they expect to see, whether it is there or not; the more unexpected the message, the more the mind refuses to see it.*

We are concerned here not only with wrist motion but also with finger motion. For absolutely smooth, seamless execution of a passage, it is necessary that while one note is sounding, the finger for the next note must be brought not only into the right position over the next key, but it must be actually in contact with that key. When one finally accomplishes this, the sound suddenly becomes not only just what one wanted; at the same time, there is a wonderful sensation, that you have finally achieved complete control over the exact phrasing and dynamics, and are therefore able to explore fine differences in phrasings that were not possible before. Once you have experienced this you will never again use any other hand motions on a really expressive passage, and it is easy to understand why Liszt's playing sounded like nobody else's.

Why did Amy Fay mention only what the hand must do in playing an upward scale? Because the downward (in the right hand) motions always seemed to come relatively easily; everybody learns quickly how to do it. Indeed, in playing scales, arpeggios, and even parallel thirds, the right hand finds downward passages much easier to execute smoothly than upward ones. Nevertheless, one might think that the motions required for downward scales must be the same as for upward ones, only in the reverse direction; so why do not the same considerations apply?

To answer this, merely play any scale, very slowly, and watch what your right hand is doing. On the upward passage, the break occurs when the thumb must be moved – not so much under, but past – the third or fourth finger; the new thing Amy Fay learned is that the hand should be pivoted about the third or fourth finger, which requires an unusual and unaccustomed large sideways bending and forward lateral motion of the wrist. But on the downward scale, the third or fourth finger must be passed over the thumb; and now things are very different, in two respects. In the first place, smooth execution requires the hand to pivot instead about the thumb. It is *not* the same motion in reverse direction; the pivot point is now much closer to the wrist, and less sideways motion of the wrist is needed.

But secondly, a new factor factor comes into play here; if the downward passage calls for the fourth finger immediately after the thumb, then everything we said above applies unchanged. But if it calls for the third finger, another motion – counter–clockwise rotation of the hand about the arm as an axis – is now available, which will accomplish the same smooth transition.† This rotary motion is easier for a pianist to discover by trial – and –

this is what Amy Fay saw while watching Liszt, and what we would be able to see today, had that movie been made.

* The writer has observed this phenomenon many times when he tried to expound some unconventional ideas about physics; no matter how hard I labored to achieve absolute clarity – every sentence rewritten a dozen times over many months to avert every possible misunderstanding – several readers would miss the point completely, and dash into print, accusing me of saying all kinds of different things, entirely unrelated to what I *did* say. At its best, the human brain is an imperfect reasoning device; the surprised brain, having no prepared response, may become totally irrational.

† It is impossible to see the reason for this from a verbal description; one must try it at the keyboard, and then it will become clear why it works so well.

error practice, and this is why we find downward passages easier to execute. In any event, some conscious thinking and practising with both of these hand movements in mind can improve the smoothness of downward passages also, by increasing the usual amount of wrist bending and adding a little hand rotation, so that the legato is achieved more easily.

The ease of discovering the rotary motion is shown by another historical incident. Some forty years after Amy Fay's German study, Karl Leimer (Founder of the Municipal Conservatory in Hannover) was a successful piano teacher there. His most notable pupil was Walter Gieseking, whose sole piano instruction was from Leimer, in 1912 – 1917. This collaboration resulted in a very small book (Leimer–Gieseking, 1932) on piano teaching methods. They start with some excellent advice about using your brain first, fingers second. Then they discuss, very succinctly, some of the points we make above in a way that we consider, from the standpoint of physics, almost entirely correct and important, only incomplete.

In particular, they stress the inadequacy of pure weight transfer and the necessity of avoiding all unnecessary finger movements and of keeping the fingers on the keys in order to achieve the smooth, sonorous tone for which Gieseking was famous in his interpretations of Debussy (just what Schonberg did not understand in the case of Clara Schumann). They recommend this hand rotation movement for the same purpose we did. However, there is no mention of Amy Fay or the lateral wrist bending movement, which we consider far more important and more generally needed. This work communicates to the reader almost as well as does Amy Fay's, because it is presented in objective terms.

Liszt's Dummy Keyboard: These considerations also suggest an explanation of something that has been puzzling to pianists for a Century. We know that Liszt, on his concert tours, carried with him a little silent keyboard on which he practiced when alone in his room. A photograph of it may be seen in the Larousse Encyclopedia of Music (1974, p. 319); it has standard size keys but only four octaves, C_2 to C_6. The puzzle has been: it seems that such a toy could be of interest only to a child in the first week of piano practice; of what use could it possibly have been to Liszt? With only four octaves, he could not have rehearsed what he would be playing at the concert; and with no sound it could not possibly lead him to correct dynamics and phrasing of anything.[‡].

We have now a plausible conjecture for what Liszt did with this strange device, because we have discovered that practicing the Amy Fay movements can be done as well on an electronic keyboard with the sound turned completely off. What is essential is only that the size and spacing of the keys and extent of key motion be correct. If one's execution of a running passage is not perfectly smooth, the fastest way to correct it is to play it very slowly, while watching the hand. This makes it evident at once how much lateral wrist motion is required at each turn–over point so that the next finger is brought into exactly the proper position for the smoothest execution of the next note. Then one increases the velocity while keeping the same wrist and finger movements.

‡ Lawrence Schauffler (1937, p. 119) expressed the same view more strongly: "The vogue of the clavier or 'dummy' keyboard is so far past that we need hardly mention the often disastrous musical results of such practice. It might possibly be used in the one case of practicing exercises, provided the key resistance were made no greater than that of the piano, but even then it would serve no real purpose."

This is purely a matter of geometry, for which both the production of sound and the key resistance are quite irrelevant. We suggest, then, that Liszt may have used this keyboard for touching up – before anyone else detected them – passages which he had noticed, in his previous concert, did not go with perfect smoothness. For getting the exact lateral wrist movements needed, a dummy keyboard is just as good as a real piano. We are unable to conceive of any other way in which such a keyboard could have helped him.

Summary: The Three Commandments

Although we have been through a large mass of details, it can all be summarized very quickly. There are three basic rules for achieving accurate control and endurance in any coordinated muscular activity, from piano playing to pole vaulting:

(1) Do not make unnecessary movements or muscle contractions.

(2) Do necessary movements as smoothly as possible.

(3) Use the strongest muscles that will do the job.

On meditation, it will be seen that all the detailed recommendations we have made, can be reasoned out as simple consequences of these rules. We suggest that all the grains of truth in the various 'piano methods' of the past, are contained in these three Commandments. In the third, "do the job" means, of course, "do what needs to be done, at sufficient velocity and *under full control*."

CHAPTER 7

MOZART AND BEETHOVEN COMPARED

"*Above all else, I wish people would have the courage to say what they really think about music, and not be so eternally worried over what somebody else may think and say.*" - - - Sigmund Spaeth (1933)

The partisan comparisons of the relative merits of Mozart and Beethoven have continued for over a Century. There are the fervent Mozartians, who become enraged at the suggestion that Beethoven's music has more substance than Mozart's, and insist that Mozart's music has an altogether more lofty quality than Beethoven's crudities. But there are just as fervent Beethovians, who dismiss the Mozart piano sonatas as mere finger exercises, suitable only for warming up before playing Beethoven. Indeed, there is a very different quality to their music, which cannot be explained merely by supposing that Beethoven used greater dynamic and rhythmic excursions; both used the full range of dynamics, tempo, and pitch that was possible on the pianos available to them. In this Chapter we shall try to describe and explain the difference in other terms, and make some comments on the performance of their piano music.

Current Gamesmanship

Today Mozart seems to be winning this, at least as judged by mass communications output; in the late 20'th Century we have seen an explosive increase in *Mozartiana*, from Mozart festivals, to "mostly Mozart" concerts, to the TV documentary "*The Mozart Mystique*" narrated by Peter Ustinov, another by André Previn, the movie "*Amadeus*", $\cdots$. All of this is presumably intended to inform the general public about Mozart and his music, by almost hysterical effusions about the marvelous music he wrote. There is even a science fiction episode in which, many Centuries from now, the rediscovery of Mozart's music changes the course of civilization. We do not seem to have any comparable attention to Beethoven.

But we feel that this Mozart *hype* has been overdone to the point where it has defeated its own purpose, and is actually discouraging public appreciation of Mozart. For most people, to hear the reputedly great experts constantly raving about the wondrous quality of his music – and not to be able to sense it for yourself – is to conclude that "Music is not for me!" and to perceive that gamesmanship is being played on us. In the Previn documentary we see an unidentified young man playing the last Mozart piano concerto, with such ridiculous facial expressions of agony and ecstasy, as if he were performing the most magnificent work of art of all time – in passages which are nothing but slow children's pieces.

We hear his symphonies but they seem rather primitive, lacking the bigness, the cohesiveness, and the musical content of the Beethoven and Brahms symphonies – but we are afraid to say this out loud because one of those gamesmen would accuse us of having insufficiently refined taste to perceive what *he* perceives. Everywhere, where Mozart is concerned, we are in a scenario much like the fable of the Emperor's New Clothes, in which everybody is playing the game of pretending to see, and marveling at, what nobody is actually able to see. Only the little boy has the naïveté to blurt out the truth: "But he has nothing on but his underwear!"

Recognition of this situation is hardly new. In the 1930's Sigmund Spaeth had a popular weekly radio show, "The Tune Detective" in which he analyzed the content of popular and classical music and found surprising relations between different works. He also wrote popular books explaining classical music to the general public, which are still interesting reading today. In our opening quotation, he deplored this same gamesmanship, which was then applied to all classical music. Today we seem to have moved beyond that universal gamesmanship, but it continues stronger than ever for Mozart and Debussy, of whom one still does not dare speak his true views in public.

We have both that difficulty and another one with Mozart's piano music. Czerny reports that legato touch was unknown before Beethoven. In his edition of the Mozart piano sonatas, Saint–Säens (1915) comments further: "One is accustomed in modern editions to be prodigal with ties, and to indicate constantly *legato, molto legato, sempre legato.* There is nothing of this in the autograph manuscripts and the old editions. Everything leads us to believe that this music should be performed lightly, that the figures should produce an effect analogous to that obtained on the violin by giving a stroke to each note without leaving the string. When Mozart wished the legato, he indicated it."

But, as we noted in Chapter 6, he does not indicate it, so in effect we are forbidden to play Mozart legato at all. While we understand and appreciate Saint–Säens' reasoning, we feel obliged to note also another side to this by raising the issue: *What is the purpose of playing Mozart today*? Is it to recreate the same physical acoustics that Mozart's listeners heard in the 1780's from a piano incapable of real expressiveness? Or is it to present his music in the best possible light that only the modern piano is capable of?

And we can raise, antiphonally, the same questions as they appear from the side of the listener. To today's ears, accustomed to the smooth legato of properly played Beethoven or Chopin, to hear an entire work played in the same unvarying staccato touch, drives a perceptive person nearly mad. Couldn't we have occasionally just a bit of legato for ear relief?

The question does not involve only the piano. When we hear a Mozart piano concerto today, on what kind of instruments is it being played? Certainly not on any instruments available to Mozart except for the violin family, which had reached its present form before Mozart was born. There are a few French horns and trumpets, although valved brass instruments did not exist until Mozart had been dead for 25 to 40 years, a few clarinets and oboes with mechanisms that did not exist until Mozart had been dead for fifty years – and finally, a nine–foot concert grand piano, the like of which did not exist until Mozart had been dead for eighty years. There can be no pretense that the resulting sound is what Mozart heard.

We suggest that the purpose of playing Mozart today cannot be to recreate the same *acoustics* that his contemporary listeners heard; but to try to recreate as best we can the *music* as Mozart heard it in his own mind, making full use not only of the evidence of the score as he wrote it, but also every other bit of relevant evidence that we can find, of an historical or technical nature. We agree with Saint–Säens that it is wrong to fill his scores with arbitrary *legato* markings that Mozart did not indicate. But we think also that the performer today should use legato whenever his own musical taste calls for it. Then it will become apparent rather quickly which performers have perceptive good taste and which do not.

In 1991 the writer heard a lecture by a pianist specializing in Mozart, in which he enthused over the variety of thematic material, claiming that with Mozart the listener always knows "where he is" in a movement because Mozart might use seven or eight different themes in it. He said that you get no such sense of position in Beethoven, because there would be only two or three themes in a movement.

We would put it in just the opposite way: with Mozart you do not know where you are in a movement because there is no coherent plan; only the calling forth of one short theme after another, at random. In Mozart there is almost no sense of 'development' of a theme; the closest he comes to it is to add a little ornamentation. Usually, when a theme remains for some time it is merely repeated unaltered – sometimes to the point of boredom. Indeed, he composed so rapidly that there was no time to work out a development even if he had thought in those terms. Beethoven used fewer and simpler themes because he gave them elaborate developments (that often required long series of revisions in his notebooks); and just for that reason, you know "where you are" in a Beethoven movement, from the stage of the development.

Although the lecturer gave examples of the variety of themes in a few Mozart movements from different works, he seemed unaware that the same themes had been used in several other compositions – so with Mozart we not only do not know where we are in a movement; we may not even know which composition is being heard. He played Mozart in a way painful to hear because every note was in the same sharp staccato, giving the effect of a poorly regulated harpsichord. With such a habit he probably could not have played Beethoven acceptably in any event.

Passing on to Mozart's operas, they are always represented to us as perfect program music, each aria beautifully and uniquely adapted to its occasion. But not being able to perceive any difference in the nature of the music whatever the occasion – and again being afraid to say it out loud because of the reactions of those who are intent on putting us down with their gamesmanship – leaves one in a frustrated state hardly conducive to appreciation of Mozart.

Commentators marvel not only at the quality, but also at the quantity of music that Mozart composed in 35 years. Richard Strauss recalled his father telling him: "*Our best copyists could not copy it all in 35 years.*" Even more marvelous seems to be the fact that the autograph manuscripts show it all written down in final form without corrections, suggesting that every detail had been thought out in his head before putting pen to paper (or perhaps he was just not enough of a perfectionist to bother with corrections).

The Explanation

When one has heard too much Mozart in a short time, the realization comes suddenly: nearly all of his music sounds vaguely the same, whatever the instruments, whatever the musical form, and whatever the ostensible programmatic purpose. You could interchange the musical material of almost any two Mozart works, and they would still have just the same effect.

This suggests a conjecture which would explain these mysteries very easily. If almost all of Mozart's music sounds the same, perhaps it really *is* the same. That is, perhaps his works are just different samples of abstract music, all constructed from the same basic material. Suppose that Mozart had built up in his head a collection of perhaps 100 nicely polished stock phrases, and simply used them over and over again, in different combinations. Then we could understand how he could compose faster than a copyist could copy, and without errors; he *was* a copyist, but with the great advantage that he was copying from his own head, and he had copied the same thing many times before.

One of these stock phrases, almost a Mozart signature, is the melodic line which descends and then ascends, changing to subdominant harmony at the bottom note. Listening to an unknown composition of that period, when we hear that we can be quite sure that it is Mozart.

This is not to say that no late work of his contained anything new; of course, he would invent for each some introductory sweet–sounding melody† and then call upon the library, adapting the chosen phrases if necessary so as to be compatible with it. This theory about how he composed – at least in his later works – is a little more than pure conjecture; we know from the independent evidence of notes in his handwriting that Mozart was very consciously aware of 'machine assisted' principles for composing music.

Aleatory, or Random, Music

'Random music' is sometimes thought to be fairly recent, made possible by the development of computers in the mid 20'th Century. Quite the contrary; there is nothing the least bit new in the idea.

Johann Philipp Kirnberger (1721 – 1783), a pupil of Johann Sebastian Bach, published a book (1757) which explained how to compose Polonaises and Minuets for two violins and harpsichord by throwing dice. In 1790 two similar but anonymous works appeared, one for the composition of minuets, entitled *Guioco Filarmonico*, and another for composing waltzes. They were long attributed to Haydn and C.P.E. Bach respectively; but it was discovered recently (O'Beirne, 1971) that the former was plagiarized from a work by an Austrian composer, Maximilian Stadler, published in 1779.

Mozart too played this game: Alfred Einstein, in the 1937 revised Köchel catalog (Anhang 294) attributes to him a work which appeared in 1793, for the composition of various musical forms with two dice.‡ This reappeared in England (Wheatstone, 1806)

† Such a melody is not difficult for anyone to produce. It seems that when Mozart or Verdi did this, they were always praised for it; but when Meyerbeer or Massenet did the same thing, they were laughed at for it. Beethoven usually avoided this, as did Chopin. As Liszt noted very perceptively in his obituary notice of Chopin, he used melodies which by themselves sound trivial or banal; but turned them into something wonderful by the way he harmonized them.

‡ Mozart specialists sometimes deny this attribution in spite of the evidence of Mozart's handwritten notes; evidently they do not want it thought that Mozart composed music this way. We do not suggest that he did, only that he was aware of the idea, and found it interesting; indeed, this would have slowed him down intolerably. Our theory about how he composed is quite different.

under the name *Mozart's Musical Game*, described as "Showing by an easy system how to compose an unlimited number of Waltzes, Rondos, Hornpipes and Reels".

These works are not easy to find today, but the Kirnberger work and a German edition of *Mozart's Musical Game* are in the British Museum. The system seems to be fairly simple; choose a harmonic/rhythmic sequence appropriate for the style intended, then for melody choose any notes belonging to the current chord by the toss of the dice. By tossing two dice one can generate any number from 2 to 12; almost enough to produce the full chromatic scale. Of course, this *may* produce a decent tune; more likely, it will not.

Put in computer terms, Mozart's Musical Game is a crude 'machine language' version (that is, one at the level of individual notes) of what we have conjectured to be his own method of composing. But he composed in a 'higher level' language (at the level of choosing whole phrases instead of individual notes). Today, a computer using the system of Mozart's Musical Game could compose in one second a work that would have required weeks by hand tossing of dice. The result might remind us of some works by modern composers – at least, of those who use the concepts of chords and tonality. The resemblance to the product of an intelligence could be increased very markedly with a smarter computer program that generates strong similarities (correlations) after 4, 8, or 16 bars. Occasional good luck might produce something that reminds us of early Haydn.

Also, we expect that a computer, given Mozart's library of source material in its memory, could compose 'higher level random music' that sounds very much like Mozart, and do it many thousands of times faster than he did. It would be interesting to check this conjecture by listening to many Mozart works and writing a library of the phrases he used most often.

But it would require an almost infinitely smarter computer program to produce anything that would remind us of middle or late Beethoven; here a directing intelligence perceives things on such a far higher level than mere correlations in notes or themes that we can scarcely comprehend it ourselves, much less teach a computer to imitate it.

The Unity of Beethoven's Music

As just noted, Mozart's music has a certain detached quality – even when the purpose is ostensibly programmatic, the music itself remains abstract, not really connected to any program. But can we call Beethoven's music 'abstract?'

Something about the structure of Beethoven's music – outwardly complex, yet with a kind of inner unity that is hard to put one's finger on – has been sensed by many, who have reacted to it in various ways. One persistent theory, not wholly unlike our above conjecture about Mozart, is that he had some kind of 'secret formula' that he chose never to reveal; and if we can only discover what it was, we shall have the key to understanding all his music.

For example, Robert Haven Schauffler, a cellist with many years of familiarity with his orchestral music, published a book (1929) in which he claimed to have discovered a certain melodic pattern which Beethoven "*used in his principal themes with astonishing frequency, investing it at each recurrence with a disguise sufficiently varied and effective to have preserved its incognito up to the present day.*"

But if this is true, then we think Beethoven's disguise was so effective that he has preserved the incognito from everybody except Schauffler, for sixty more years. We will not even disclose what that constant 'germ–motive' was, because Schauffler's claim seems to us ludicrous. He goes to absurd lengths to try to see every Beethoven theme as a disguised form of the secret one. And indeed, any melody can be transformed into any other melody – if you change enough notes.

Beethoven obviously had no need of any such device – in a serious composition, his active inventiveness needed more to be held in check than to be assisted with such crutches. This is well attested by those who heard him improvise on the spot, under circumstances where he could not have rehearsed it in advance. In any event, it appears to us that Beethoven's unity did not lie in melody at all; and there is no reason to suppose that the same unifying principle is used in all works. A Beethoven composition stands as an isolated whole, complete in itself and utterly unlike any other. The subtle unity of Beethoven's music is something that lies within each work separately; and he who seeks it in a similarity of different works is looking in the wrong place.[†]

This is not to deny that, occasionally, a theme would stay in Beethoven's mind for a time, appearing in two or even three works. The first movements of his Second Symphony and of the *Waldstein* sonata Op. 53, both probably written in 1803, have the same transitional passage introducing the main theme. The final movement of his Third Symphony is built upon the same theme that he had used earlier in *Prometheus* and the *Twelve Contradances*. There are moments in *Fidelio* when you think you are hearing the Ninth Symphony instead. But there is never any attempt to disguise these re–used themes; he comes right out and states them in the most forthright way, and they never become part of a Mozartian toolbox to be used over and over again in all his later works.

Also, we know that Beethoven studied the works of other composers in a way that Mozart seems not to have done, and this must have influenced his own work, both consciously and unconsciously. For example, the opening theme of his "Emperor" concerto Op. 73 of 1811 so strongly resembles that of the Mozart trio K 498 of 1786 that it strains our credulity a bit to think this is a mere coincidence. The keys are the same (E♭), the melodies are almost identical, the rhythms are only slightly different. In our view, Beethoven's version has that natural and inevitable quality that we expect from him; while Mozart's is a bit awkward (the turns delayed a little too much, and then accelerated too much). As another example, two of the themes in Beethoven's Rasoumovsky Quartet # 2 are almost identical with two in Haydn's C Major Cello Concerto.[‡]

[†] However, we agree with Schauffler that Beethoven sometimes achieved unity within a work by using disguised forms of the same phrase in all its movements. The *Pathétique* Sonata Op. 13 is an outstanding example of this, in which – if it has not been noticed already – the reader will find it interesting to discover that phrase independently. It is amusing that in an early review of this sonata, the critic remarked that the theme of the last movement sounded vaguely familiar to him, although he could not recall where he had heard it before. He had heard it in the first movement.

[‡] This is probably not deliberate copying; the writer has had the experience of being assigned, in a harmony course, the writing of a short composition; whereupon the instructor complained that I had plagiarized Chopin. On hearing the Chopin work it was clear that this was true, although it was certainly not done consciously. What happened is just that Chopin's style of harmonization had been absorbed so thoroughly that it became an automatic part of my own thinking, so any

The writer's theory is that almost all of Beethoven's music is really programmatic, but in a more rudimentary way than one usually understands by the term. Because of this, Beethoven is not really keeping secrets from us; he does not explain the programmatic basis because there is so little to explain. Even when it is ostensibly "pure" music, I am convinced that Beethoven had an organizing principle in mind; perhaps only a spoken phrase of two or three words, or two such phrases, which the music imitates repeatedly.

But the imitation is not in the melody. In a spoken language, we may repeat a phrase in many different inflections and sing it in many different pitches and different rising and falling melodic forms, but always with the same basic rhythm and dynamic emphasis; and that is what Beethoven does.

I feel, from many years of playing and studying his piano sonatas of the "middle period" (say, Op. 10 to 57) that I understand the source of their unity. In each work there is a very simple pattern, that might represent some short German phrase, that recurs in the most widely varying melodic forms but always with the same rhythmic and dynamic form. In a movement in sonata form ABA, it appears inverted in the B section. To Beethoven there is no secret; the presence of this recurrent pattern forming, so to speak, the framework on which the movement is built, would have seemed to him so obvious that he expected the performer to see it at once without being told. What particular German phrase it represented in his own mind at the time, is quite irrelevant and would only distract us. Perhaps it was a topical personal comment – his own little private joke – that he dared not divulge then and we would not understand now.

Here are two places where it is easy to spot these patterns. In the Op 31 #3 slow movement marked *menuetto*, the A theme is dominated by a two note descending pattern, with the emphasis on the first note. It appears first as $(E\flat - D)$ in measure 2, then as $(A\flat - G)$, $(B\flat - A\flat)$, $(G - F)$, in measures 4, 7, 8. After the repeat, it appears in measures 9, 11, 13, 14, 16 in more adventurous melodic forms, but with the same dynamic pattern. In the contrasting B section marked 'trio' it appears inverted in the first two notes, $(G - A\flat)$ with the emphasis on the second note; this pattern is repeated in many different melodic guises.

Perhaps the reader's first reaction to this is that we are straining nearly as hard as Schauffler, trying to see things that are not there. But try it at the keyboard and see for yourself that these things *are* there in his middle period sonatas and, as that fact becomes more familiar, these recurrences increasingly dominate one's interpretation of them. The performer who has recognized this, and so gives all these recurrences same dynamical rendering, brings out the unity of a work in a way that others cannot approach.

A much more dramatic example is the final movement of Op 10 #3, marked *rondo*, where the recurrent pattern, stated immediately as $F\sharp\ G\ B$, is a rising three note one, with the emphasis on the middle note. This is repeated many times in the most obvious way, but even more times non–obviously (find it in measures 36, 38, 40). At measure 72, the left hand takes it up and plays it nineteen times consecutively.† The same rhythmic/dynamic

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accidental similarity in melody became also a similarity in harmony.

† One will ask: "When nineteen consecutive triplets are played, must we suppose that they all represent the same phrase?" The answer is: "Probably yes, if the dynamics is also the same in all of them."

pattern is in the chord progressions of bars 101–105 without any melodic content. Then in the remaining eight bars of the movement, while the right hand is occupied with stylized scales and arpeggios, the recurrent pattern jumps back to the bass notes and fades out over twelve more repetitions.

This example is more dramatic, because recognizing these recurrences changes the whole mood of the movement. This sonata is the one containing the famous *Largo e mesto* slow movement, in which it is widely believed that Beethoven announces his reconciliation to becoming deaf. But then most performers seem to think that he recovers fully in the *menuetto*; accordingly they give a joyous, almost flippant, rendering to the final movement just discussed.

But when we play it just a bit more slowly, and give full recognition to all these recurrences, that final movement changes its character entirely; it becomes perhaps the saddest movement ever written, far more so than the *Largo e mesto.* Astonished at this discovery, made after I had been playing that movement in a flippant way for thirty years without suspecting any such thing, I could not help speculating on the meaning that pattern had to Beethoven; what words is he saying to us here? Rightly or wrongly, I fancy that I have succeeded in this quest, for the following reason.

Our theory that Beethoven's music is saying to him some simple German word or phrase was not just wild speculation, because we learned later that on several occasions Beethoven confirms this by revealing to us just what they were. The first movement of the Sonata Op. 81a, recording his sadness at the Archduke Rudolph leaving Vienna, starts with three descending notes (G – F –E♭) of equal time and emphasis, over which Beethoven wrote *Le–be–wohl* (Literally, "live well", which in German is a sentimental way of saying "farewell"). This same three note pattern recurs throughout the movement in the most varied melodic guise, and it is hard to see how anyone performing the work could fail to recognize that Beethoven is saying 'lebewohl' over and over again.

In two symphonies, although he did not put the words into the score, Beethoven disclosed to others what his meaning was. The opening four notes of the fifth symphony were described by him as: "Thus Fate knocks at the door." The "Metronome" section of his eighth symphony starts with ten notes that Beethoven described as saying, "ta–ta–ta, ta–ta–ta, lieber Maelzel".

Another confirmation of our conjecture appears in the string quartet Op. 132, where Beethoven twice writes three words over three notes, whose German pronounciation fits their rhythmic and dynamic emphasis and which pattern is then repeated many times. Those same phrases fit perfectly both the rhythmic pattern and the mood in the Op. 10 #3 final movement. The three note pattern starts as a rising one "*Muss es sein*?" (Must it be?, or with the middle note emphasis, a better English rendering is Must *that* be?) and gradually evolves into a falling one "*Es muss sein*!" (It *must* be!). In music, unlike a spoken language, a transition from one statement to another can be made gradually, through a sequence of almost imperceptible small changes. At bar 100 the transition is complete, and we enter those chord progressions that signal the end of the movement by repeating the phrase, neither rising nor falling, first more loudly, then more softly, and fading away into silence with the falling phrase.

This movement has some other minor recurrent patterns, and it would be pure speculation to guess what special meaning, if any, they may have had for him. But the unity is further enhanced if one recognizes these and gives them the same dynamic rendering.

It is very easy to spot (and feel smugly superior to) a performer who does not perceive these rhythmic/dynamic recurrences in Beethoven, however far his technical powers surpass my own. But the unity of Beethoven's late string quartets and piano sonatas seems to have a different basis, that I do not claim to understand. How ludicrous it would be to try to analyze Mozart's music this deeply! We would find nothing there to analyze.

In the writer's view, Beethoven's music has an intellectual content that is completely missing in Mozart's, and therefore it requires an intellectual effort to appreciate it. Indeed, as just noted, one can study a Beethoven work for many years and still discover new things in it. But that is already enough to account for the greater popularity of Mozart in the mass media.

In summary, we suggest that Beethoven wrote program music of many different kinds, and usually presented it as abstract music; Mozart wrote abstract music of one standard kind, and tried to pass it off as program music of many different kinds. But neither strategy was generally noticed; as someone put it: "For the listener, all music is program music."

Personality Differences

Mozart and Beethoven differed greatly in personality and relations to other people. Mozart was accustomed to the company of royalty, and the fine dress and stiff formal politeness that went with it. If Beethoven was indifferent to such mundane matters as clothing and saw no reason to be obsequious to anybody, we have noted that he was not wrapped up completely in his own work. He took the trouble to study the works of other composers and voluntarily praised many, including Handel, Clementi, Field, Cherubini. He visited taverns where untrained peasant musicians held forth with local folk music, made friends with them, and absorbed their idiom.

In contrast, Mozart almost never had a good word to say for any other musician. For example, where Beethoven praised Clementi's playing, Mozart openly sneered at it. This unthinking juvenile behavior was undoubtedly the reason for his final troubles, due to his inability to find a secure position anywhere (in his last days, this man familiar with the insides of most of the palaces of Europe, could not buy firewood to heat his own rooms). Mozart turned down offers of positions that he considered beneath him, although they would have sustained him long enough to find a better position; and indeed would have been good stepping–stones to a better position. This behavior, too, would make him enemies in high places; having been snubbed once, who would make him a second offer? He was greatly respected as a musician and feared as a competitor; but except for Haydn he had no real friends, as Beethoven had, who were concerned with his welfare. A person whom he had ridiculed might have the good sense not to ridicule Mozart in kind; but he would hardly turn about and help Mozart find the position he needed.

Mozart was so often at his worst that we are glad to note the one incident we have been able to find, where he actually showed a trace of modesty about his own accomplishments. The pianist Richter once expressed a mixture of admiration and dismay at the effortless way he was able to achieve his results at the keyboard. Mozart replied, simply, "*I had to labor once in order not to show labor now.*"

Problems in Playing Beethoven

If our first playing of a passage sounds awkward, what do we do? With Beethoven or Chopin, we should keep on trying other phrasings, because we have confidence in them. They never wrote a passage that cannot be played so that it sounds "right" and all awkwardness disappears. But the printed score cannot convey every detail of dynamics and timing, the subtle emphasis on one particular note, the tiny micro–pauses at particular places; and so it is up to us to find this natural phrasing.

We cannot have this confidence in any other composer; we expect some inadvertent awkwardness in Schumann or Moussorgsky, and some quite deliberate awkwardness in Debussy and Ravel; but even Mozart, Schubert, and Brahms have passages for which, this writer is convinced, it is impossible to find any phrasing that does not sound awkward. The recorded performances of the greatest virtuosos and Mozart specialists confirm this; nobody can make them sound "right." Perhaps they are copyist's errors; but in the case of Mozart we know that some of his piano sonatas were written only as exercises for his pupils; they were never intended to be serious music for performance in concert halls. So he would not have been concerned with a momentary awkwardness; his pupils were already producing a great deal of that, and a bit more did not matter. Indeed, it is easy to imagine that Mozart inserted awkward spots quite deliberately, as traps for his pupils; to see which ones were able to get out of them gracefully.

But what if we encounter a passage where the problem is not phrasing but that it is too difficult technically to play as written – often impossibly fast? We can find out readily enough what the recording artists of the past have done. Rudolph Serkin slowed down just to the point where he could play every note; Artur Rubinstein simply charged ahead at full speed, leaving behind a trail of wrong and missing notes. Both approaches sound awkward and wrong to this writer, but they might have at least the following rationales.

We know that Beethoven was a superbly powerful pianist, and he surely knew better than anybody what is and is not possible for human fingers to do. Then what are we to make of the fact that his piano sonatas have occasional passages which Beethoven himself could not possibly have performed as written in the modern score? Even if his fingers could do it, the pianos he had available, lacking the modern escapement action, were mechanically incapable of it. There is no way to be sure, but there are two possibilities:

(A) It is conceivable (although we think highly unlikely) that Beethoven neither expected nor wanted the sound to correspond to the score; he wanted the effect of a pianist *trying* to play what is written. This conjecture seems to us ruled out by what we know of the orderliness of Beethoven's own playing. But if this *was* his intention, then we must say that he succeeded and Rubinstein's approach is correct.

(B) The following line of speculation seems to us much more plausible. Beethoven's autograph scores are very carelessly – even sloppily – written and almost impossible to decipher. It seems inevitable that copyists and printers often misunderstood his intentions. The writer certainly could not reconstruct a Beethoven sonata, given only what Beethoven put on paper. Then what proofreading did they receive?

Beethoven would have given extremely careful proofreading, out of youthful pride, to his first published works (just as the present writer did with his first published scientific works). But soon, occupied with other things, we tend to give them more and more cursory attention. The works published in the period, say, 1798–1805 (that is, roughly Op. 10–45) might have received very little proofreading. Then for some time starting in 1805 (that is, roughly from the *Kreutzer* Sonata Op. 47) Beethoven entrusted the proofreading of his works to Carl Czerny, who would surely have done a very conscientious job of it. But exactly how careful was he? Did he rely more on the autograph score or on his own musical taste? Did he trust his musical instincts enough to give him the courage to suggest to Beethoven that there might be an error on the autograph score – and seek his approval for a change?‡ We just do not know.

A plausible theory is then that Beethoven wrote down all the notes, but in his haste failed to write down all the bars – just as we do today when we write music by hand. Indeed, this is most likely to happen in just those passages where a single chromatic run, black with notes, extends over several measures. If the result is taken literally, the effect of leaving out a bar is to double the speed momentarily, compressing the notes for two measures into one.

Then, in order to fit the notes Beethoven wrote into the bars he wrote, copyists would be obliged occasionally to put 64'th notes where Beethoven had intended 16'th or 32'nd notes. This is an error that Czerny could not have detected even by checking every measure of the proofsheet against every measure of the autograph score (and, of course, which we could not detect today even with the autograph score in hand). If this is what happened, then Serkin's approach is correct in spirit, although the slowing down should have been not just to the threshold of possibility; but by a factor of exactly two, three, or four.

So what is a pianist to do today when such a passage appears? We have experimented with several instances of impossible passages, trying the effects of slowing them down by a factor of exactly two or four; and in every case we think it sounds so "right" musically that it is almost surely what Beethoven really intended.

But of course, only your own musical taste can answer this question for you. Here are some suggestions of places where you can try this out easily and decide the matter for yourself. At the beginning of the "Pathétique" sonata Op 13, the bad measures 4, 9, 10 – and the horrendous measure 11 – can be played naturally, and sound much better, if the heavily barred notes are played at 1/4 the indicated speed. The rhythm now fits together smoothly where before those sudden bursts of speed would not sound right – but rather awkward and out of place – even if one could play them as written.

The slow movement of Op. 10 #1, marked *Adagio molto*, is one of those places where, in the middle of complacency, suddenly you are kicked in the face by measures 28 – 30, where Beethoven appears to demand that you quadruple the speed instantaneously. Then, escaping somehow from the wreckage of the attempt, you again lapse into complacency until he does it to you again in measures 75 – 77. But for these six disaster–creating

‡ Czerny may have been less inclined to consult Beethoven than he should have been. Schindler (1860) reports (p. 377) that Beethoven "was thrown into a rage when a copyist or some other person asked him about specific points in a composition without having the score in hand." Donald Francis Tovey accuses Czerny of inserting arbitrary *sempre p* and *rinforzando* markings, that destroy the musical sense and that Beethoven could not possibly have wanted. But, of course, Czerny had unparalleled opportunity to hear Beethoven's own performance of these works; from this he would have learned many things that are not in the autograph score and were not available to Tovey. So we are inclined to trust Czerny's judgment.

measures, this would be one of the most serene and beautiful sonata movements ever written. Even if they could be played as written, they would have a disruptive, jarring effect that ruins the musical sense of it.

But just try playing them at half the indicated speed; the trouble disappears. There is still acceleration, but it is acceleration under control and without awkwardness. The rhythm fits together just right, and you have a smoothly coherent musical statement, in impeccably good taste. We feel sure that this must be what Beethoven really intended; he may do things vigorously, but never awkwardly. In any event, whatever the modern scores seem to say, sudden and grossly exaggerated changes of either tempo or dynamics are simply in bad taste, and the performer who commits them – or trys to commit them – should not put the blame on any composer; he is revealing something about his own musical perceptiveness.

Loesser (1954, p. 147) tells us about Beethoven that "Even before his deafness became severe, we can be sure that he craved an extreme intensity of tone (*i.e.* loudness) to express the extreme intensity of his feelings." Our reply is that extreme intensity of feelings is *not* conveyed by extreme loudness; quite the opposite, as Beethoven demonstrates repeatedly, better than any other composer. Extreme loudness conveys only a situation out of control.

We suggest that nothing in Beethoven's piano sonatas requires extreme loudness; indeed, the attempt to do this invariably results in a harsh tone, just the opposite of what Beethoven wanted. A player with good musical sense will prepare for a crescendo by starting softly; then the full dramatic effect is achieved without exceeding the range of good piano tone.

It might be thought that these problems surely have come up so many times that the solutions must be long since known; did not both Artur Schnabel and Donald Francis Tovey write detailed instructions for performance of the Beethoven sonatas? Unfortunately, neither seems even aware of this problem; Schnabel is more concerned with 'correcting' Beethoven's tie marks,[†] while Tovey points out only the obvious things that everybody can see for himself on a second reading.[‡] Both miss the subtle things that need to be explained, which one perceives only after long acquaintance with the work.

In this Chapter we have departed from our presentation of established scientific facts, and indulged in tentative personal conjectures that seem plausible from our experience, in the hope of stimulating further thought on these issues. Perhaps readers with different knowledge and experience may be in a position to confirm – or refute – our conjectures.

[†] After some study we found that we disagree with Schnabel's phrasing instructions about as often as we agree with them, so it is easiest simply to ignore his instructions altogether – particularly since in his recorded performances he too ignores them. The difference amounts to this: from Czerny's comments we suggest that for Beethoven a slur indicates something entirely different than for Mozart. In Beethoven, absence of a slur does not indicate non–legato; rather, the breaks between slurs indicate the momentary suspension of legato – one of those little micro–pauses. Saint–Saens told us that, when Mozart wished the legato, he indicated it. But when Beethoven wishes the non–legato, he indicates it.

[‡] While we rarely disagree with Tovey, we even more rarely learn anything from him, so again it is easiest simply to ignore his instructions and trust to our own judgment.

m8a, 6/7/94

CHAPTER 8

ELECTRONIC MUSICAL INSTRUMENTS AND DEVICES

Before about 1920, all the world's work was accomplished by mechanical moving parts. But the development of the vacuum tube – originally for radio – opened an entirely new area of other applications. With the ability to amplify small signals and generate new signals of almost any frequency and wave shape, many things involving information handling and processing, formerly done mechanically, could now be done electrically with enormous advantages in speed and cost.

By 1930 the technology existed by which new musical instruments were possible, in which the notes, of any pitch and tone quality could be generated electrically. What was oscillating was not a string, sound board, or air column; but only an electric current or voltage in some circuit; but after processing it electrically in almost any conceivable way and for any purpose, the final result could be made audible by the loudspeakers developed for radio. The list of potential advantages for keyboard instruments is impressive:

(1) Even large variations in temperature and humidity would no longer throw an instrument out of tune.

(2) One has a much wider variety of pitch and timbre available, so that a single instrument can be made to serve, at the player's will, the musical functions of a piano, harpsichord, clavier, organ, xylophone, carillons, *etc.*.

(3) The quality as a musical instrument can be fully as great – actually far greater – than that of any mechanical instrument. Good timbre can be maintained over a much greater dynamic range than is possible in any acoustical instrument.

(4) The instruments can be much more reliable; broken strings, hammers, worn out felts, cracked soundboards, are things of the past.

(5) The instruments can be smaller and lighter and much less expensive.

One would think that, with all these obvious advantages, they would be exploited at once, and by now a revolution in keyboard instruments should have been long since accomplished. But sadly, our task here is not to explain how these wonderful things are done today; rather, we must try to understand why they have *not* yet been done in spite of our full technical capability of doing them.

Perhaps the first commercial electrical instrument to be made in any quantity was the Hammond organ of the 1930's.[†] The sound of it became familiar to everyone in the 1940's because it was promoted so vigorously. A radio commercial, played thousands of times, featured a performer named Ethel Smith, playing on a Hammond organ the music of a current little song with a Spanish flavor, "Ticho–Ticho", whose lyrics praised the reliable little cuckoo in a clock. This was repeated day and night with such maddening regularity that every note and intonation of it is burned permanently into my memory. The sound was utterly unlike that of any real organ, and was closer to what would be called today, "vibes." The main result of this saturation advertising campaign was that, although relatively few people ever saw a Hammond organ, everyone could whistle "Ticho–Ticho".

[†] For a comprehensive review of the state of the art at that time, see B. F. Meissner (1936). Technical details of the Hammond organ are given by L. Hammond (1939).

The Hammond organ technology seems today to be almost of the stone age; to see how far we have advanced, we note that in a small part of it the twelve highest notes were generated by a rotating shaft carrying twelve cogwheels with approximately the right number of cogs,[‡] which induced oscillating electric currents in twelve electromagnets placed near them. Then a cascade of vacuum tube frequency dividers generated the lower octave signals from these, after which many other vacuum tube circuits are needed to supply the upper partials (by borrowing in the proper proportions the voltages in the circuits belonging to higher octaves). Finally, each key must have a switch to turn on the proper note, after which they are all combined and amplified to loudspeaker level.

Thus merely to generate all the required pitches – before we have even started to generate the proper timbres – required apparatus that weighed perhaps thirty pounds (with the motor to drive the shaft and the power supply for the vacuum tubes), must have cost about $200 in 1940 dollars to manufacture, consumed about 100 watts of power; and was highly unreliable, with a dozen potential failure points. Today, all of this is accomplished by a single integrated circuit containing thousands of transistors on a semiconductor chip about the size of an aspirin tablet, which consumes about a milliwatt of power and costs about one dollar in 1990 dollars – perhaps 15 cents in 1940 currency – to manufacture; and has spacecraft reliability. Thus has technology advanced in fifty years.

Despite all its technical and musical shortcomings, the fact that the Hammond organ was the pioneer of a new field made many regard it with affection, and surviving instruments maintained in working order are becoming valuable antiques. Indeed, there is an active market in these old (see the personal ads in the back of such periodicals as Keyboard magazine). Hammond organs are being offered for sale at over $4,000.

Other makes of electric organs (Lowry, Schober, *etc.*) appeared, operating on other principles and producing quite different sounds. Some of these used authentic Rube Goldberg devices; in one the effect of tremolo, which could have been produced so easily electrically if one wanted it, was made instead by the astonishingly crude, ineffective, and costly method of mechanically rotating the speaker so that it faced alternatively toward and away from the listener!

With the advent of solid–state electronics and integrated circuits in the 1960's, all these early efforts became obsolete. It could all be done now with superior performance, in a way vastly easier, cheaper, and more reliable. Again one would have expected high quality electronic pianos to appear. Indeed, an attempt at this was made by the Baldwin piano company, and for a time the result was also promoted by radio commercials, now featuring Glenn Gould playing Bach on the electronic piano (in contrast, the famous organist E. Power Biggs refused to perform on any electronic organ).

The writer, after many years of playing a Bösendorfer grand, acquired one of these electronic Baldwins largely out of curiosity; and found it so unacceptable as a musical instrument that one could not understand why the Baldwin Company had bothered to manufacture it at all, much less why they would allow their name to be put on it. The tone

[‡] Exercise for you to ponder: explain why it is not possible, with this arrangement, to produce an exact equal tempered scale, although an eight–note diatonic scale is possible. Thus the Hammond organ produced thirds smoother than equal tempered thirds, at the price of making some other intervals worse.

quality varied greatly across the keyboard and at no point was it anything like acceptable piano sound. The sound was so muffled by insufficient harmonic content – particularly in the bass – that it was almost impossible to recognize a note unless it was played staccato. Glenn Gould's performances partially hid this defect because he played everything staccato anyway. Not only in articulation, but also in maximum volume and dynamic range – all of which would have been trivially easy to accomplish electrically – it was hopelessly deficient, in a way that could not be corrected by any further amplification or filtering of the output. Although it was in a sense also a pioneer in a new field, nobody could regard it with affection and it will never become a valuable antique.

More recently, other manufacturers – Roland, Kurzweil, Casio, Yamaha – produced portable electronic piano keyboards, of which the writer proceeded to acquire a 1985 vintage Roland HP–100, and a 1992 Yamaha YPP–50. They showed a slight, almost negligible improvement in quality. The Roland went to the opposite extreme of too much harmonic content in the bass, making it sound cheap and tinny, while the treble notes had a shrill, unpleasant peanut–whistle quality. At least, the balance between bass and treble was acceptable.

The Yamaha actually approached acceptable piano sound in the bass, for perhaps the first time in any electronic piano, but now produced dull treble notes with insufficient harmonic content, lacking the brilliance of piano sound. Astonishingly, the user was given no way of controlling brilliance, although the Roland offered this in a sequence of steps. Even worse, the Yamaha preserved the worst defect of the acoustical piano, about which Johann Sebastian Bach had complained already in the first piano – bad balance across the keyboard, with booming bass and weak treble, just the opposite of what a good piano ought to give us for reasons explained in Chapter 3.

Equally exasperating, the volume could not be turned up to normal piano loudness without great deterioration in sound quality – what the experienced hi–fi ear recognizes at once as distortion due to nonlinearity in the electronics. It would have been so easy to design the electronics to give greater dynamic range than an acoustic piano without departing from good piano tone; but in fact, it had far less range, making effective crescendos almost impossible. In addition, the decay was far too fast, making it almost impossible to play anything legato (the designers were apparently unaware that an acoustical piano note has two decays; a fast and a slow one, and any acceptable electronic instrument must duplicate both of them).

In short, like the proverbial Japanese tailor, the Yamaha piano keyboard faithfully copied the defects of the acoustical piano, while failing to copy its good features. But we found that this could be compensated, bringing the result up to the border–line of acceptability, by passing the output through a hi–fi amplifier set for maximum treble emphasis and bass suppression.

Although it is possible to do anything electrically millions of times faster than mechanically, in all of these attempts at an electronic piano the response is so sluggish that it is impossible to execute a trill at anything like the speed of an acoustical piano. It seems to us that there is something deliberately perverse in the design of those circuits or the keys (in particular, the lack of tactile sense of when the key rises to the point where it can be repeated, and rate of key rise when the finger is removed; perhaps this needs to be speeded up).

In addition, there is something too 'rigidly fixed' about the sound of the above electronic pianos; the original acoustical piano has a kind of flexibility and expressivenness that they all lack. Perhaps the stretched octaves of acoustical pianos actually give an enhanced melodic quality to the high notes. Bear in mind also that on an acoustical piano a more loudly struck note automatically has not only a greater brilliance (harmonic content) but also a slightly higher pitch (the average tension on the string is increased by the greater amplitude of its motion, which stretches the string just as would tightening the peg by a tiny amount). Of course, if psychological experiments should show that this is indeed an important factor in musical expressiveness, it could be duplicated electronically.

However, with all their defects, the quality of electronic keyboards of the type discussed above, is already about equal to that of the cheapest 'spinet' acoustical pianos. And the price of the former comes down while that of the latter continually increases; the spinet piano is already more expensive than an electronic keyboard of comparable musical quality, so we think that the low–end spinet pianos are headed for swift obsolescence. But the high–quality acoustical grand piano is as yet unthreatened.

In summary, there is no technical reason why one cannot make an electronic piano that has a musical quality surpassing the finest concert grand, can be folded up and carried as easily as a cello, has all the above practical advantages, and sells for about the same price as the TV – VCR combination in most living rooms. But the history of attempts to produce this much–needed instrument is one of persistent failure to achieve even the most elementary necessities of a piano from a musical standpoint. We do not yet have any electronic instrument – of whatever size and price – that is a satisfactory substitute for a good acoustical grand piano.

This is not a failure of our currently available technology; it is a human failure. The engineers who designed those instruments, although they presumably knew their electronics, simply lacked the musical perceptiveness to comprehend what is important in a piano.[†]

Since the electronic keyboard manufacturers never produced a satisfactory piano, they never attracted many buyers and their interest shifted to other electronic instruments of the "synthesizer" genre. Here the attempt to imitate a piano was abandoned, and one concentrated instead on special effects that are possible only in an electronic instrument. In 1993 rather elaborate synthesizer keyboards could be bought for about $2,500. A new synthesizer is the Yamaha VL–1; it can reproduce a quite realistic oboe sound, and also crazy things like a "bowed flute". Indeed, synthesizers can produce an amazing variety of weird sounds made to order by the user, and thus make instructive demonstrations of some principles of acoustics and sound perception. But in our view there is no musical reason to want such weird effects, so these devices are expensive toys, not serious musical instruments.

It is problematical whether this situation will ever be corrected, short of a new producer entering the field with a new philosophy. We think that only a person who has in the same head a thorough understanding of both electronics and classical piano music – at

[†] Worse, the writer knows one competent electronic engineer for whom the terms "music" and "rock and roll" are synonymous. I do not think that this musical illiterate has any conception of what classical music is; he appears never to have ever heard a Beethoven sonata, or even to know what that means, or who Beethoven was.

the level of actual competent performance – can do for the piano what Theobald Böhm did for the flute; so the high quality acoustical grand piano will continue to be with us for many more years. It might remain the instrument of choice almost indefinitely if some of the improvements noted in Chapter 6 were made.

MIDI

However, another intriguing possibility is beginning to appear, developing in a different direction than the synthesizer, in the passage of music through computers, in which the musical response is determined by the particular software that is controlling the computer. The MIDI (Musical Instrument Digital Interface) system carries full information about what the player is doing on a piano keyboard, essentially instantaneously, over a single coaxial cable, making it possible to accomplish the functions of keyboard, piano action, and sound production in three separate and separated components, each of which can be designed separately for any number of different purposes.

For each key, a signal is sent indicating the pitch, the exact time of key depression and release, and the velocity of the key at the point (about 2/3 of the way down) where the escapement would disconnect the hammer from the key on a conventional piano. This provides all the information that is available to the Érard piano action, therefore it must be possible for a computer, given that information, to reconstruct everything the Érard action does.† Equally well, one can make the computer do anything else one may want with that information, which no instrument has ever been able to do before. Once this information is available as input to a computer, then merely by writing different software, one can make the computer process it in any way we please, to produce any volume, timbre, attack and decay pattern, we want; and these parameters may be chosen differently for different keys, reproducing the piano's bass, midrange, and treble response and reproducing the piano's variation of timbre with loudness, if that is what we want. With experience, one could surely make the computer deliver response far superior to what the Érard action gives.

With the MIDI interfaces a single keyboard could suffice, once and for all, to emulate any number of different musical instruments. A single hi–fi speaker system suffices, once and for all, to deliver any sound the human ear is capable of perceiving. The individuality of the instrument would be determined entirely by the computer module connected between them, which can be replaced with a different one at any time (or more easily, one replaces the software with new kinds). Obsolescence itself would be a thing of the past.

RECORDING

The place where modern technology – electronic and otherwise – has made a really big and valuable impact on music is, of course, in the making of recordings, which started with Thomas Edison's wax cylinders. These mechanical/acoustical machines arrived too late to

† Or, for that matter, what the Stein or Streicher pianos, Beethoven's Broadwood, the Späth non–piano, the Cristofori piano, or the harpsichord did; or what the organ or xylophone do now, since the MIDI information includes everything that they use concerning what the player is doing. But, interestingly, one could not emulate the clavichord, which makes use of extra information (variation of finger pressure on the key after it has sounded) that the present MIDI system does not transmit.

preserve the performances of Liszt, but just in time for others such as Enrico Caruso and Camille Saint–Saens. The play–back machines were of wretched musical quality by today's standards, but with their long flaring horns, often imitating trumpets or flowers, they had a very elegant appearance, fit for the finest salons. Probably the world's greatest collection of fancy old phonograph and gramophone machines is in the museum at Burgdorf near Bern, Switzerland.

With the invention of the electrical microphone all the existing electrical technology could be applied at once to development of both radio and greatly superior recording devices. These evolved from the wax cylinder to flat 78 RPM disks to 33 1/3 RMP disks, to tape recorders, and finally to our present laser–operated Compact Disks with digital computer electronics, which seem to leave nothing to be desired as far as quality of reproduction is concerned. We doubt whether anybody's ear is able to distinguish between a live performance and a reproduction on a modern hi–fi system properly set up.

Musicians need to know a little about this technology in order to make good recordings of their own performances. Reverberation, etc.

************ MORE HERE ON RECORDINGS **************************

refsn, 7/20/94

REFERENCES

A Partially Annotated Bibliography

Abraham, Gerald (1980), *The Concise Oxford History of Music*, Oxford University Press. A massively non–concise (990 pp.) account of music from Ancient Egypt to Stravinsky.

Auer, Leopold (1921), *Violin Playing as I Teach it*, F. A. Stokes Co., New York; reprinted by J. B. Lippincott Co., Philadelphia (1960), and by Dover Publications, Inc., New York (1980).

Austin, Wm. W. (1987), *"Susanna," "Jeanie," and "The Old Folks at Home"; The Songs of Stephen C. Foster from His Time to Ours*, Univ. of Illinois Press, Urbana.

Bach, Carl Philipp Emanuel (1753), *Versuch über die wahre Art das Clavier zu spielen*, Berlin. Written while Bach was at the court of Frederick the Great at Potsdam, this is the work that, as recalled by Carl Czerny, Beethoven told his pupils to read as their first assignment.

Baines, Anthony (1963), *Woodwind Instruments and their History*, Norton, New York. Paperback reprint by Dover Publications, Inc. (1992).

Baines, Anthony (1992), *The Oxford Companion to Musical Instruments*, Oxford University Press. Lavishly illustrated, concise descriptions of many instruments from all over the world, with pitch, playing techniques, and orchestral use.

Barclay, Robert (1992), *The Art of the Trumpet–Maker*, Oxford University Press (Early Music Series 14). The materials, tools and techniques of the 17'th and 18'th Century in Nuremberg.

Bartholomew, W. T. (1942), *Acoustics of Music*, Prentice–Hall, New York.

Barzun, Jacques, editor (1956), *Hector Berlioz: Evenings with the Orchestra*, New York

Bate, Philip (1956), *The Oboe: An Outline of its History, Development and Construction*, Ernest Benn, London.

Bate, Philip (1978), *The Trumpet and Trombone; an Outline of Their History, Development, and Construction*, Ernest Benn, London.

Bate, Philip (1979), *The Flute: A study of its History, Development and Construction*, Ernest Benn, London.

Békésy, Georg von (1960), *Experiments in Hearing*, McGraw–Hill Book Company, Inc., New York. The author spent some 34 years in microscopic dissection of human ears and in acoustical experiments with live persons. Everyone should read, at the very least, his Chapter 1 concerning the historical background of the subject, full of informative illustrations and amusing anecdotes.

Benade, Arthur H. (1976) Fundamentals of Musical Acoustics, Oxford University Press, Inc., New York. Second revised edition, Dover Publications, Inc., 1990. The fundamental, authoritative source of technical information on wind instruments.

Beranek, L. L. (1962) *Music, Acoustics, & Architecture*, J. Wiley & Sons, Inc., New York. Valuable first of all for its photographs, plans, and dimensions of 54 of the most famous concert halls all over the world, with comments of musicians on their acoustical merits or demerits and measured reverberation times. Secondly, it is a now famous case history of the steps and the thinking that prepared the way for the greatest acoustical disaster of all time: the Philharmonic Hall in Lincoln Center, New York. Leo Beranek was the acoustical consultant on its design, and he goes into great detail concerning all the measurements and adjustments that were made on it. In the end, it was so intolerable acoustically that it was torn down and rebuilt only 14 years after its opening in 1961. The story was repeated in 1987 when the Detroit Symphony Orchestra abandoned the modern Ford Auditorium with its intolerable acoustics, and returned to the old

Orchestra Hall, built in 1919. Evidently, the masses of acoustical measurements and calculations made by modern acousticians were irrelevant to the real problem of musical quality. It seems to us that the simple factors that *were* relevant, were also obvious at a glance without any acoustic measurements at all – but they were ignored in the design of modern auditoriums. As Leopold Stokowski had pointed out long before, the slight asymmetries and fancy rococo decorations of old halls were not only pleasing to the eye; they performed the essential acoustical function of *diffusing* the sound uniformly without absorbing it. In contrast, the flat surfaces of modern auditoriums reflect concentrated beams of sound, producing an acoustical mess; the sound of any one instrument will miss some locations in the hall, while coming on far too loud in others. (These things come rather close to home, because the writer's older brother, Vernon H. Jaynes, was a college classmate and lifelong friend of Leo Beranek).

Berlioz, Hector (1975), *The Memoirs of Hector Berlioz*, David Cairns, editor, W. W. Norton & Co, Inc., New York.

Böhm, Theobold, *The Flute and Flute–Playing*, Dover reprint (1992).

Brockway, Wallace & Weinstock, Herbert (1939), *Men of Music*, Simon & Schuster, New York. Biographical sketches of some 30 composers from Palestrina to Stravinsky. Comparable to Schonberg (1970) but relatively heavier on German and lighter on French composers. For example, Berlioz and Bizet are mentioned in passing but do not rate separate Chapters. With a larger book but fewer subjects, the sketches here give more information than do those of Schonberg.

Burney, Charles (1773), *The Present State of Music in Germany, the Netherlands and United Provinces*, London. Dr. Burney travelled to many places, meeting musicians and writing this interesting account of their activities. In particular, he spent a day in the home of Carl Philipp Emanuel Bach in Hamburg, and reported on his lifestyle and musicianship.

Chase, Gilbert (1987), *America's Music: From the Pilgrims to the Present*, 3rd edition, Univ. Illinois Press, Urbana

Clinkscale, Martha N. (1993), *Makers of the Piano 1700 – 1820*, Oxford University Press. Details of nearly all extant pianos built in its earliest years.

Coates, Kevin (1985), *Geometry, Proportion, and the Art of Lutherie*, Oxford University Press. A study of the use of geometry and numerical proportion in the design of European bowed and plucked string instruments of the 16'th - 18'th Centuries. Lavishly illustrated. "Finally dispels the idea that musical instruments of the classical period were developed arbitrarily."

Cooper, Barry (1990), *Beethoven and the Creative Process*, Oxford University Press. An attempt to understand Beethoven's underlying creative motivation, the relationships between his different works, and the influence of external factors in his life on his output. See also Frohlich (1992).

Debussy, Claude (1977), *Debussy on Music*, translated and annotated by Richard Langham Smith, Alfred A. Knopf, New York. Claude Debussy was, like Hector Berlioz, an on–and–off music critic whose writings show a high literary quality and a genial wit. Like the criticisms of Hanslick and Schumann, those of Debussy give us a very different picture of their author than we get from other writers. Debussy, contrary to the impression given by others, was not a radical, sour, misanthrope contemptuous of all music except his own. He appreciated other works fully, was as inclined to praise as to criticize, and commented in a way more interesting and succinct than Hanslick and more sensible and to the point than Schumann. For example, he appraises Wagner's music as "A beautiful sunset which has been mistaken for a sunrise", saying in ten words what Hanslick had said in thousands. The only thing we deplore is that, for reasons we cannot comprehend, he did not like Beethoven. But we think that reading this work will give you much useful information and a higher opinion of Claude Debussy as a person.

Dolge, Alfred (1911), *Pianos and Their Makers*, Covina Pub. Co., Covina, Calif. Reprinted by Dover Publications, Inc., New York, 1972.

Ehrlich, Cyril (1990), *The Piano; A History*, Oxford University Press.

Fay, Amy (1880), *Music–Study in Germany*, A. C. McClurg & Co., Chicago; innumerable later reprints, including Dover Publications, Inc. (1965).

Fay, Amy (1986), *More Letters of Amy Fay; the American Years 1897–1916*, M. W. McCarthy, editor, Information Coordinators, Detroit.

Fischer, J. C. (1907), *Piano Tuning*, Theo. Presser, Philadelphia; Second edition by Dover Publications, Inc., New York (1975). An appalling documentation of the state of knowledge of piano technicians of the time; he has no conception even of overtones generated by a vibrating string, much less their inharmonicity in a piano string. This results in his giving very wrong statements about the beat periods of slightly detuned intervals, particularly the octave and fifth. In some respects, Fischer's understanding of these 'combination tones' is inferior to that of Tartini and Rameau in the 18'th Century, although by 1907 the facts had been explained thoroughly and correctly decades before, by the scientists Helmholtz and Rayleigh. White (1946) finally was aware of overtones, but not yet of inharmonicity.

Forkel, Johann Nikolaus, (1802) *Ueber J. S. Bachs Leben, Kunst und Kunstwerke*, Hoffmeister & Kuhnel, Leipzig. English translation by C. S. Terry, *Johann Sebastian Bach: His Life, Art, and Work*, Constable & Co. Ltd., London 1920. First Bach biography, with details of his interactions with Frederick the Great.

Frohlich, Martha (1992), *Beethoven's 'Appassionata' Sonata*, Oxford University Press (Studies in Musical Genesis and Structure). A detailed case history of Beethoven's method of composition, with analysis of all the sketches and revisions, with their transcriptions and facsimile reproductions. See also Cooper (1990).

Galilei, Vincenzo (1589), *Discorso intorno alle opere di Gioseffo Zarlino*, Venice; facsimile reprint Milan, 1933.

Gibian, Gary (1977) *Cochlear Microphonic Studies: Propagation of Cochlear Distortion Products*, Ph.D. Thesis, Washington University, St. Louis.

Gold, T. (1987), "The Theory of Hearing", in *Highlights in Science*, H. Messel, Editor, Pergamon Press, New York. Suggests a partial return to the original theory of Helmholtz.

Haimo, Ethan (1990), *Schoenberg's Serial Odyssey*, Oxford University Press. Traces the evolution of dodecaphony from its beginnings in 1914.

Hallé, Charles (1896), *The Life and Letters of Sir Charles Hallé*, (edited by his son and daughter), London. Valuable eyewitness accounts of Paganini, Mendelssohn, Berlioz, Cherubini, Chopin, Liszt, and their contemporaries. Karl Hallé (1819–1895) was a German pianist who studied and taught in France for several years, during which he met the aforementioned musicians. The revolution of 1848 induced him to flee to England, where he introduced the Beethoven piano works to the British, performing the first full sonata heard there (Op. 31 #3). His early success led him to settle permanently in England, where he organized the Hallé Orchestra of Manchester and was knighted Sir Charles Hallé for his musical accomplishments.

Hammond, L. (1939), Science, **89**, p. 6; Electronics, **12**, p. 16. Technical aspects of the Hammond organ of the 1930's and 1940's.

Hanslick, Eduard (1988), *Hanslick's Music Criticisms*, translated by H. Pleasants, Dover Publications, Inc., New York. A selection of 39 articles on contemporary music composition and performance, from Wagner's *Tannhäuser* (1846) to Johann Strauss (1899). We are accustomed to reading of Hanslick as a doddering old fool, who unfairly attacked Wagner because he could not comprehend Wagner's "Music of the Future." Then it is a shock to read his actual words and realize that this was only Wagnerite propaganda; the facts are that Hanslick (1825–1904) was twelve years younger than Wagner but far better educated than Wagner, very well informed about music, much more inclined to praise than condemn, and he fully recognized the quality of

Wagner's work. But he also saw – as did Claude Debussy – that this was leading pure music in a direction that had no future. It is like profanity; going in that direction, you quickly reach the limits of possibility, beyond which there is nowhere left to go. Both Hanslick and Debussy predicted correctly that Wagner's works, far from being the beginning of the "music of the future", would be the end of the "music of the past." Our conclusion is that, far from Hanslick attacking Wagner unfairly, Wagner and his friends attacked Hanslick unfairly. Reading this book greatly increases our respect for Hanslick; just the opposite of the effect that Schumann's criticisms have.

Helmholtz, Hermann L. F. von (1885), *Sensations of Tone*, English translation of fourth (1877) German edition. Reprinted by Dover Publications, Inc. (1954). This is still the greatest, and most useful, monumental work on the scientific basis of music, including acoustics, origin of scales, operation of instruments, mechanism of hearing, and musical aesthetics. Helmholtz was the greatest German scientist of the 19'th Century, a master of all existing knowledge of physics and physiology (to both of which he made important contributions); and also an accomplished pianist, who performed the Beethoven works with professional competence and was personally acquainted with contemporary musicians like Joachim. There are probably not a dozen persons alive today who have all the factual knowledge he had, and nobody should attempt to write on these subjects without first checking what he had to say about them. Everything he wrote is still valid and important today, with the exception of the material on physiology and functioning of the ear (practically nothing was known about this in his time, and he made speculations that seemed very plausible then, but which modern research has found to be in need of revision). The situation here is still far from understood; more recent discussions are given by Wever (1949), Békésy (1960), Gibian (1977), Gold (1987).

Hofmann, Josef (1909), *Piano Playing, With Piano Questions Answered*, Doubleday, Page & Co. Reprinted (1920) by Theodore Presser Company and (1965) by Dover Publications, Inc. Josef Hofmann (1876–1957) was one of the great pianists active at the turn of the Century, and later Director of the Curtis Institute of Music in Philadelphia. Here he offers many short pieces of good advice; some nearly obvious, some showing deeper understanding than one can find in any of the works on piano 'methods'. In particular, he stresses the legato touch; and not only for musical reasons. Points out that legato is not only desirable musically, but mechanically *necessary* in order to play rapid passages. He sees facts like this correctly, and thus debunks a great deal of the superstitious nonsense then current; not only a superior musician, but also a superior mind.

Holoman, D. K. (1989), *Berlioz*, Harvard University Press. A massive (736 pp.) biography, with more information than we really wanted to know.

Hotteterre, Jacques–Martin, *Principles of the Flute, Recorder and Oboe*, English translation, Dover Publishing Co. (1992).

Hubbard, Frank (1965), *Three Centuries of Harpsichord Making*, Harvard University Press. The surviving evidence concerning the harpsichord in the 16'th – 18'th Centuries as it was made in Italy, Flanders, France, England, and Germany.

Kircher, Athanase (1650), *Musurgia Universalis.* Reprinted by Hildesheim, New York, 1970. A short work on instruments of the time, but with details not given in others. Father Kircher (1602–1680) was a Jesuit mathematician and linguist who dabbled in all the knowledge of his time. He taught at Würzburg and later at Rome. His collection of musical instruments and other antiquities became the beginning of the Kircherian Museum in Rome. But not all of his many activities commend themselves to us today. He was an observer in the affair of Galileo (1564–1642) and afterward, Kircher was so indiscreet as to reveal that the Jesuit scholars were aware that Galileo was in the right; but kept their silence and allowed him to be persecuted (only in 1992 did the Catholic Church officially admit this). We must add that Kircher was also a weird occultist, and wrote a huge volume of nearly 500 pages, *Ars Magna Sciendi sive Combinatoria*, (Amsterdam, 1669) full of magic diagrams; and another of 250 pages giving every detail of the construction

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of Noah's ark! As we are obliged to note constantly, scholars of that time lived in a dreamlike state, with little conception of the difference between external reality and inner fantasy. For every factual relation which they perceived correctly, they believed with equal force in a dozen supernatural ones. Fortunately, musical instruments, unlike Noah's Ark and magic spells, are things which one can see with his own eyes and hold in his own hands, leaving relatively little room for superstition.

Kirnberger, J. P. (1757), *Der allerzeit fertige Polonaisen und Menuettencomponist*, G. L. Winter, Berlin. First known example of a recipe for production of "aleatory" or "random" music, some 200 years before the days of the computer. The idea of automatic composition by machine occurs even earlier; Kircher (1650) gives plans for such a machine somewhat like a slide rule, but it does not seem proper to call this 'random.'

Köchel, L. von (1937), *Chronologisch–theoretisches Verzeichnis Sämtlicher Tonwerke W. A. Mozarts*, 3rd edition, edited by Alfred Einstein, Breitkopf & Härtel, Leipzig.

Krummel, D. W., Jean Geil, Doris Dyen, & Deane Root, (1981), *Resources of American Music History*, Univ. Illinois Press, Urbana. A guide to hundreds of thousands of manuscripts from Colonial times to World War II.

Krummel, D. W. (1987), *Bibliographical Handbook of American Music*, Univ. Illinois Press, Urbana. Examines over 750 bibliographies of books, periodicals, and other writings about American music, as well as lists of compositions, titles, scores, and recordings, from 1698 – 1988.

Lark in the Morning, Musical Catalog (1993). It is not our usual policy to take note of commercial advertising; but in this case an exception must be made. Lark in the Morning (P. O. Box 1176, Mendocino CA 95460, U.S.A.; Fax 707–964–1979) is a mail order musician's service that specializes in hard–to–find instruments, music, and instructional material. Its catalog is an education in itself; in it one can find for sale illustrated hammer dulcimers, baroque flutes, Renaissance lutes, some 25 kinds of bagpipes, medieval fiddles, a dozen kinds of harps and lyres, Swiss alphorns, Turkish ouds, Indian sitars, Chinese shengs, Buddhist gongs, Roumanian panpipes, one–of–a–kind old instruments of every description, plus rare music for them and books about them.

Larousse Encyclopedia of Music (1974), The Hamlyn Publishing Group, Ltd., London. This is an English version of a work published in France in 1965, expounding the history of music and musical instruments. Its virtue is in about 1,000 interesting illustrations, several in color and suitable for framing. Unfortunately, the connecting text fails to meet the scholarly standards of accuracy that we require in historical work. As we note in Chapters 3 and 6, this work gives us imaginative versions of some events concerning, Beethoven, Pleyel, and Schumann, that are totally at variance with all other sources. Worse, the author of any section is nowhere identified, and so one cannot trust any section give the details correctly. The Introduction by Antony Hopkins starts, prophetically, with a declaration that " - - - *facts are overrated and often irrelevant* - - - ." But even if that were true, it would justify only silence; not publication of false statements.

Loesser, Arthur (1954), *Men, Women, and Pianos: A Social History*, Simon & Schuster, New York. Paperback reprint by Dover Publications, Inc. A weird book, in which many interesting and useful facts about the history of the making and use of pianos alternate with interludes of social commentary, much of which appears downright silly today. Here is the ideologue of the 20'th Century, passing absolute moral judgment on the 18'th Century – without ever considering the alternatives or the resources available to them. He has a morbid preoccupation with the subject of money, and takes a stance of high moral indignation over every financial transaction, however beneficial to the parties concerned and to society as a whole. Put in modern terms, he views every economic process as a zero–sum game in which, if anybody makes a single penny, then someone else is necessarily swindled (a view which the present writer had also, at the age of 19). Loesser is, to the best of our knowledge, the inventor of the term "politically correct" (p. 169), decades before it was picked up by others. But after all this criticism, we must acknowledge that his historical scholarship is surprisingly thorough; he digs up many significant old references unknown to other 20'th Century writers. Do not miss the Bibliography (pp. 614–624) with some 400 references where one can find vastly more historical material than we can include here. In the long run, this Bibliography may be seen as the most valuable part of the book; in it there is something "new" for everyone interested in the history of music.

Mach, Ernst (1988), *Die Mechanik in ihrer Entwicklung*, R. Wahsner & H. v. Borzeszkowski, Editors, Akademie–Verlag Berlin. Ernst Mach (1838–1916), a Professor at the University of Vienna, was a remarkable combination of scientist, philosopher, and historian. His great work on mechanics went through seven editions in 1883–1912. It is particularly famous today because it greatly influenced Albert Einstein in his youth. This book contains a reprint of the 1912 edition, plus a long appendix which contains an autobiographical sketch by Mach, the letters between Mach and Einstein, Einstein's obituary of Mach, and a survey of Mach's theoretical ideas by Max Planck. The work is very much worth reading today, not only because of the depth of Mach's thought and his careful historical scholarship, but because many will find it easier to read than a modern physics textbook. It is easy to understand why he influenced Einstein so much, because he still influences us in the same way today. On the other hand, some of his positivistic philosophical notions – in particular his refusal to accept the reality of atoms, which he considered unsupported by sufficient evidence – are now obsolete because that sufficient evidence was found at about the time of his death, by Einstein and others.

Maconie, Robert (1990), *The Works of Karlheinz Stockhausen*, 2nd. Edition, Oxford University Press. Descriptions of his works and his aesthetic/philosophical positions on many topics.

Manniche, Lise (1991), *Music and Musicians in Ancient Egypt*, British Museum Press, London. Dr. Manniche is a professional Egyptologist, and we learn from her some details, not given by others, of the rise and fall of musical tradition over the very long period (some 2000 years) represented. However, it is apparent to the reader that her knowledge of Egyptology greatly exceeds her knowledge of music. She is most meticulous in identifying each of the hundreds of different tombs from which musical information has been obtained. Yet on p. 7 she tries to present a table defining the musical intervals, which just does not make sense to anyone familiar with what the musical intervals really are in terms of whole tones and semitones. Elsewhere, in speculating on the tuning of ancient harps, she calls a ratio of 2:3 an 'augmented fifth'. She purports to distinguish between clarinets, oboes, and flutes from tomb drawings in which no visible difference exists. But such anomalies cannot deceive anyone with musical training, and in other respects this book contains much interesting information; in particular one realizes the widespread presence of highly developed musical instruments of many different kinds, whose existence implies an equally highly developed musical tradition. Contains an extensive bibliography of other books and articles on Egyptian musical instruments.

Manning, Peter (1993), *Electronic and Computer Music*, 2nd Edition, Oxford University Press. Discography, technical developments such as MIDI, and philosophical aspects.

Matthay, Tobias (1947), *The Visible and Invisible in Pianoforte Technique*, Oxford University Press. 2nd. edition, 1960. Tobias Matthay (1858–1945) was an English piano teacher who became well known because he published innumerable books about piano technique starting in 1903. This is his final attempt to digest it all in one book. Matthay may have played reasonably well himself, and inspired others to do their best (his best known pupil was Myra Hess); but he is utterly ignorant of the principles of physics and physiology that necessarily control the situation. He has no comprehension of the distinction between the reality of what is actually happening in hand and piano, and his own subjective feelings while playing it; we note some outstanding examples of this in Chapter 6. He tells us that no more energy is required to play a note *ff* than *pp*, for we simply carry out the same motion at a faster speed! The fact is that, since the energy required is proportional to the square of that speed, it requires over 100 times as much energy to play a note *ff*. We do not see how the resulting greater muscular fatigue could escape the notice of the most unperceptive piano player; that is why most of us have to change fingers constantly on rapidly repeated notes. Fortunately, he could not lead others very far astray because he lacked the command of language to convey any clear ideas to readers. He is demolished effectively and almost correctly, by Lawrence Schauffler (1937). Harold Schonberg (1963, p. 277) states that "··· most modern theoreticians ridicule the ideas of Matthay."

Meissner, B. F. (1936), Proc. I. R. E., **24**, p. 1427. A review of the early state of the art in electronic musical instruments, before the introduction of the transistor.

Mersenne, Marin *Harmonie Universelle* (Paris, 1636–37). Reprint by Fayard, Paris (1985). Father Mersenne (1588–1648) was a Jesuit scholar who lived mostly in Nevers and Paris. He was a good friend of Descartes and had all the learning of his day in both mathematics and music. The relation of pitch to string length was well known from the time of Pythagorus. Galileo had started finding the relation of pitch to vibration frequency and the laws of vibrating strings; Mersenne finished the job. He also translated the works of Galileo into French (Paris, 1634).

Mozart, Leopold (1985), *A Treatise on the Fundamental Principles of Violin Playing*, Oxford University Press (Early Music Series 6). First published in Augsburg in 1756 (the year of birth of his son Wolfgang Amadeus Mozart), this was the major work of its time.

Noss, Luther (1989), *Paul Hindemith in the United States*, Univ. Illinois Press, Urbana.

O'Beirne, T. H. (1971), "From Mozart to the Bagpipe with a Small Computer", Bull. Inst. Mathematics and is Applic, **7**, pp. 3–8.

Ortmann, Otto (1929), *The Physiological Mechanics of Piano Technique*, E. P. Dutton & Co., New York. Reprinted, with an Introduction by Arnold Schultz (1962).

Pallottino, M. (1956), *Tarquinia: Wandmalereien aus Etruskischen Gräbern*, R. Piper Verlag, München. Beautiful paintings in full color, many of which show musical instruments in use; most commonly, the two–tube oboe discussed in Chapter 2, in better detail than is given in the Egyptian tomb wall sketches. See also the companion volume, Schefold (1956) with very similar paintings from Pompeii. These paintings tell the story so well that one does not need to read German in order to understand them, although the German text gives details of exactly where the various tombs were found.

Praetorius, Michael (1619), *De Organographia.* A large treatise on instruments of the time, at least as they were known in Germany. English translation by David Z. Crookes, *Syntagma Musicum II*, Oxford University Press (Early Music Series 7), 1986.

Rameau, Jean Phillippe (1722), *Traité de L'Harmonie, Reduite à ses Principes Naturels*, Ballard, Paris. English translation with introduction and notes by Philip Gossett, *Treatise on Harmony*, Dover Publications, Inc., New York (1971). In five later books, dated 1726, 1737, 1750, 1754, and 1760 Rameau shows a gradually improving understanding of the physical principles, but no major change in his perception of the musical principles.

Rayleigh, Lord (1877), *Theory of Sound*, 2 vols., Macmillan, London; 2nd revised and enlarged edition (1894); reprint of second edition, two volumes bound as one, Dover Publications, Inc., (1945). Possibly the most massive scholarly work ever produced by a scientist, and the most influential for the subsequent development of science; today, the mathematics of quantum theory is still based mostly on the methods introduced by Rayleigh. In §137 he gives the simple explanation and calculation of inharmonicity of piano strings due to stiffness, which results in stretched octaves. But 70 years later, this information had not yet reached the piano tuners who had the most need to know about it (White, 1946).

Rendall, F. G. (1971), *The Clarinet: Some Notes upon its History and Construction*, Ernest Benn, London.

Rice, Albert R. (1992), *The Baroque Clarinet*, Oxford University Press (Early Music Series13). The early history from shortly before 1700 to about 1760.

Rowland–Entwhistle, Theodore (1967), *Teach Yourself the Violin*, English Universities Press, Ltd. This work purports to get an absolute beginner started on the violin; so we chose it as indicating the level of present beginning violin pedagogy. Indeed, he does not get around to putting the bow on the string until page 66!

Sabine, W. C. (1922), *Collected Papers on Acoustics*, Harvard University Press; reprinted by Dover Publications, Inc., New York (1964). Wallace Clement Sabine (1868–1919) was Hollis Professor of Mathematics and Natural Philosophy at Harvard University. What makes him unique is that he was nearly the first scientific student of musical acoustics; and he remains to this day the most successful practitioner of that art. He was the acoustical consultant in the design of Boston's Symphony Hall, which after more than 90 years remains one of the three or four best auditoriums in the world for symphonic music. His methods are explained in this book. Later attempts at acoustical design of concert halls, with infinitely more *appearance* of scientific erudition, ignored elementary common sense and produced ever worse results, leading finally to disaster; see Beranek (1962).

Saint–Saëns, Camille (1921), *Musical Memories*, London.

Schaeffner, André (1936), *Origine des instruments de musique*, Payot, Paris. Later edition, 1968.

Schauffler, Lawrence (1937), *Piano Technic: Myth or Science*, Gamble Hinged Music Co., Chicago. This professional musician and piano teacher finally took the trouble to listen to what scientists like Dayton C. Miller and Otto Ortmann were trying to tell musicians about the mechanics of piano action. He is far from appreciating all of the physics involved here; he fails to see the distinction between the terms "energy" and "force", and nowhere does he recognize that the force applied to a key determines the *acceleration* of the hammer (Newton's law). Of course, this means that has no way of seeing the notion of effective mass of a key. Therefore he does not have even the concepts needed to perceive the greater mechanical efficiency of the nonpercussive, steady force touch, and makes the same error as Schonberg in thinking that a percussive touch enables one to play louder. Nevertheless the first part of the book is a big advance over authors who paid no attention whatsoever to the physical facts; or even angrily rejected them. Unfortunately, his treatment of the physiology of piano playing in the second part is even less successful. He includes Amy Fay in the list of references, but makes no mention of her in the text. A major problem is caused by an incredible misunderstanding of the technical meaning of the word "weight." For him this word implies *motion* – a meaning that it has never had for any other person, scientist or musician, before or since. This reduces his discussion of "weight" methods to incoherent nonsense. The book includes a bibliography of 54 works on piano technique dated 1889 – 1935.

Schauffler, Robert Haven (1929), "Beethoven, The Man Who Freed Music". Reprinted 1944 by Tudor Publishing Co., New York. A biography well worth reading, and a useful list of Beethoven's published works by Opus numbers, marred only by a weird theory that Beethoven used a fixed 'germ motive' in all his music; we cannot find it even after he has told us what to look for.

Schauffler, Robert Haven (1945), *Florestan: The Life and Work of Robert Schumann*, Henry Holt & Co., New York. Paperback reprint by Dover Publications, Inc., New York (1963). Provides, in a footnote, the only good clue to the truth of Schumann's crippled finger. In the Appendix the author lists 18 other biographies of Schumann, dated 1865–1931.

Schefold, Karl (1956), *Pompeji: Zeugnisse Griechischer Malerei*, R. Piper Verlag, München. A companion volume to Pallottino (1956). Here the two–tube oboe and Lyres or Harps appear in very well preserved paintings, found in homes rather than tombs.

Schindler, Anton F. (1860), *Biographie von Ludwig van Beethoven*, Aschendorff, Münster. English translation by C. S. Jolly, *Beethoven as I Knew Him*, University of North Carolina Press (1966);

reprinted by W. W. Norton & Co., New York, (1972). Anton Schindler knew Beethoven well for a number of years, and one should read this for his general impressions of Beethoven. Unfortunately, his recollections were written down when he was an old man many years later, and he is demonstrably wrong on many documented facts. The editor tries his best to correct these, but there is no way of knowing how many errors remain undetected.

Schnabel, Artur, editor (1935), *Ludwig van Beethoven, 32 Sonatas for the Pianoforte*, Memorial edition, Simon & Schuster, Inc., New York. A highly edited version, with instructions that we ignore, for reasons explained in Chapter 7.

Schonberg, Harold C. (1963), *The Great Pianists*, Simon & Schuster, New York. Second enlarged edition (1987). Every serious musician – certainly every pianist – should be familiar with the background information in this work for its general cultural value. There are also some attempts to discover the technique of the great pianists of the past, which if successful would have been useful to piano students today. But as noted in Chapter 6, that requires additional factual knowledge of piano mechanism, physics, and physiology that Schonberg did not have.

Schonberg, Harold C. (1970), *The Lives of the Great Composers*. W. W. Norton & Co., Inc., New York; revised Edition (1981). Short biographies of about 50 composers, from Bach to Webern. The approximate equivalent of Brockway & Weinstock (1939), which starts before Bach and ends with Stravinsky; but Schonberg has far more on 19'th and 20'th Century French composers.

Schultz, Arnold (1936), *The Riddle of the Pianist's Finger*, Carl Fischer, Inc., New York. Very important insight, unfortunately obscured as described in Chapter 6.

Schumann, Robert (1988), *Schumann on Music: A Selection from the Writings*, translated by H. Pleasants, Dover Publications, Inc., New York. A collection of his music criticisms dated 1831–1853. Unfortunately, reading his actual words discloses to us a very different Schumann than the civilized, urbane person, the kindly helper of talented young people, portrayed by his sympathetic biographers. Brockway & Weinstock (1939) perceived this also: "*Schumann has been called a great music critic so often that it is annoying to discover that he was nothing of the sort.*" We are appalled at the gross factual inaccuracies (wrong names, dates, places, *etc.*) and criticisms that seem not only harsh and unfair, but irrelevant to the subject. We can see a wandering of the mind, the music ostensibly under review sometimes receiving almost no mention. Perhaps this records the beginnings of his mental breakdown, which led to his death in an insane asylum three years after publication of the last article reprinted here. One puts this book down sorry for having read it.

Sitwell, Sacheverell (1955), *Liszt*, Constable & Co., London. Paperback reprint by Dover Publications, Inc., New York (1967).

Slobin, Mark (1982), *Tenement Songs: The Popular Music of the Jewish Immigrants*, Univ. Illinois Press, Urbana.

Slobin, Mark (1989) *Chosen Voices: The Story of the American Cantorate*, Univ. Illinois Press, Urbana.

Smith, Bradley (1966), *Spain: A History in Art*, Simon & Schuster, New York. Numerous color photographs of Spanish art from prehistoric cave paintings up to 1931, covering particularly the period of Arab occupation, roughly 711–1400. Shows a number of early musical instruments in great detail.

Solum, John (1993), *The Early Flute*, Oxford University Press (Early Music Series 15). The transverse flute from 1500 to the early 19'th Century.

Spaeth, Sigmund (1933), *The Art of Enjoying Music*, McGraw–Hill Book Co., New York. Reprinted by Garden City Publishing Co., Inc. (1942).

Stevin, Simon (1605), *Hypomnemata Mathematica*, Leiden. The title page has the elaborate design reproduced here on p. ***, with the very concise and cryptic motto: "Wonder en is gheen wonder".

Its meaning for him requires many more words to explain: 'What seems wonderful to us, is no more wonderful than other things that we know instinctively and consider obvious". Although Galileo is much better known today, Simon Stevin (1548–1620) in many ways anticipated and complemented the discoveries of Galileo (1564–1643), as explained in Mach (1988). Both were deeply interested in the operation of musical instruments and contributed fundamentally to knowledge about them.

Sumner, Wm. L. (1952), *The Organ: Its Evolution, Principles of Construction and Use*, Mac Donald, London. Later editions, 1955, 1962.

Thayer, Alexander Wheelock (1921), *The Life of Ludwig von Beethoven*, 3 Vols. Edited by H. E. Krehbiel. Translated from the 5 volume German edition of 1908.

Theophilus (1963), *On Divers Arts*, Translated from 12'th Century manuscripts and edited by J. G. Harthorne & C. S. Smith, Constable & Co., Ltd., London. Paperback reprint by Dover Publications, Inc., New York (1979). Detailed descriptions of how masterpieces of metalworking – including portable organs and tuned sets of bells – were created in the early 12'th Century.

Toff, Nancy E. (1979), *The Development of the Modern Flute*, Taplinger Publishing Co., New York.

Tovey, Donald Francis (undated), Commentaries in *Beethoven's Pianoforte Sonatas*, 3 Vols., The Associated Board of The Royal Schools of Music, London. The individual sonatas with Tovey's recommendations on performance are available also in sheet music form from the same publisher.

Tovey, Donald Francis (1976), *A Companion to Beethoven's Pianoforte Sonatas: A Complete Book of Analysis*, The Associated Board of The Royal Schools of Music, London. Gives "complete bar–to–bar analyses of the sonatas" – an undertaking which seems to us like counting the notes.

Vail, Mark (1994), *Vintage Synthesizers*, Miller Freeman Books, Gilroy CA 95020. The first 30 years (1962–1992) with emphasis on particular ground–breaking instruments, with many photos.

van Bergeijk, W. A., Pierce, J. R. & David, E. E. (1960), *Waves and the Ear*, Doubleday Anchor Books, Garden City, N. Y. An account of experiments, largely conducted at the Bell Telephone Laboratories, in the psychology of hearing. Undoubtedly, there are some correct and important results here, but also some blatant nonsense, and we do not know how to separate them. In our view, they mix subjective and objective factors so badly that many of their procedures and conclusions just do not make sense. What does it mean to say that one sound is "twice as loud" as another; or one pitch is "twice as high" as another? The subjects of these experiments – whatever their educational level – could not possibly have understood what they were supposed to do; therefore no meaningful conclusions can be drawn from what they actually did.

Wainwright, David (1984), *Broadwood — by Appointment*, Quiller Press, England. A history of the Broadwood piano company [we understand that it may be obtained also from: John Broadwood & Sons Ltd., 6–18 Northampton Street, Essex Road, London N1 2JB, England].

West, M. L. (1992), *Ancient Greek Music*, Oxford University Press. After being accustomed to a common belief that all of this music is lost, it came as a shock to see here thirty surviving examples of it, with analysis and accounts of the place of music in Greek life.

Wever, E. G. (1949), *Theory of Hearing*, John Wiley & Sons, Inc. Paperback reprint by Dover Publications, Inc., 1970. Ernest Glen Wever (1903–1991) was Professor of Psychology at Princeton University. Here he gives the history of attempts since Helmholtz to understand the mechanism of hearing, and presents his own researches and his "volley" theory as almost the diametric opposite to the Helmholtz theory. However, his criticisms of Helmholtz reveal that he lacked Helmholtz's understanding of basic physics; in particular (pp. 35–39) the response of resonators. He thought that every discernible pitch requires its own separate resonator, although Helmholtz already gave the cogent explanation of why this is not true. Also, adding loss to a resonator broadens its frequency response curve, but Wever draws erroneous conclusions about this because he fails (p. 194) to comprehend that it does not do this by increasing the response off resonance;

rather, it decreases the response on resonance. Apparently, he never examined the solution of the simple differential equation that governs the behavior of a resonator; today, every physicist and electrical engineer understands these things perfectly well because he has worked it all out in an undergraduate homework problem. To the best of our knowledge, we have at present no really satisfactory single theory of hearing; it seems to be rather a hodge–podge of random evolutionary development with several different mechanisms and principles, each doing part of the job. Like most evolutionary developments, it is more like something built over many years by a sequence of workmen – each forbidden to modify what the previous ones had done – instead of the design of a single comprehending intelligence.

Wheatstone, C. (1806), *Mozart's Musical Game*, London. Rules for composition of "random" music by tossing dice.

White, W. B. (1946), *Piano Tuning and Allied Arts*, 5'th edition, Tuners Supply Co., Boston. A notable advance in technical understanding over Fischer (1907), but he still does not comprehend the 'stretched octaves' phenomenon, although the explanation by Rayleigh had been available in the English language for some 70 years; White supposes it to be a mysterious property of the human ear, instead of a simple mechanical property of piano strings due to their stiffness against bending. Finally, 100 years after Rayleigh, Benade (1976) gave the correct explanation and calculation of the effect again.

Wier, Albert E. (1940), *The Piano: Its History, Makers, Players, and Music*, Longmans, Green & Co., London. Contrary to what the title suggests, this contains a very extensive discussion of the earliest keyboard instruments; but only a rather sketchy account of the piano, with far less information than Dolge or Loesser.

Zarlino, Gioseffo *Harmonic Institutions*; Venice (1558); translated by V. Cohen, Yale Univ. Press, New Haven, (1983).

Zarlino, Gioseffo, *Sopplementi musicali*, Venice (1588); Facsimile reprint by Broude Bros., New York (1979).