CHAPTER 1 THE MUSICAL NOTE

1.1 Musical and physical terms

If a musician were asked to list the various attributes of a single note played on an instrument, he might mention the following: pitch, quality, loudness, duration, attack, decay, vibrato. Each of these has a physical counterpart, which could in principle be measured. The instrument sounding the note causes rapidly alternating variations in the pressure of the surrounding air. It is these pressure variations which, having spread out through the air as sound waves, cause the ear-drum to vibrate in sympathy, and which a physicist would measure in order to describe the note in his terms.

What follows is intended only as a brief summary of the relationship between some of the relevant physical quantities and their musical counterparts. In each case it has been necessary to ignore some of the complications which arise from the behaviour of the ear, which converts the pressure variations into electrical signals, and of the brain, which interprets these signals. Nor has any attempt been made to mention all the factors which may affect the sound of a note. The purpose of this chapter is only to make the ideas of the next, and to a lesser extent of the rest of the book, intelligible to a reader with no previous knowledge of musical acoustics.

1.2 Pitch: frequency

A musical sound is distinguished from a noise by the fact that its waveform (the variation of pressure with time) is not a random succession of peaks and troughs, but repeats itself regularly. The number of repetitions per second is called the *frequency* in Hertz (Hz). Provided that the frequency lies somewhere between 20 Hz and 20,000 Hz (these limits varying from person to person and the upper limit decreasing with age), a note of definite pitch is heard. If the frequency increases, the pitch is heard to rise; if it decreases, the pitch falls. Fig 1.1 shows some notes on the guitar, together with their corresponding frequencies. These are calculated according to the equally tempered scale (see section 2.5), the ones above 100 Hz being rounded off to the nearest whole number.

Fig 1.1 Frequencies of some notes on the guitar

Note	E	A	D	G	B	E	A	E	B	E
Frequency (Hz)	82.4	110	147	196	247	330	440	659	988	1319

The musical interval between two notes is given not by the difference but by the *ratio* of their frequencies. For example D (147 Hz) is a perfect fourth above A (110 Hz) and a perfect fourth below G (196 Hz). Clearly, the difference 196-147 is not equal to 147-110; but the ratios 196:147 and 147:110 are both close to 4:3. The reader may verify that all the intervals of a perfect fourth shown have the same frequency ratio, to the accuracy given.

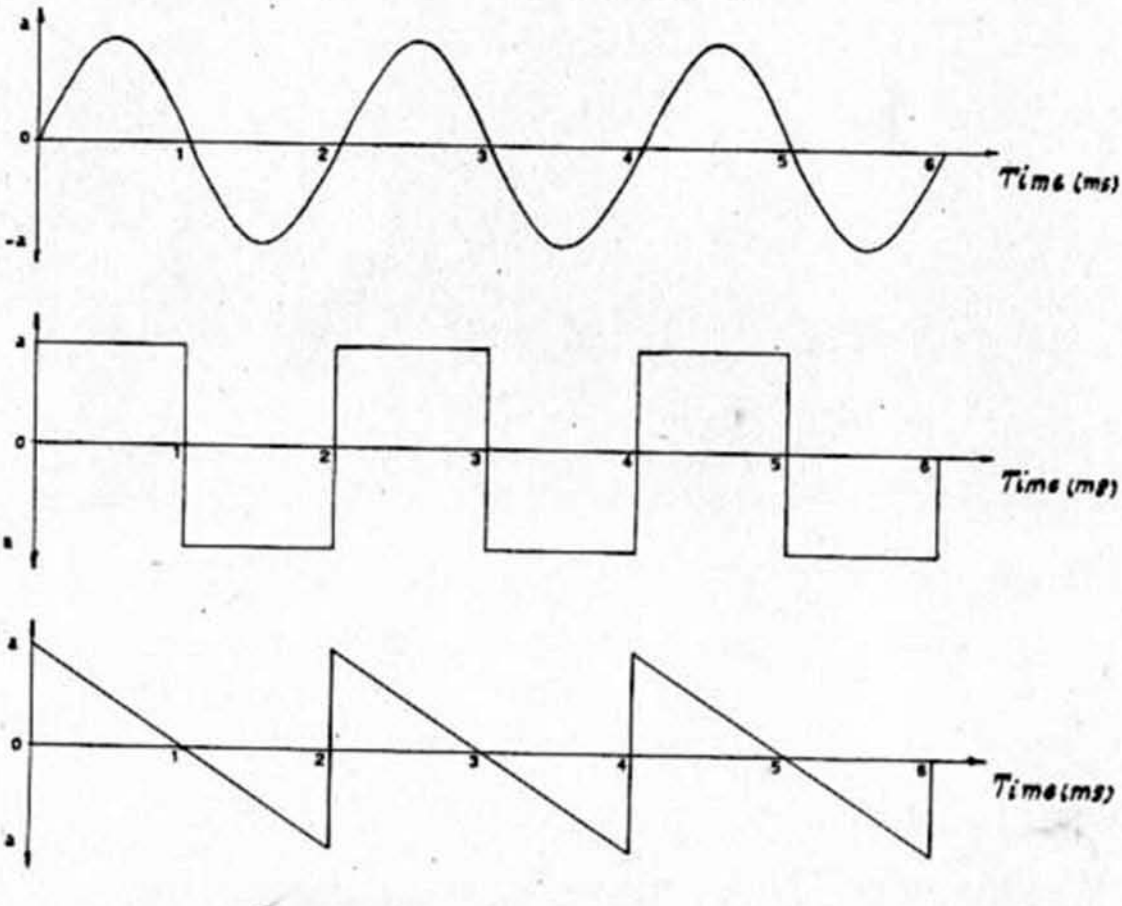
vo notes an octave apart have the simplest frequency ratio of all: it is exactly Therefore, if the notes are two octaves apart, the ratio is 4:1; if three octaves , 8:1 etc. The range of human hearing, quoted above, covers rather less than ten es, corresponding as it does to a frequency ratio of 1,000:1.

om here on, it will be useful to have a general idea of the frequencies of notes in ent registers of the guitar and of the relationship between frequency and pitch. eader may find that a little time spent studying Fig 1.1 and working out some of equency ratios (e.g. of the perfect fifth and the major third) proves helpful later.

Quality: mixture of frequency components

ave seen that the waveform of a musical sound repeats itself with a definite ency. Three different waveforms, which all happen to be easy to generate elec- cally, are shown in Fig 1.2. Each of these graphs is assumed to represent a small on of a continuous oscillation. The horizontal axis is marked off in equal time als of a thousandth of a second (i.e. in milliseconds). Pressure variations above elow the mean are shown by distance above and below the time axis. In each hree complete cycles are shown, and one cycle takes two milliseconds, corres- ing to a frequency of 500 Hz. Also, the pressure varies between the same limits h case: in other words, each of the waveforms has the same pressure *amplitude*

Fig 1.2 Three different waveforms



anyone who has used a synthesiser knows, these three types of wave give notes ite different *quality*. Compared with the reedy buzz of a sawtooth wave, the sine sounds smooth, but characterless and dull. Similarly, when two different instru- play the same note at the same dynamic level, it is generally easy enough to guish the two by their different qualities. Such quality differences are due, in at least, to differences between the regularly-repeating waveforms which the ments produce.

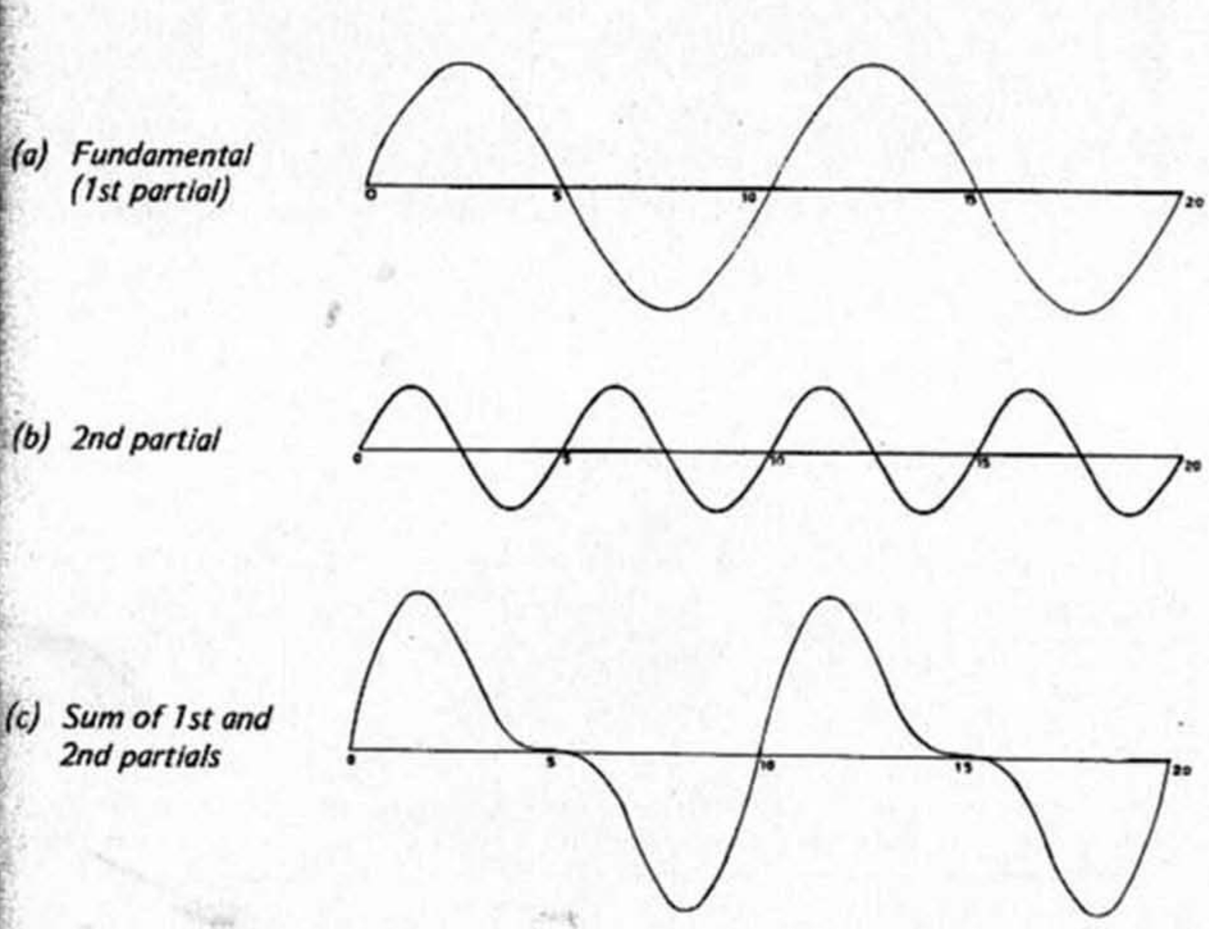
The *analysis* of different waveforms depends on a very important mathematical principle: that any complex waveform may be considered as consisting of a number of simpler waveforms with their displacements added together. It is easy enough to imagine two waveforms of the same frequency being superimposed to make a resultant waveform of that frequency. With a little thought, one can also see that adding a component of exactly twice the frequency, or *any whole number times the frequency*, will modify the waveform without changing the rate at which it repeats itself. If, for example, the original wave has a frequency of 100 Hz, components of frequency 200 Hz, 300 Hz, etc., may be added, and the resultant wave still has a repetition rate of 100 Hz.

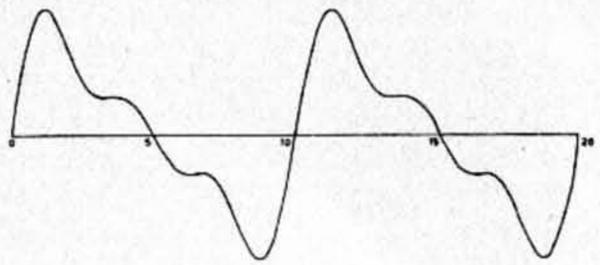
In general, any regularly-repeating waveform may be regarded as being built of components whose frequencies are related in this way. The sole exception is the sine wave, which consists of only one frequency. For this reason sine waves are also called *simple tones*, and are considered as the ultimate "building-blocks" of a complex wave. These sinusoidal components, whose frequencies are exact whole-number multiples of the fundamental frequency, are called *harmonic partials*, or simply *harmonics*.

A problem of terminology arises here, because a "harmonic" played on the guitar is not, in fact, a simple tone, but itself consists of a number of partials, as we shall see in the next chapter. Therefore, the term "harmonic" will be used from now on only in this more familiar (though less strictly correct) sense, and the single-frequency components of a musical sound will be called its "partials".

Fig 1.3 shows an example of the synthesis of a wave from simple tones. The first partial (fundamental) has a frequency of 100 Hz; the second partial has half the amplitude of the fundamental and twice the frequency. When the displacements of these two sine waves (a) and (b) are added together, the result is the waveform (c). Note that this waveform still has the same repetition rate as the fundamental. Addition of a third

Fig 1.3 Synthesis of a sawtooth wave





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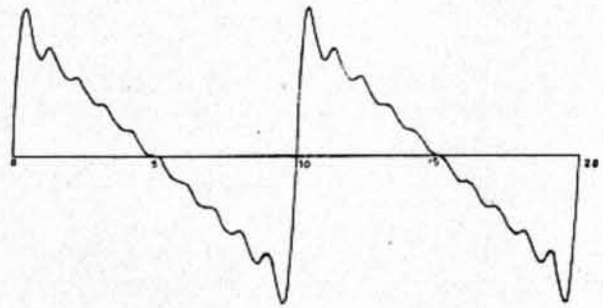


first 10

l of frequency 300 Hz and one-third the amplitude of the fundamental gives the orm (d). If more and more partials are added, with frequencies 400 Hz, 500 Hz, and amplitudes one-quarter, one-fifth, etc., of the fundamental amplitude, the comes to resemble more and more closely the sawtooth waveform shown in .2(c). The sum of the first ten partials is shown in Fig 1.3(e). One can imagine hundred partials would give a better fit, but still not a perfect one because no urve has sharp points like those of the sawtooth wave. In theory, an infinite of partials would be required for a perfect synthesis of the sawtooth wave; ver, the sharp points themselves represent discontinuities which could not lly occur in nature. (An electronically generated sawtooth wave usually has the rs rounded off to prevent the sound from being unpleasantly harsh.) The er of detectable partials in any guitar note is, in fact, measured in tens rather hundreds.

e reedy quality of a sawtooth wave is associated with the more or less sharp rs and lack of symmetry of its waveform compared with that of a simple tone. put it in another way, all the possible partials, with frequencies extending over l octaves, are required to synthesise these features. The reediness may therefore d to be due to the presence of a large number of partials with appreciable ampli-

course, a musical waveform need not contain all the possible partials. (A wave, for example, is formed of the odd-numbered partials only.) The funda- l itself may even be absent: as long as some other partials, both odd and even, esent, the waveform repeats itself at the fundamental frequency, and it is this ency which the ear identifies as the pitch of the note[1]. However, the absence of ndamental results in a lack of "body". This is strikingly demonstrated by the hat a double-bass, playing notes whose fundamentals are perhaps in the region Hz, may sometimes be heard on a small transistor radio whose loudspeaker only nds to frequencies above about 200 Hz. In this case, only those partials higher the fourth will actually be heard, but the ear may identify the notes as having true pitches, albeit with unnaturally thin quality.

The words we use to describe tone quality are necessarily subjective and, interestingly enough, seldom primarily musical at all (e.g. "bright", "dark", "warm", "round", "hard", etc.). The fact is that there are not enough words in the language to describe the infinite variety of musical sounds. However, a number of descriptive words will be used throughout the book, and it may help at this stage to have a rough idea of how some of them relate to the mixture of partials in a note.

"Body" is associated with the presence of the fundamental and lower partials, "brilliance" with the presence of some higher partials. If the latter are very prominent, the sound may become "hard" or "edgy"; if they are suppressed, the sound may vary from "round" and "warm" to "thick" and "dull". If the lower partials are weak, the sound will be "thin".

Apart from these general trends, each partial imparts its own particular flavour which is related to its musical interval above the fundamental. Many of the higher partials, beginning at the seventh, make dissonant intervals, and this is believed to be the reason for the harshness they cause. The intervals between partials will be considered in the next chapter.

1.4 Loudness: amplitude

Since sounds are due to pressure variations in the air, it may seem obvious that the loudness of a sound is associated with the *amplitude* of the pressure variation. It is true that if a waveform is kept identical in all other respects, an increase in amplitude causes the loudness to increase. However, if the *frequency* of even a simple tone is varied, the sensation of loudness varies in a complicated way with both amplitude and frequency; and the complications are increased in the case of a note containing a number of partials or for a combination of notes. The fact is that hardly anything is obvious in this tricky subject, and a proper discussion of it is really beyond the scope of this book. Since, however, the ability to command a wide dynamic range is of particular importance in guitar technique, a few salient points will be mentioned.

(a) The variation of loudness with frequency is investigated using a simple tone of constant power. If the simple tone sounds moderately loud around the frequency of the open first string (330 Hz), it seems to get quieter as the frequency is lowered. At the frequency of the open sixth string (82.4 Hz) it may sound only half as loud as it did at 330 Hz, and below about 20 Hz it is inaudible. If the frequency is raised above 330 Hz, the loudness decreases slightly around 1,000 Hz, but then increases rapidly, reaching a peak in the region of 3,000 Hz, where it may sound twice as loud as it did at 330 Hz. At still higher frequencies the loudness again falls away, but a young person with good hearing may still be able to hear the simple tone at 20,000 Hz or even higher. The main points to remember are that the ear is particularly sensitive to frequencies around 3,000 Hz, but progressively less sensitive to higher frequencies and to those below about 100 Hz.

(b) When the same test is done with the power reduced, so that the constant pressure amplitude is smaller, the loudness falls off even more rapidly at the low and high frequencies. If the power is very low, anything below about 200 Hz may be almost inaudible. (This is why some audio amplifiers are fitted with a "loudness contour", which prevents the bass and extreme treble sounds from being lost when the volume is low.)

(c) If the power is adjusted to give the same subjective loudness at different frequencies, the necessary variations in power can be considerable. For example, the power which gives a moderately loud sound at 500 Hz may have to be increased a hundredfold (corresponding to a tenfold increase in pressure amplitude) to give the same loudness at 50 Hz, and reduced tenfold to keep it the same at

3,000 Hz. Even larger factors are involved if the initial power is lower. However, these figures must be seen in relation to the extraordinary range of the human ear; the pressure amplitude of a simple tone loud enough to cause physical pain can be a million times that of a barely audible tone of the same frequency. This corresponds to a power (or intensity) ratio of a million million to one!

(d) In the more restricted range of intensities in which music is normally heard, it is approximately true to say that the loudness of a note is doubled if its power is multiplied by ten. This is why not two, but *ten* violins are required to double the loudness of a single violin, if they are playing in unison. However, the same rule does not seem to apply to notes of different frequencies, so that two violins playing *different* notes may well sound twice as loud as either. Oddly enough, the *partials* of a single note may behave like separate sources in this respect[2].

The information presented above contains some clues as to how the loudness of a note might depend on its *quality*. For example, if low E (82.4 Hz) were played in such a way that nearly all the power were concentrated in the fundamental, it would not sound very loud, for two reasons. In the first place, the fundamental itself would only be about twice as loud as if 10% of the power had been put into it, whereas the same power distributed more evenly among, say, the first six partials, could give up to six times the loudness of each. Secondly, the ear is less sensitive to the fundamental frequency of this note than to the frequencies of its higher partials, especially those around the fourth. The ways in which the player may control the relative power put into the different partials will emerge in due course, and the response of the guitar body, another vital influence on volume, will also be considered later. For the present, one thing is for sure: if a note is to ring out loud and clear on the guitar, it must be rich in partials covering a wide frequency range. Conversely, a note with a very "thick" quality (i.e. with the higher partials suppressed) is unlikely to sound very loud, unless the guitar body happens to be particularly responsive to the fundamental frequency of that note.

Paragraph (b) above explains another familiar characteristic of guitars, that they sound thin if played too gently. The same applies to many instruments, but the guitar's lack of power and rather low register make it especially prone to the problem. Similarly, any instrument sounds thin at a distance, but at the back of a very large hall the guitar may be barely audible. In this case one may well be hearing only those partials which lie within the frequency range 1,000 to 5,000 Hz approximately; but the hall acoustics may affect the sound in many different ways[3].

These are just a few of the implications for the guitarist of the factors affecting loudness. The reader may like to think of others which apply to particular musical situations; but even an awareness of the *variety* of factors involved, without any detailed knowledge of them, may be beneficial in encouraging him to believe his ears. There is more to dynamic control than merely playing with more or less force, and the dynamic contrasts achieved by varying the *quality* of the sound rather than its overall power are no less real, and can be every bit as effective.

1.5 Attack, decay and vibrato

The explanation of sound quality outlined in section 1.3 contained the over-simplified idea that the waveform of a musical note must always repeat itself exactly. This cannot be true throughout the time of a note played on any real instrument. In this section some of the deviations from uniformity, all of which actually add to the interest of a note, are considered[4].

A steady-state vibration never begins instantaneously, but takes a certain time to build up. The guitar has an unusually quick *attack*, but it never really achieves a steady-state vibration because each note begins to *decay* as soon as the full amplitude is reached. Facts such as these would not, however, challenge the theory that instrumental timbre is due to a particular mixture of partials. Indeed, at one time it was hoped to be able to synthesise instrumental sounds electronically by imposing suitable attack and decay characteristics on a waveform made up of sine waves blended in the right proportions. However, such synthesised sounds rarely deceived the ear for one moment, suggesting that there must be more to the sound of a musical instrument than this.

In recent years it has become increasingly clear that the *irregular* behaviour at the beginning of a note, called the *starting transient*, is as much a characteristic of some instruments as the steady-state vibration to which it gives way. Starting transients arise mainly from the interactions between the different parts of an instrument. The guitar, for example, consists of two coupled vibrators, the string and the body. Left to itself, the string would vibrate in a more or less regular way from the moment of release; but its vibration must be passed on to the body in order to be radiated as sound. The body, having its own natural modes of vibration, does not immediately vibrate with the string, but responds initially in a complicated way which gives rise to the starting transient.

There are several ways of studying starting transients[5], a particularly striking one being to tape-record a note and then to cut the tape so as to remove the starting transient. The change this makes to the sound can be dramatic, and it is no longer easy to identify the instrument (one may easily mistake a 'cello for a bassoon, or a clarinet for an oboe). I have heard recordings of guitar notes shorn of their first tenth of a second; they sounded more like synthesised notes than like any real instrument, but their quality did vary considerably as the plucking point along the string was changed.

Notes generally sound much more interesting with their starting transients than without them. This seems to be one example of a general principle that the ear prefers a degree of variation to exact repetition, even within the time of a single note. A guitar note is necessarily changing throughout its duration, not only in loudness but in quality too, since the partials decay at different rates.

The guitar is far from unique in making notes which decay gradually and change in the process. What it has that is lacking in such instruments as the piano, harpsichord and harp, however, is the possibility also of *vibrato*. This is the periodic variation of the pitch of a note (i.e. of its fundamental frequency), although amplitude and quality may also vary to some extent. Good orchestral players have been found to favour a vibrato rate of 6 or 7 Hz, which curiously turns out to be the natural rate at which singers modulate the voice[6]. Thus it may be that vibrato appeals by bringing a human quality to instrumental sound. The range of the pitch variation is typically about a quarter-tone either side of the note among singers, but only half that amount among violinists. This "width" of vibrato is very much a matter of taste and fashion. Few things are considered so repugnant as an excessive vibrato; but it is generally agreed that a vibrato of about the optimum frequency and of moderate width is not experienced as a variation in pitch at all, but is felt to bring "life", "warmth", or "richness" to the tone. Lest it be thought that there is a single optimum speed and width for vibrato, however, it should be remembered that a constant and unchanging vibrato (as on an electric organ) can sound almost as boring and inhuman as none at all. The principle of variation applies equally here, and it can be particularly effective on the guitar to intensify a note with vibrato *after* it has begun. The flexible and imaginitive use of vibrato is arguably the guitarist's most valuable single resource of tone colour and expression.

CHAPTER 2 THE PLUCKED STRING

2.1 The need for a theoretical model

In this chapter and the next, an attempt will be made to outline the physical principles which govern the techniques of tone production on the guitar. These principles are dictated by the behaviour of the guitar's two coupled vibrators, the string and the body. Unfortunately, the latter is still comparatively little understood acoustically, partly because individual guitars vary in so many details, but also because the guitar has not yet come in for the extensive scientific research which the bowed string instruments and the piano have enjoyed. However, thanks mainly to the work done on these other instruments, a great deal is known about stretched strings in general. In this chapter, therefore, our attention will be focussed on the behaviour of the string itself, and we shall find that many (but by no means all) of the methods of producing different sounds on the guitar may be understood in this way, without entering into the details of the interaction between the string and the body.

Even when this interaction is ignored, the motion of a plucked string is difficult enough to describe accurately. The string will have some stiffness; its vibration will be damped by internal friction and by air resistance; its effective length may be uncertain because of some movement over the end supports. Faced with complications of this kind, the physicist does not normally attempt to include them all in one huge calculation. Instead, he resorts to a theoretical model whose behaviour is easier to understand, and then sees whether the model can be modified or extended to include the various factors he has chosen to ignore. This has been done, with some success, in the case of plucked strings[1]. Indeed, when stripped of the complications listed above, the plucked string is among the simplest of all vibrating systems, and a favourite of mathematicians, since its motion admits of exact analysis. The string is assumed to be perfectly flexible and uniform, subject to no damping of any kind, and fixed rigidly at each end. A surprising amount can be learned from this model, despite the fact that there never was a real string quite like it. The model will therefore provide many of the ideas of this chapter; but, since the purpose of this book is essentially practical, we shall not hesitate to digress from the idealised theory to any implications for the techniques of playing real strings which arise along the way.

2.2 Fundamental frequency of a stretched string

Some readers may be familiar with a school experiment with that most unmusical instrument, the sonometer, in which it is shown that the frequency of vibration of a stretched string depends only on its vibrating length l, its tension (i.e. stretching force) T and its mass per unit length m. Fortunately, there is no need to describe the experiment here, but the result (which may also be derived mathematically using the simple model) is worth knowing:

$$\text{Fundamental frequency } f_1 = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

This formula shows that the frequency increases in proportion as the length is reduced, or as the square root of the tension is increased, or as the square root of the mass per unit length is reduced. Thus, halving the length doubles the frequency and the pitch rises an octave – as is well known, since the twelfth fret lies halfway between the bridge and the nut. The tension, on the other hand, would have to be increased fourfold in order to raise the pitch by an octave. This is why it is not a good idea to tune the strings much above their proper pitch: for example, tuning them all a tone sharp will increase the load on the bridge, and on the strings themselves, by 26%. The tension of a string tuned to its proper pitch is similarly sensitive to the scale length of the instrument.

With a given scale length, the proper tension is proportional to the string's mass per unit length. In other words, high-tension strings are heavy strings, low-tension are light strings. However, the tension will vary considerably from string to string within a set. If the three treble strings are all made of the same nylon material, the third needs to have a much lower tension than the first, in order to avoid excessive thickness. For the same reason, the bass strings are made of nylon fibres overspun with metal wire, which adds weight without also adding too much bulk and stiffness. The fourth string, being the first of the metal-wound strings, usually has a much higher tension than the third, and a slightly higher tension than the lowest two strings.

2.3 Techniques of vibrato

String tension is directly relevant to tone production in one respect at least: on the guitar, all *vibrato* is made by varying the tension, since the vibrating length of the string is defined by the fret. Therefore the rolling of the left-hand fingertips, used by players of the violin family of instruments to produce vibrato by varying the string's vibrating length, would be ineffective on the guitar. Instead, vibrato is normally made by keeping the fingertip firmly fixed on the string and moving the hand alternately towards and away from the nut slightly, so as to raise and lower the tension in the vibrating portion of the string.

It is important to realise that in doing this, one is also raising and lowering the tension in the non-vibrating portion of the string between finger and nut. When playing a note at the twelfth fret, one's efforts are divided about equally between the two portions of the string, but in the lower positions the non-vibrating portion takes up more and more of the force. At the fifth fret, for instance, only about a quarter of the applied force actually goes to raise and lower the tension in the vibrating portion, while at the first fret, all but about one-eighteenth of the applied force is wasted.

In fact, one has to work quite hard to make any noticeable vibrato in the normal way below about the fourth fret, and in this region of the fingerboard, *lateral vibrato* is often used instead. This consists of alternately drawing the string aside, in a direction perpendicular to its length, by moving the fingertip towards the palm of the hand, and letting it return. (Since an increase in tension results from displacing the string either towards or away from the palm, there is little to be gained by doing both, as some authors recommend. It is neater and less awkward to pull in the one direction only.) Lateral vibrato may be used anywhere on a string, but round about the middle a string tends to feel too floppy. Also, there is always the disadvantage that the pitch is only raised above normal during lateral vibrato, causing the note to sound slightly sharp. In most cases the normal vibrato is easier to control and altogether more satisfactory.

We have seen that normal vibrato requires less and less effort, the higher the number of the fret. For the same reason, good intonation requires more and more care in the higher positions. In the first position one can pull or push a string along its length more or less with impunity, but above the twelfth fret any string so treated will sound horribly out of tune.

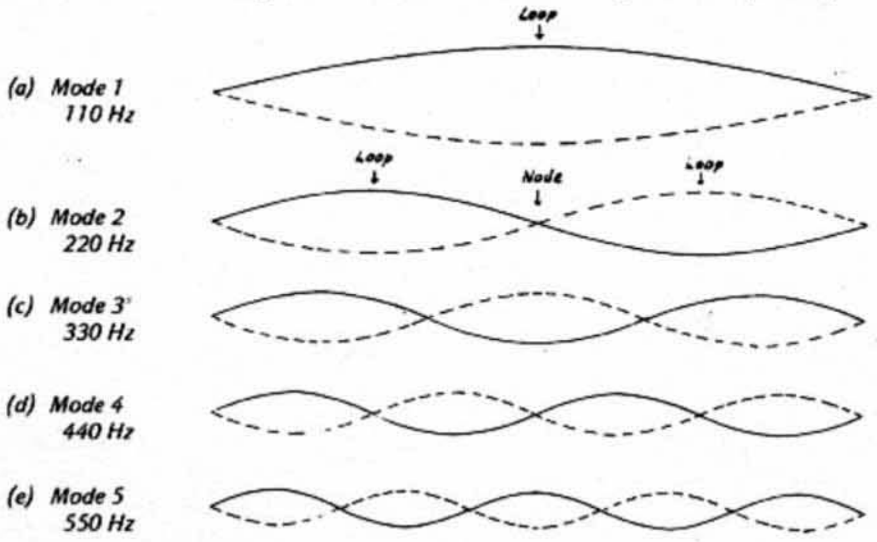
Finally, it is worth noting that the pitch changes which occur during vibrato are proportional to the *fractional* changes in string tension. Therefore, low-tension strings are more sensitive to vibrato than higher-tension strings; and conversely, they are more difficult to play in tune. The same applies to guitars of short scale-length, other things being equal.

2.4 Modes of vibration of a string

As everybody knows, the sound of a note on the guitar can vary considerably, according to where and how the string is played. We saw in section 1.3 that tone quality is related to the mixture of partials, or single-frequency components, present in the waveform of the note. Given these two facts, it will come as no surprise to learn that a string may generally be considered to be vibrating at a number of different frequencies simultaneously. In the case of a string plucked and left to vibrate freely, these are the *natural frequencies* of the string.

One way of finding these natural frequencies is to force the string to vibrate at a single frequency and to observe its response as the frequency is varied. For example, a steel string or a metal-wound nylon string may be placed between the poles of a magnet and the current (suitably amplified) from a sine wave generator passed through the string. Let us suppose that the string has been tuned to the pitch of the open A, 110 Hz. At frequencies well below this value, the string's response is relatively feeble, but in the immediate neighbourhood of 110 Hz, the vibration suddenly builds up to a much larger amplitude. The string is said to *resonate* at 110 Hz, with the vibrational shape shown in Fig 2.1(a). (The two extremes of the oscillation are shown by the continuous and the broken lines.) This is the first, or fundamental, *mode of vibration*, and is most strongly excited by a force applied at the centre of the string, where this mode has a *loop*.

Fig 2.1 Modes of vibration of string tuned to A (110 Hz)



As the frequency of the driving force is increased above 110 Hz, the response immediately falls back, but resonance occurs again at 220 Hz. This is the second mode, shown in Fig 2.1(b). It has a *node*, or stationary point, at the centre, and two loops; excitation is strongest if the alternating force is applied at one of the loops, but falls to zero at the node. The third mode, shown in Fig 2.1(c), has frequency 330 Hz, and has three loops and two nodes. The next two modes illustrate the continuing pattern: every time the frequency is increased by 110 Hz another resonance occurs, each new mode having one more loop and one more node than the last.

In fact, one effect of string stiffness is to spread the higher modes rather wider apart in frequency. However, to a first approximation the mode frequencies of a real string follow the relation predicted by the simple theory:

Frequency of nth mode = n times the fundamental frequency

The reader may recognise this as the relation which must obtain between the fundamental frequency and the frequency of any partial which may be added without altering the repetition rate of the resultant waveform (see section 1.3). This, in a nutshell, is the reason why strings are such useful sources of musical sounds. A string may be vibrating in several modes at once, but it will still make a musical sound because its natural frequencies are *harmonically related*.

2.5 The harmonic series

We have seen that successive string modes are equally spaced according to frequency. This means that the musical intervals between them become *smaller* as the mode number increases (see section 1.2). For example, the second mode is an octave higher than the fundamental, since it has double the frequency; but the interval between the second and third modes is only a perfect fifth, since their frequency ratio is 3:2.

The series of pitches corresponding to the frequencies of the successive modes is, in fact, well known to musicians as the *harmonic series*. Its first ten members are shown in Fig 2.2, for a fundamental frequency of 110 Hz. Where the mode frequency differs from that of the indicated note, the latter is given in brackets (calculated according to the tempered scale, in which the octave is divided into twelve equal semitones[2]). The pitch of the open A string has been chosen for convenience, but of course the same series applies, suitably transposed, to any other note on the guitar. The correspondence holds right down to the discrepancies between the mode pitches and their nearest notes in the tempered scale, expressed as fractions of a semitone.

Fig 2.2 Pitches corresponding to the first ten modes of the open A string

Mode number	1	2	3	4	5	6	7	8	9	10
Frequency (Hz)	110	220	330	440	550	660	770	880	990	1100
(Frequency of written note)			(329.6)		(554.4)	(659.3)	(784)		(987.8)	(1109)

No. of octaves above fundamental	0	1		2				3		

The first real discrepancy occurs for mode 5. According to the tempered scale, the pitch of this mode is about an eighth of a semitone flat, a small but quite noticeable difference. This is the reason why the fourth fret natural harmonic on the sixth string is apt to sound flat to G sharp on the first string, even though the two open strings have been tuned exactly two octaves apart. (See section 2.10 for an explanation of harmonics on the guitar.) It is also part of the reason why the third string, when carefully tuned to give a consonant G sharp in a chord of E major in the first position, sounds slightly flat when played open, as the fifth of a C major chord, the other reason being that a nylon third string is so sensitive to changes in tension that even the act of stopping it at the first fret may send it a little sharp.

The discrepancy for mode 7 is so great (about a third of a semitone) that the pitch of this mode cannot be said to have a place in our western musical system at all. It is also the first member of the series which makes a dissonant interval with the fundamental and with its immediate neighbours. From mode 7 upwards, all the modes are dissonant with their neighbours and many also with the fundamental. This is probably the reason for the harsh quality of a note rich in the higher partials, the hard "edge" being associated particularly with those partials which lie at least three octaves above the fundamental.

2.6 Excitation of the modes by plucking

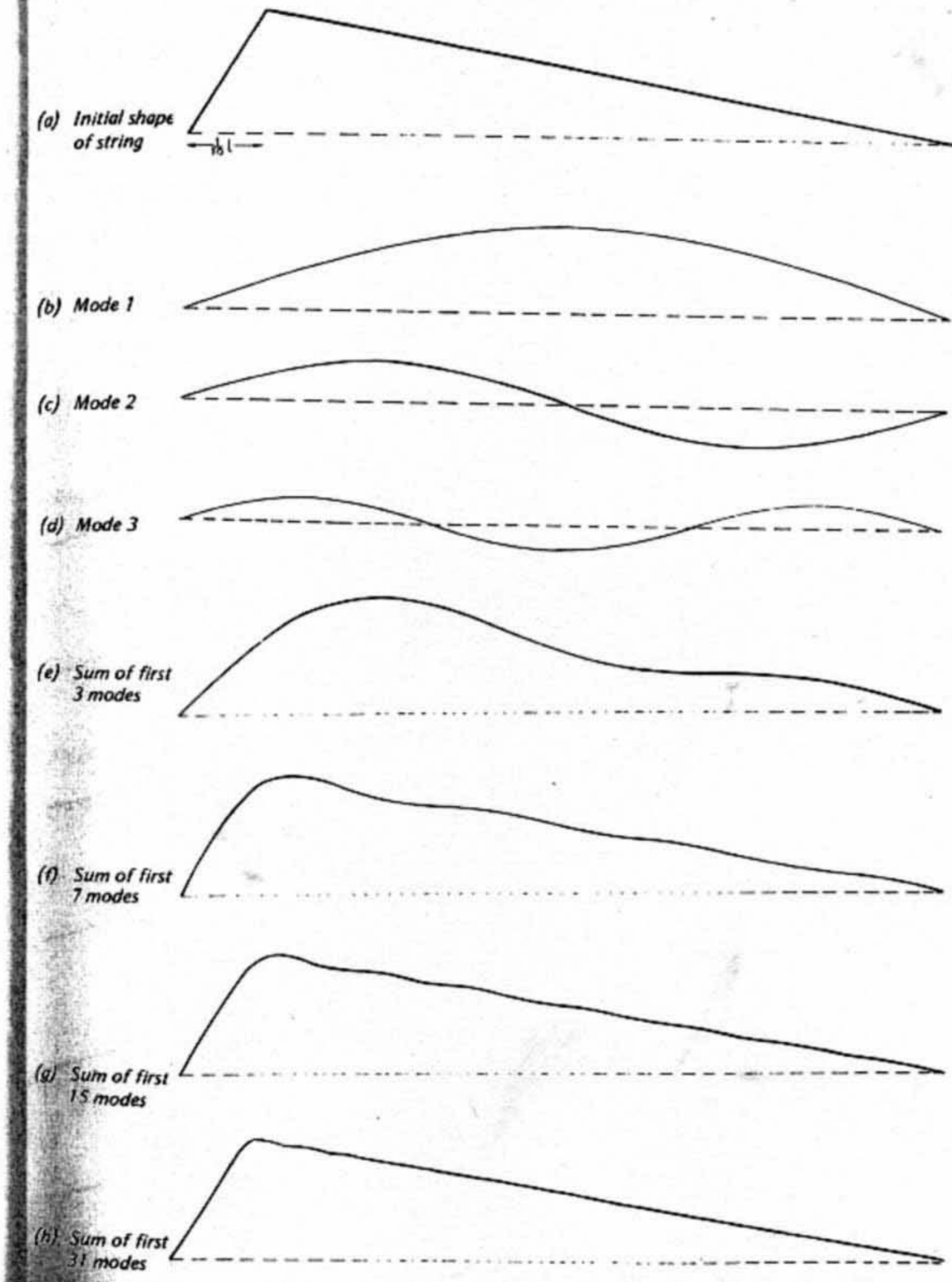
In Section 2.4 the response of a string to an alternating force of a single frequency was described. One may imagine a more elaborate experiment in which the applied force contained several components of different frequencies, each corresponding to one of the string modes. The string would vibrate in all these modes simultaneously, the strength of excitation of any one mode depending on the amplitude of the corresponding force component and on the position along the string where the force was applied. For example, if applied a quarter of the way along from either end, the force would give maximum excitation of mode 2 (which has a loop at that point) but zero excitation of mode 4 (which has a node there). Generally speaking, the lower modes would be favoured by a force applied in the middle section of the string, and the higher modes by a force applied near one end.

However, a more straightforward way of making a string vibrate in a number of different modes at once is simply to pluck it. The general remarks of the last paragraph are relevant in this case too, but here the simple model comes in especially useful in allowing an exact calculation of the amplitude of each mode, once the shape of the string before release is known. If the ideal string is drawn across at a point a certain fractional distance from one end (call this fraction p) and released, the result of the analysis is a neat formula[3] giving the amplitude of the nth mode in terms of p and n.

Without entering into the mathematics, it is quite easy to visualise how this *Fourier analysis* works. (We have already seen an example of the same principle, in the synthesis of a sawtooth wave.) The shape of the string before release is considered as being built of sine curves which represent the different string modes shown in Fig 2.1. In effect, the string is held ready to vibrate, and will indeed vibrate after release, in precisely the mixture of modes corresponding to the sine curves required to synthesise the initial shape.

An example of this synthesis is shown in Fig 2.3, for a string plucked one-tenth of the way along it ($p = \frac{1}{10}$). The shape to be built up is shown first, with the displacement much exaggerated for clarity. Next, the first three modes are shown, with their proper amplitudes. Curve (e) is the result of adding the displacements of these three modes: at this stage the triangular shape is just beginning to emerge, but there is obviously a long way to go before anything like the straight lines and sharp corner of the initial shape will appear. Adding also modes 4 to 7 (those which lie in the third octave above the fundamental) gives curve (f), which is clearly a great improvement. This is to be expected, since the plucking point lies at a loop for mode 5, and reasonably near one for modes 4, 6 and 7. However, the general trend is for the higher

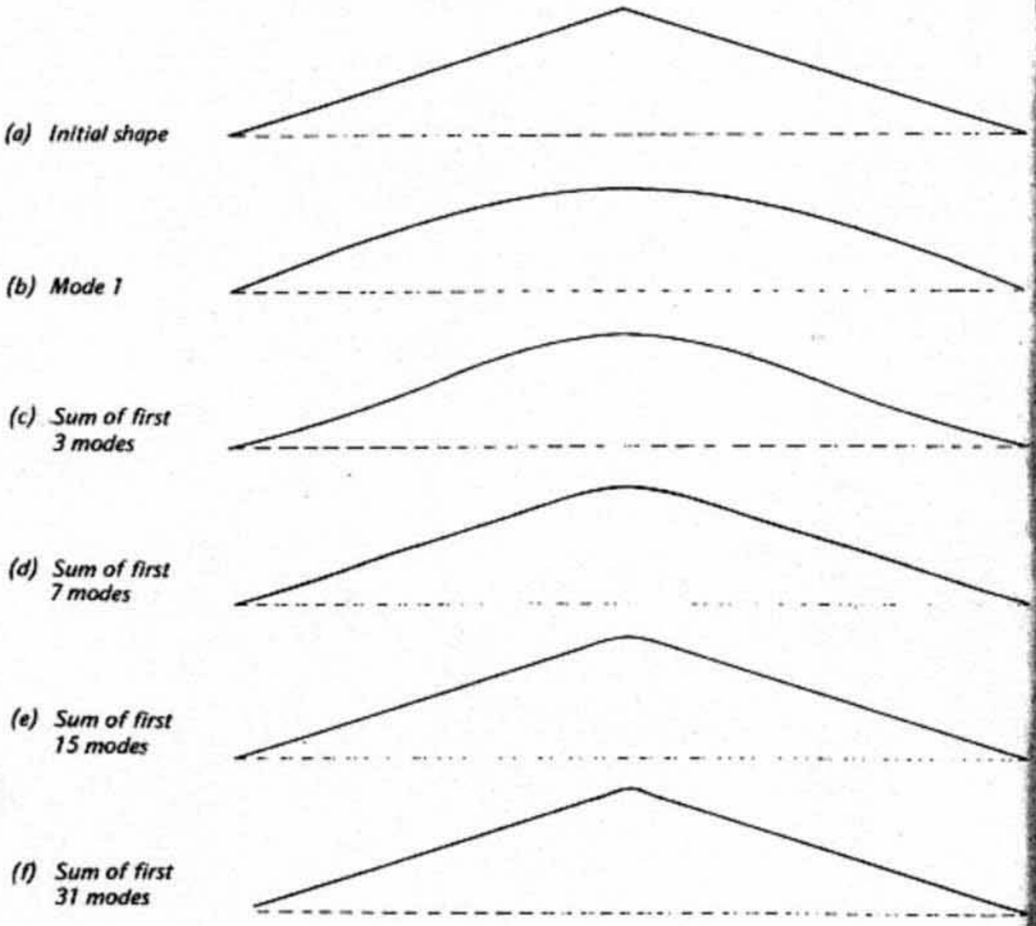
Fig 2.3 Synthesis of shape of ideal string before release, $p = \frac{1}{10}$



modes to contribute less and less to the curve. The next eight only sharpen it up to the extent of curve (g), while modes 16-31, which lie in the fifth octave, together make only the slight improvement shown as curve (h). Indeed, at this stage there is very little to be done to improve the fit. As in the synthesis of the sawtooth wave, an infinite number of modes of ever-decreasing amplitude would be required to give a perfect fit to the sharp point, but such a discontinuity could never actually occur. In fact, string stiffness tends to set a limit, somewhere between twenty and forty, to the number of effective modes of a guitar string, as we shall see in section 2.11.

A second example, this time for a string plucked at the centre ($p = \frac{1}{2}$), is shown in Fig 2.4. In this case all the even-numbered modes are missing, since they have a node at the plucking point. Of the remaining modes, all of which have a loop at the centre, the fundamental is by far the most significant, the highest modes being very weakly excited in comparison. The absence of the even-numbered modes gives the sound of a string plucked at its exact centre a peculiar hollow quality, often described as "harp-like", if only because harpists seem to regard the centre of the string as the normal plucking point.

Fig 2.4 Synthesis of shape of ideal string before release, $p = \frac{1}{2}$



2.7 Energy distribution among the modes

When a string is plucked, energy is put into it. Plucking in different places along the string has the effect of varying the distribution of energy among the modes. For example, one may direct energy preferentially into the second mode by plucking a quarter of the way along the string, or into the tenth mode by plucking one-twentieth of the way along. The general trend of this energy distribution is shown in a striking, if rather unusual way, in Fig 2.5. For each value of p (the fractional distance along the string of the plucking point), I have calculated the relative energies put into all the modes up to the thirty-first, and lumped them together in octaves. Thus, the first octave contains only the fundamental, the second contains modes 2 and 3, the third modes 4-7, the fourth modes 8-15 and the fifth modes 16-31. In this way the energy distribution over the full *musical* range above the fundamental may be seen, and it is also possible to compare this diagram with Figs 2.3 and 2.4, where the same grouping of modes was used.

Fig 2.5 Energy distribution over first 5 octaves for ideal string plucked at different points

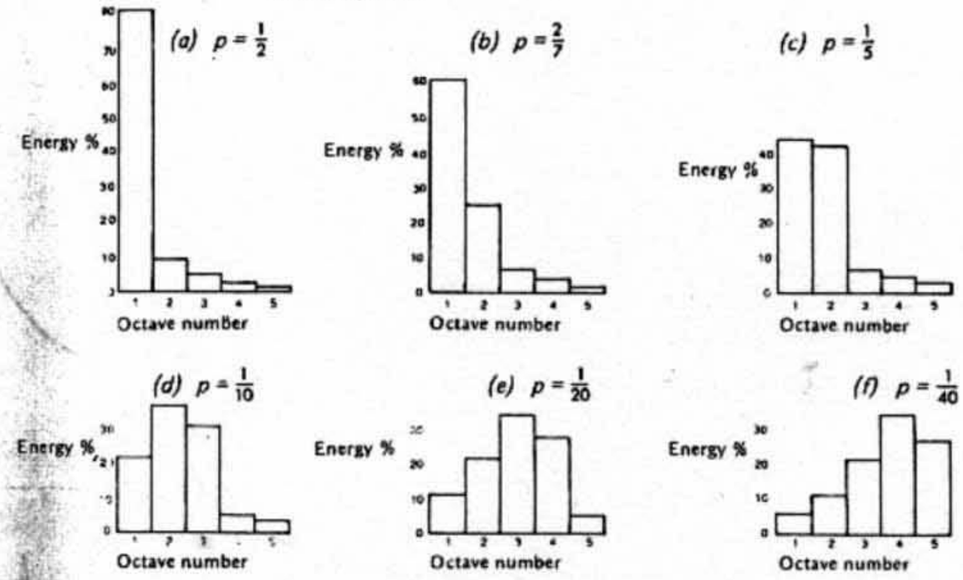
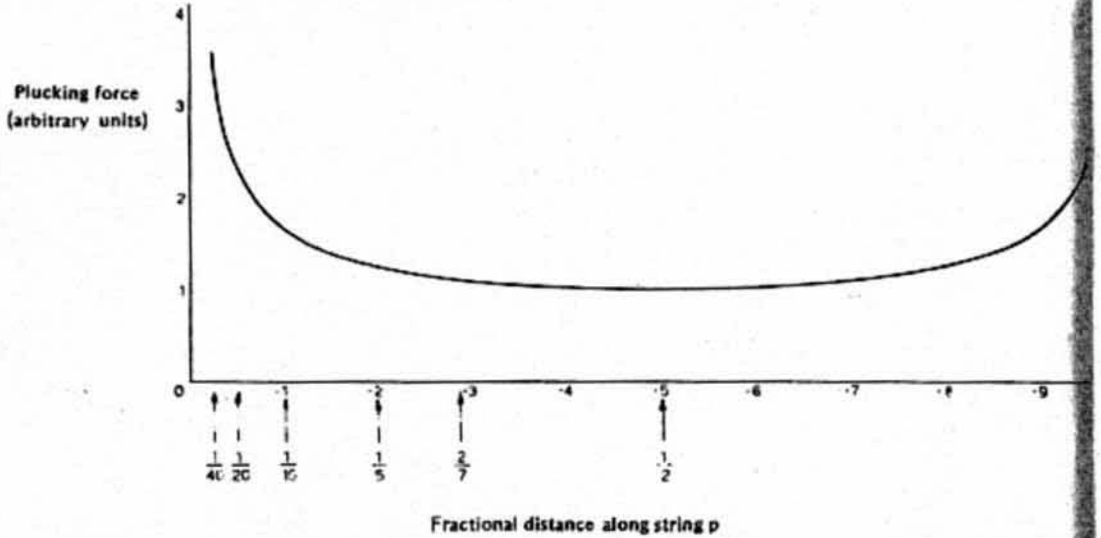


Fig 2.5 shows that if the string is plucked at the centre ($p = \frac{1}{2}$) nearly all the energy is put into the fundamental, with less than 20% left over for all the other modes put together. Plucking an open string over the soundhole ($p = \frac{2}{7}$) moves some energy into the second mode, but the modes in the three highest octaves are still relatively feebly excited. In the "normal" playing position (which I take to be around $p = \frac{1}{5}$), the second and third modes together take nearly as much energy as the fundamental, but still there is little energy left over for the higher modes. Moving towards the bridge ($p = \frac{1}{10}$) has the effect of taking energy away from the fundamental and putting it into the modes in the third octave; but the modes in the fourth octave are little favoured, on the whole, because those around mode 10 have a node near the plucking point and, of course, mode 10 itself is missing completely. However, these same modes are emphasised if the plucking point is near the bridge ($p = \frac{1}{20}$), while the highest modes are favoured if one plucks as near the end of the string as practicable ($p = \frac{1}{40}$).

Some caution is required in interpreting these diagrams. In the first place, they tell us only how much energy is put *into* the various modes, whereas only the energy which subsequently gets *out* can possibly be radiated as sound. Our ideal string suffers from a rather serious defect in this respect: once plucked, it would go on vibrating in the same way indefinitely, being subject to no energy losses of any kind, and would never make any sound! A real string loses energy by damping and, via the guitar body, as sound. What we hear therefore depends critically on the response of the guitar body, which can vary considerably from one note to another and indeed between different paritals of the same note[4].

Secondly, the diagrams of Fig 2.5(a) to (f) can only be compared with each other if it is assumed that the same energy is imparted to the string in each case. To do this, one has to pluck with rather more force near an end of the string than near the middle, as Fig 2.6 shows. The rapid increase in the necessarv force at the extreme ends is one reason why it is not practicable to play too near the bridge. Over tne normal range of plucking points, from $p = \frac{1}{20}$ to $p = \frac{1}{2}$ say, the guitarist learns to vary his force and knows that he *can* use more when playing near the bridge (where the string feels "tight") than he can near the soundhole, without fear of overplaying.

Fig 2.6 *Variation of plucking force required to put the same energy into string at different points*



With these reservations in mind, we can still pick up some useful points from the energy-distribution diagrams. They show why plucking a string near the bridge ($p = \frac{1}{2}$) can give a brilliant and hard sound – brilliant because the partials in the third and fourth octaves above the fundamental are favoured, and hard because many of these partials are dissonant with the fundamental. It may be instructive to note that if the open sixth string is plucked at this point, the favoured modes lie in the frequency range of the highest notes on the guitar fingerboard; and if it is the open first string which is played there, the favoured modes lie two octaves higher still, in the frequency range to which the ear is most sensitive.

We can also, with due caution, draw some general conclusions about the *loudness* to be expected when a string is plucked at different points, using some of the ideas developed in section 1.4. There, loudness was discussed in terms of *power* (a measure of the rate of energy *transfer*) whereas here we can only be sure of the initial *energy* in each mode. Nevertheless, we can see, for instance, that the diagram for the string plucked at the centre, with its high peak for the fundamental, does not necessarily indicate a louder sound than do the other diagrams, with their lower peaks. At $p = \frac{1}{2}$ the fundamental takes about nine times as much energy as mode 3, but it will not therefore have nine times the loudness; it is more likely to sound only about twice as loud. An even distribution of energy among the modes will give a louder sound than concentrating most of the energy into one, other things being equal. In practice there is the instrument's response to consider, as well as the greater plucking force required near the bridge; but it is true that the loudest and most declamatory guitar sounds are generally made by playing the strings well to the bridge side of the soundhole.

Finally, we may note one implication of the fact that the energy distribution depends on the *fractional* distance along the string of the plucking point. Guitarists sometimes play a melodic phrase along a single string in order to avoid sudden changes of timbre. But moving from one fret to another with the left hand without also adjusting the position of the right has the effect of changing the fraction p, and hence also the energy distribution among the modes and the resulting tone colour. In most situations it is neither feasible nor desirable to be constantly adjusting the right hand position, but where a really even sound is required it is a good idea to move the two hands up and down the string in tandem. The reader may verify that if the right hand always moves in the same direction as the left, but only p times the distance, then the value of p remains about the same.

2.8 Methods of suppressing the higher modes

We have now come to the end of a fairly lengthy discussion of the effect of plucking a string at different points. However, this is by no means the end of the story as regards tone control. The sound of a note depends not only on *where*, but also on *how* the string is played. Up to now it has been assumed that our ideal string was drawn aside at a single point and released instantaneously. This would be roughly equivalent to using a hard, pointed plectrum which, of course, would tend to make a hard, pointed sound. There are two basic ways of making a smoother sound, both of which have the effect of reducing the excitation of the higher modes.

(a) *Use of a rounded plucking object*

Looking back to the diagrams showing the synthesis of the initial shape of the string for two different plucking points (Figs 2.3 and 2.4), one can see that in each case the effect of the modes in the higher octaves is mainly to give a better fit to the sharp corner at the plucking point. It follows that if the string were drawn aside by a rounded object instead, the higher modes would be less strongly excited.

This fact is mentioned in most of the general books on musical acoustics[5], and there is certainly something in it. However its significance for the classical guitarist has perhaps been overestimated, as the following rough calculation shows. Suppose that, instead of plucking with a narrow plectrum, a fingertip all of 2 cm (nearly an inch!) wide is used. This may be expected to suppress any mode having a node within a 2 cm length of the string. For a string 65 cm long, this means that all the modes above about the thirty-second should be missing – but string stiffness already sets an upper limit of about this number! Another way of looking at this is to note the contour of a string drawn aside with a pointed object. Any nylon string is far too stiff to form a sharp corner around the object, and one can see that it would make little difference to the string's contour to draw it aside with a fleshy fingertip instead. Clearly, the difference in the string's initial shape is much too small to account for the radical difference in sound which these two objects produce.

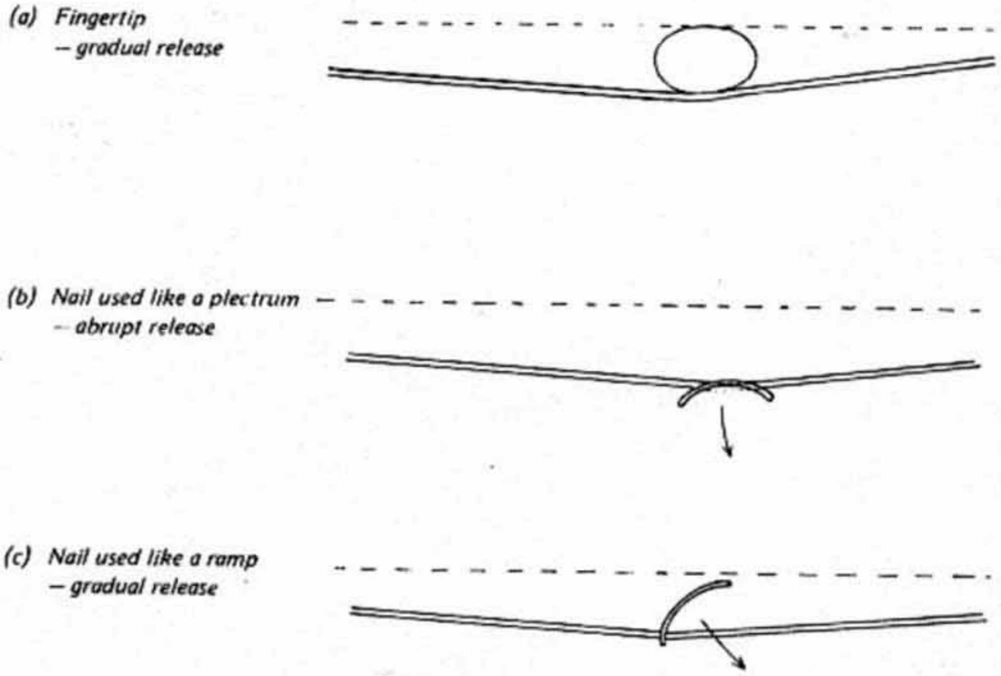
(b) *Gradual release of the string*

The vital factor which we have not yet considered is the *manner* in which the string is released. Let us do so now, returning first to the simple model. Before release, the string is held in place by a force applied at the plucking point. When this force is suddenly removed, at the instant of release, an unbalanced force due to the string tension acts at that point. As a result, the string is immediately jerked into motion at the plucking point, and subsequently at every other point between its fixed ends.

If the sharp point of the string before release is a discontinuity in *space*, then it may be said that the sudden jerking of this point into motion is a discontinuity in *time*. The two go hand in hand, and the higher modes may be considered as being excited by either kind of discontinuity. Conversely, these modes may be suppressed by smoothing out either the discontinuity in space, by rounding off the sharp corner, or that in time, by releasing the string gradually rather than instantaneously. We have seen that a guitarist's scope for smoothing out the string's initial contour is limited by the small width of a fingertip compared with the length of a string. On the other hand, there is no such practical limit to the time a fingertip or nail may take over releasing the string.

Some examples may help to clarify this idea of gradual release. Suppose that a soft fingertip draws the string aside to the extent of its own depth, as shown in Fig 2.7(a). If the string now begins to slip over the fingertip, it still has the full distance of its displacement over which to accelerate before leaving the fingertip. This is as gradual a release as one would ever want, being spread over most of the first half-cycle of the string's motion. Any more than this, and the fingertip would begin to smother the vibration. Indeed, the higher modes will already be heavily suppressed and this is probably the reason why it can be difficult to make a clear or brilliant sound using the flesh only. If, on the other hand, the tip of a nail is used straight across the line of the string, as in Fig 2.7(b), the string's "ride" over it may be of negligible length, compared with its displacement, and the release is virtually instantaneous. However, the same nail turned through an angle, Fig 2.7(c), gives the string a longer ride and it may be possible to vary the sound considerably by varying this angle. Much depends, though, on the shape and condition of the nail, which must at all events give the string a *smooth* ride in order to avoid harshness of sound. In general *any* abruptness in the initial motion of the string will tend to excite the higher modes and give a hard edge to the sound[6].

Fig 2.7 "Gradual" and "abrupt" release of string



(a) Fingertip – gradual release

(b) Nail used like a plectrum – abrupt release

(c) Nail used like a ramp – gradual release

It is important to understand that what we are calling a "gradual" release (spread over the time of nearly half a cycle) is still very quick by any normal standards. For example, half a cycle of the open B (247 Hz) takes about two milliseconds. The scope for controlling the motion of a string once it has begun to slip over the fingertip or nail is, therefore, virtually nil. What *can* be done, however – and this is surely the secret of tone control – is to lay out the string's path in advance, by presenting it with an obstacle of a certain size, shape and texture. More details of how this may be done will emerge in later chapters. For the present, we may note that a well-shaped nail is more versatile than any fingertip in laying out a string's path. It can be used straight on, like a plectrum, releasing the string quickly, or at an angle, like a *ramp*, letting the string ride smoothly over it. Viewed as a ramp, the nail has also another vitally important function, as we shall see in Chapter 4.

2.9 Motion of a string after release

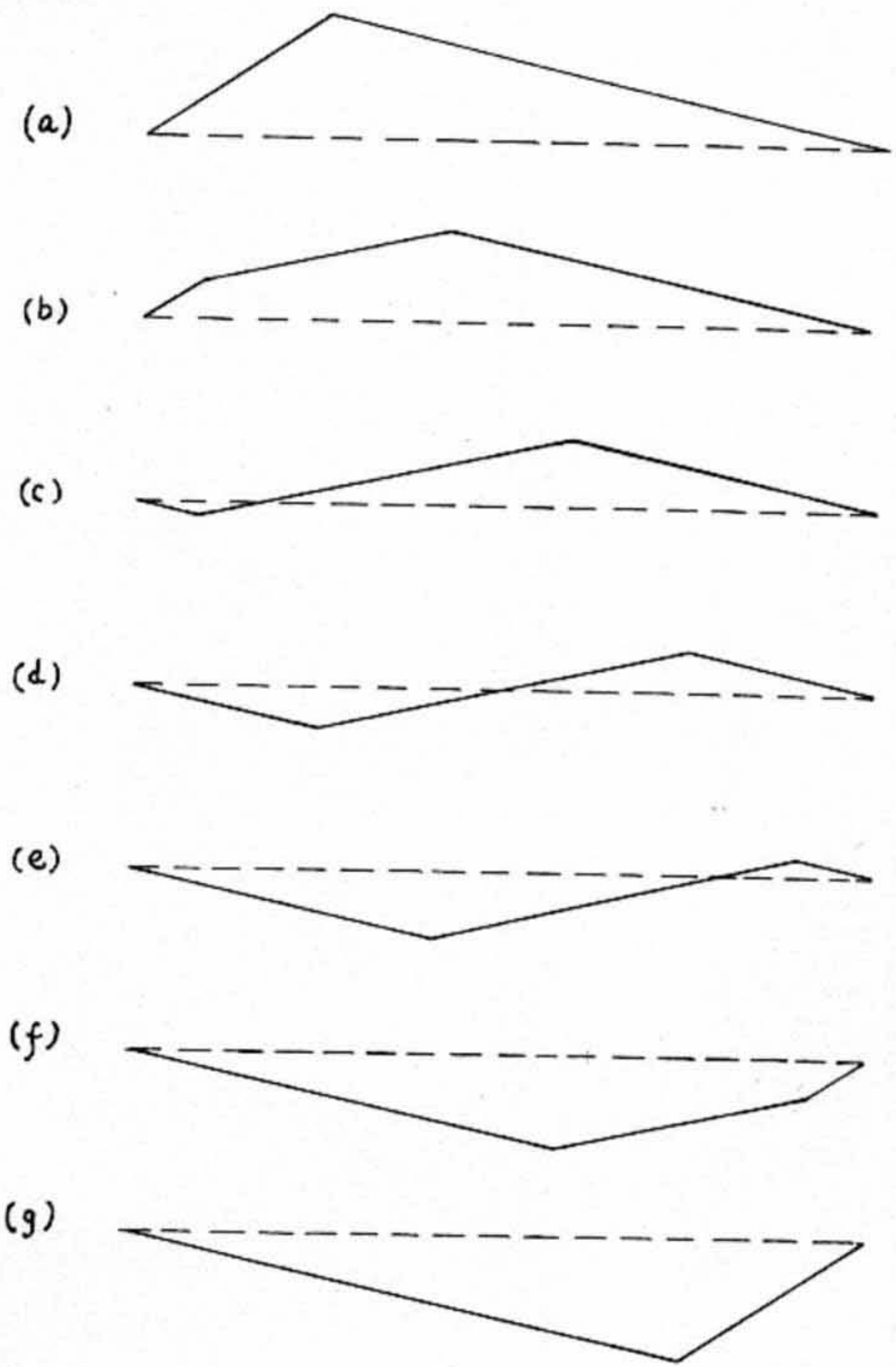
Before leaving behind our simple model, we can extract one more useful idea from it. After release, the ideal string vibrates in a perfectly predictable and regular way. This motion is shown in Fig 2.8, as a series of "snapshots" spaced at equal intervals of one-twelfth of a cycle. Thus, the string reaches condition (g) half a cycle after release from condition (a). During the second half of the cycle the string retraces these steps back to (a), and so on, *ad infinitum*. Few guitarists seem to be aware that a plucked string vibrates in this anti-symmetrical way, the displacement moving back and forth *diagonally*[7]. This fact has some very important implications, which will be discussed in Chapter 4.

Although the initial motion of a *real* string will be similar to that shown in Fig 2.8 (without the sharp points, of course), the string will never return precisely to its initial condition, because it begins to lose energy immediately. This it does in three main ways.

(a) *Interaction with the soundboard*

The ideal string, being fixed rigidly at each end, is unable to pass on any of its vibrational energy. The rigid supports act as perfect reflectors of any wave approaching them along the string and thus sustain the vibration indefinitely without themselves moving at all. To a first approximation the nut (or fret) and saddle of a guitar act as similar barriers – if they did not, the string's vibration would never get under way. However, the soundboard (also called the table or top), reinforced though it is with struts and bridge, has some flexibility. It yields slightly to the periodic force which the vibrating string exerts via the bridge, and in this way energy is gradually passed from the string to the soundboard, which in turn radiates some of the energy as sound waves. Heavier strings excite the soundboard more strongly than light ones, but

Fig 2.8 Motion of ideal string after release



therefore tend to give up their energy more quickly.

If all this seems simple enough in principle, the details of the interaction between string and soundboard can, in fact, be very complicated. No attempt will be made to account for them all, since they are more the luthier's than the player's problem. However, the fact that a guitarist may control the proportion of the string's energy passed on to the soundboard, rather than being dissipated in other ways, is of such direct concern that it forms the basis of the next chapter and is one of the main ideas of this book.

(b) *Internal damping*

The periodic distortions of the string during vibration give rise to internal friction. The extent to which energy is dissipated in this way depends on the string material. In solid metal strings the effect is generally negligible, but in nylon strings it may be the prime damping mechanism. The rate at which energy is lost internally increases with frequency, with the result that in materials with large internal damping the higher modes decay much faster than the lower. The very rapid decay of the highest modes accounts for the mellow sound of nylon compared with steel strings, and for the dull and lifeless sound of wound bass strings which are due for a change, or at least for a wash. (Presumably it is the moisture and grease from the hands, continually absorbed between the windings and into the nylon-fibred core, which gradually increases the internal damping of a bass string.) For the same reason, careful listening to a note played very close to the bridge on one of the nylon treble strings reveals that the really spiky, metallic quality is present only at the very beginning: after a fraction of a second, much of the brilliance has gone.

(c) *Air damping*

The third important way in which a vibrating string loses energy is in overcoming air resistance. The rate of energy loss again increases with frequency, but not so fast as in the case of internal damping. It is also greater for thin, light strings than for thick and heavy ones. This may be one reason why the same note will last longer on one string than on another. For example, E (330 Hz) may easily last three times as long when played as a harmonic on the fifth or sixth string as it does on the open first string, which is thinner and lighter than either. However, internal damping plays a part here, and is generally more important than air damping in nylon strings.

Of the three energy-loss processes described, only the interaction with the soundboard leads to the radiation of sound. It might be thought, then, that the other two are merely a waste of energy; but if this were the case, there would be no point in using nylon rather than steel strings. The internal damping of nylon is *selective*, causing the higher modes to decay progressively faster. This selective damping is an essential feature of the classical guitar sound. In the next section we shall see that a guitarist may introduce further selective damping of his own.

2.10 Two techniques of selective damping

(a) *Pizzicato*

If the right hand is placed with the side of the palm in contact with the strings near the bridge, the soft flesh absorbs a little of the string's energy during each cycle of its vibration. This increases the damping of all the modes, but the higher ones, which have a loop near the bridge, are particularly strongly suppressed. The result is a muffled, "woolly" sound, with a certain "punch" due to the short duration of each note.

The damping may be heavy or light, and applied directly over the saddle or a little distance along the string. (Pujol[8] lists four different kinds of pizzicato, including the rather comical *pizzicato estridente*, in which the string is made to buzz on the flesh by damping very lightly, well away from the bridge.) Alternatively, the string may be damped at its other end, by placing the left hand finger directly over the fret instead of behind it. Sor[9] recommended this method, but it requires very accurate placing and offers little variety of sound. It can be useful when the right hand is too busy to change to the pizzicato position, but in such cases it can be just as effective to "fake" a pizzicato by playing with the flesh of the thumb (to suppress the higher modes) and then quickly replacing the thumb on the string (to stop the note short).

The pitch of a note seems to become less clearly defined as the damping is increased, and generally the pizzicato is a good example of the control a guitarist has over *clarity* of sound. Although this word no doubt means different things to different people, clarity probably has as much to do with brightness and with a clean attack as with a well-defined pitch. On all these counts, the pizzicato sound lacks clarity. Conversely, when a clear sound is required, these three qualities may be emphasised in a variety of ways. Crystal clarity is difficult to achieve and therefore highly prized, but it is not *always* desirable. The principle of variation applies to this as to other aspects of sound quality, and by varying the clarity of sound a guitarist can bring light and shade to the music he plays.

(b) *Harmonics*

We have seen that damping with the flesh very close to one end of a string absorbs the vibrational energy only gradually, since the amplitude of the vibration is very small there. A finger placed elsewhere on a string will generally stop the vibration dead. However, there are certain points on a string where light damping with the tip of a finger produces not silence, but a new note of higher pitch. These points are found at simple fractions of the string length.

Suppose the vibrating string is touched exactly at its centre. All the odd-numbered modes, including the fundamental, are quickly damped out, since they have a loop (i.e. a point of maximum amplitude) at the centre. However, the even-numbered modes, all of which have a node (i.e. a stationary point) at the centre, continue more or less unaffected. If the fundamental frequency was f_1, then the modes which remain have frequencies 2, 4, 6, 8 etc. times f_1, or, to put it in another way, 1, 2, 3, 4 etc. times $2f_1$. What is heard, therefore, is a new note with a fundamental frequency of $2f_1$ – an octave higher than the original pitch.

Similarly, touching the string exactly one-third of the way along (from either end) damps out all the modes except the third, sixth, ninth, etc. The resulting note has a frequency of $3f_1$, an octave and a fifth higher than the original. Touching exactly one-quarter of the way along gives a new fundamental of frequency $4f_1$, two octaves higher – and so on.

Of course, the normal technique of playing a *harmonic* is to be already touching the string at the time of plucking it. The touching finger damps out the unwanted modes immediately, and no further purpose is served by keeping it in contact with the string after the harmonic has sounded. Indeed, if left on the string, the finger begins to damp out the harmonic itself, since it is impossible to touch the string without applying a little pressure, and any pressure, even applied at the exact nodal point, will interfere with the free vibration of the string. To obtain a clear harmonic, then, the finger must lightly touch the string, not smother it, and must leave it directly after the string is plucked.

So-called *natural harmonics* are played on open strings, using a finger of the left hand to touch the string while a right hand finger plucks it. In this case, the centre of the string is directly over the twelfth fret; the seventh and nineteenth frets are each very nearly one-third of the way along the string from either end; and the fifth fret is one-quarter of the way along. These are the only frets which lie at exact fractional distances between nut and saddle. The "fourth fret" harmonic is, in fact, obtained by touching the string about 4 mm (rather more than $\frac{1}{8}$") to the nut side of the fourth fret, since this is one-fifth of the way along the string. The same harmonic is available at the two-fifths point, about 4 mm below the ninth fret, and at the three-fifths point, just below the sixteenth fret. The pitches of the natural harmonics are, of course, the same as those of the corresponding string modes, which were shown in Fig 2.2 for the fifth string.

The loudness of a harmonic depends on the plucking point chosen. It is no use touching the string at one node while plucking at another, but this is just what happens, for example, when an attempt is made to sound a seventh fret harmonic by plucking over the nineteenth fret. To obtain a strong harmonic in this case, one would have to pluck not more than one-sixth of the way along from the bridge. The plucking point for a fifth fret harmonic needs to be still nearer the bridge, at a fractional distance not exceeding one-eighth (about 3" from the bridge). Generally speaking, the higher the harmonic, the nearer the plucking point must be to the bridge in order to produce a strong and clear sound. This is why so-called *artificial harmonics*, played on stopped strings using the right hand both to touch the string (with the index finger) and to pluck it (with the third finger or perhaps the thumb), tend to sound weak. The tip of the index finger has to be at the string's centre, twelve frets higher than the fret at which it is stopped, and so the plucking point cannot be near the bridge.

The effect which plucking at different points has on the quality of a harmonic may be illustrated by returning to the example of the twelfth fret natural harmonic. The lowest string mode present in this case is the second, which is favoured by plucking at $p = \frac{1}{4}$ (see section 2.6); however, the next two modes, the fourth and the sixth, are best excited by plucking at $p = \frac{1}{8}$ and $p = \frac{1}{12}$, respectively. Plucking this harmonic at $p = \frac{1}{4}$ would, in fact, give the same sort of quality as plucking an open string at the centre. To give the harmonic as much "bite" as an open string played in the normal position, a plucking point considerably nearer the bridge, at about $p = \frac{1}{10}$, would have to be chosen.

Much the same may be said of the plucking *action* appropriate for a harmonic. The higher the harmonic, the less point there is in releasing the string gradually, since this tends to suppress the higher modes (see section 2.8). Thus, to obtain a bright sound with a fifth fret harmonic, which contains only modes 4, 8, 12, 16, 20 etc., the nail must be used more like a plectrum than like a ramp, and must move quickly through the string.

2.11 The effect of string stiffness

It has already been mentioned that the stiffness of a string prevents it from being bent at a sharp angle and so limits the number of modes in which the string may be persuaded to vibrate. The reader may now like to carry out the following rough check to find the highest mode audible on each string.

The method is to play harmonics, touching the string not with a fleshy fingertip, but with an object which is much narrower without being too hard (I use the edge of a plastic eraser), and plucking near the bridge with a pointed plectrum or with the corner of a fingernail. In this way, harmonics much higher than those normally used in music can be produced quite clearly. As the damping object is brought closer to the end of the string (the bridge end being convenient in this case), the harmonics become higher, more numerous and fainter. Eventually there comes a point where no further harmonics can be produced, and only noise is heard. If the damper is now moved back to the point where a definite musical sound is just audible, this point may be taken as the first node of the highest effective mode. Calculating the number of this mode is a simple matter of dividing the string length by the distance between the node and the bridge saddle.

The clear nylon treble strings on my guitar all seem to give a highest audible mode in the low twenties (25 for the first, 22 for the third). The number seems to be higher for the metal-wound bass strings, varying from about 31 on the fourth to 39 on the sixth. I do not claim any accuracy for these figures, which are only intended as a rough guide. The highest harmonics on the treble strings are particularly hard to distinguish from the noise of plucking, since their frequencies are so high (up to about 8,000 Hz on the first string) and their decay so rapid. Nevertheless, we now have some idea of the length of the *smallest segments* in which each string will vibrate. On the first string, for instance, the smallest segment is about an inch long, which means that there is nothing to be gained, by way of musical sound, by plucking this string any closer to the bridge than about half an inch away.

The smallest segment cannot be expected to get any shorter if the string is stopped at a fret instead of being played open. It follows that the number of effective modes on a given string diminishes, the higher the fret at which it is stopped. Thus, if a note played on the open third string has 22 audible partials, only 11 will be audible when the string is stopped at the twelfth fret. This goes some way towards explaining why the same note has a different quality when played on different strings. For example, E (330 Hz), played on the open first string, may contain 25 partials, but the same note played on the third string (at the ninth fret) is likely to contain only half as many, so giving a darker and thicker quality. On the other hand, this same note played on the fourth string (at the fourteenth fret) will have only about the same number of partials as on the third, and yet the sound is stronger and brighter, especially if the string is new. When the energy-loss processes discussed in section 2.9 are taken into account, however, this little paradox disappears. A new fourth string is not subject to the strong internal damping which suppresses the higher modes of a nylon third, and being also heavier, it feeds the soundboard more strongly.

There are several other factors which affect the sound of a note played on different strings. For example, in moving up the fingerboard with the left hand, one tends not to adjust the position of the right in proportion, and therefore the plucking point moves closer to the centre of the string. Also, the higher the fret, the easier vibrato becomes; and the third string, for example, is overall more sensitive to vibrato than either the first or the fourth, because of its much lower tension.

All these factors, and others to do with the instrument's response, which we shall consider in the next chapter, combine to give every note on the guitar its own special flavour and range of possibilities. The more closely one listens, the more diversity there seems to be, not only between one note and another, but even within the life of a single note. A guitarist who is sensitive to this diversity, and who knows how to use colour as an integral part of an interpretation, can make even the simplest piece of music into a captivating experience. However, such magic cannot be conjured out of thin air; it requires a sound basis of technical control, and this is where a knowledge of the underlying principles can prove such a valuable tool.

CHAPTER 3 STRING AND SOUNDBOARD

3.1 The guitar body as an amplifier

In the last chapter we saw that many of the methods of producing different sounds on the guitar may be understood by considering a string in isolation. However, a string by itself can radiate sound only very feebly. I have played on a "guitar" designed to demonstrate this point: it had a fingerboard, nut, bridge, and machine-heads – everything, in fact, except a body, the whole being mounted instead on a solid block of wood. The sound of this "bodiless" guitar was extremely weak and thin, with no audible bass response whatever.

There are two reasons why a string is such a poor sound radiator. Firstly, it has a relatively small surface area, and therefore cannot produce a large disturbance of the air. Secondly, any compression wave coming from one side of the string is effectively cancelled by a wave of rarefaction from the other, since the string's diameter is very small compared with the wavelength, especially at the lower frequencies. (The wavelength is the distance the sound wave travels through the air during one cycle. Since the velocity of sound in air at room temperature is 344 metres per second, the wavelength at 82.4 Hz, the frequency of bottom E, is 4.17 metres; at 988 Hz, the frequency of top B, it is 34.8 centimetres.) On both counts, a larger vibrator is needed to radiate the sound more efficiently.

This is the function of the guitar body, which acts as an acoustic amplifier. Up to a point it would be desirable, as it is in the case of an audio amplifier or loudspeaker, for the body to give a "flat" (equal) response over the whole frequency range of the guitar (say 70-10,000 Hz). However, as we shall see presently, this ideal cannot even be approached in practice. Every guitar has a more or less sharply-varying frequency response, sometimes called its *formant* characteristic, and so colours the sound in its own way. The luthier's art (for guitar-making still owes but a small debt to science) consists of using his materials to create the particular kind of sound he has in mind.

In the following sections we shall try to gain a general idea of how the guitar body functions as an amplifier, picking up the string's vibrations and radiating them as sound. It will not be necessary to enter here into the same detail as we did in the case of the vibrating string, since we are not primarily concerned with the qualities of individual guitars. Our main interest is in how the player can best draw the sound from the instrument, and a brief general discussion will suffice to give an answer which applies to any guitar of conventional design.

3.2 The role of the soundboard

The various parts of the guitar body all contribute to the sound in different ways, but they are by no means all equally important. The reader may verify this quite simply, as follows:

Experiment 1 Strum across the open strings (to give a rich mixture of partials over a wide frequency range) and use the palms of the hands to try to smother the vibrations of (a) the sides, (b) the back, and (c) the top.

In case (a), very little vibration is felt and virtually nothing can be done to damp the sound. The back, case (b), feels more active, but the hands still have very little effect on the sound. In case (c), however, the damping effect is quite drastic, especially if the hands are placed over the area around the bridge. (There, rather an amusing "wah-wah" sound can be made by alternately lifting and replacing the hands.)

The overwhelming importance of the top is hardly surprising, since the strings are connected almost directly to it. If the top is able to respond to the strings' vibrations, then it can in turn feed the rest of the body, as well as radiating sound directly. If not, the sound cannot get out: it falls, as it were, at the first fence. For this reason I have chosen to refer to the top as the "soundboard", which gives an idea of its vital role in converting the strings' vibrations into sound. However, a second experiment may serve to dismiss any impression the first may have given that the soundboard is the *only* important vibrator in the guitar body.

Experiment 2 Place the guitar flat on its back and cover up the soundhole with some flat object which will not rattle or interfere with the strings' vibrations (I use a soft leather disc). Play single notes over the whole range of the guitar, noting the difference in sound caused by covering the soundhole. It is found that the treble response is not seriously affected, but all the bass notes (below about the open D on my guitar) suffer a very marked loss of "body". Overall, the sound is relatively weak and nasal.

Covering the soundhole has two effects. One is to cut off the sound reflected from the inside walls, especially the back; the other is to cancel the effect of a sound source second only in importance to the soundboard itself. This is the mass of air enclosed by the body, and it oscillates with a sort of pumping motion, air being alternately pushed out and sucked in through the soundhole. Of course, only a small quantity of air is normally displaced in this way, but in the frequency region of the ***main air resonance***, the air vibrations may actually be felt (if the guitar has a good bass response) by placing the hand above the soundhole. This resonance peak usually occurs around 100 Hz (near the low G on the sixth string), but this frequency varies according to the volume of the box, the elasticity of its walls, and the size of the soundhole[1]. The main air resonance gives a certain "boom" to the notes in its immediate vicinity, and generally boosts the bass response.

In this low-frequency region, then, most of the sound comes not from the soundboard itself, but from the air in the box. Nevertheless, it is still the soundboard's response which feeds the air mode in the first place. Here, as virtually throughout the instrument's range, the soundboard acts as the indispensable first link in conveying the strings' vibrations to the ear of the listener. This being the case, we may well ask whether there is any special way of making a string vibrate so as to drive the soundboard most efficiently. Before tackling this question, however, we shall need to know something about the ways in which the soundboard itself can vibrate.

3.3 Modes of vibration of the soundboard

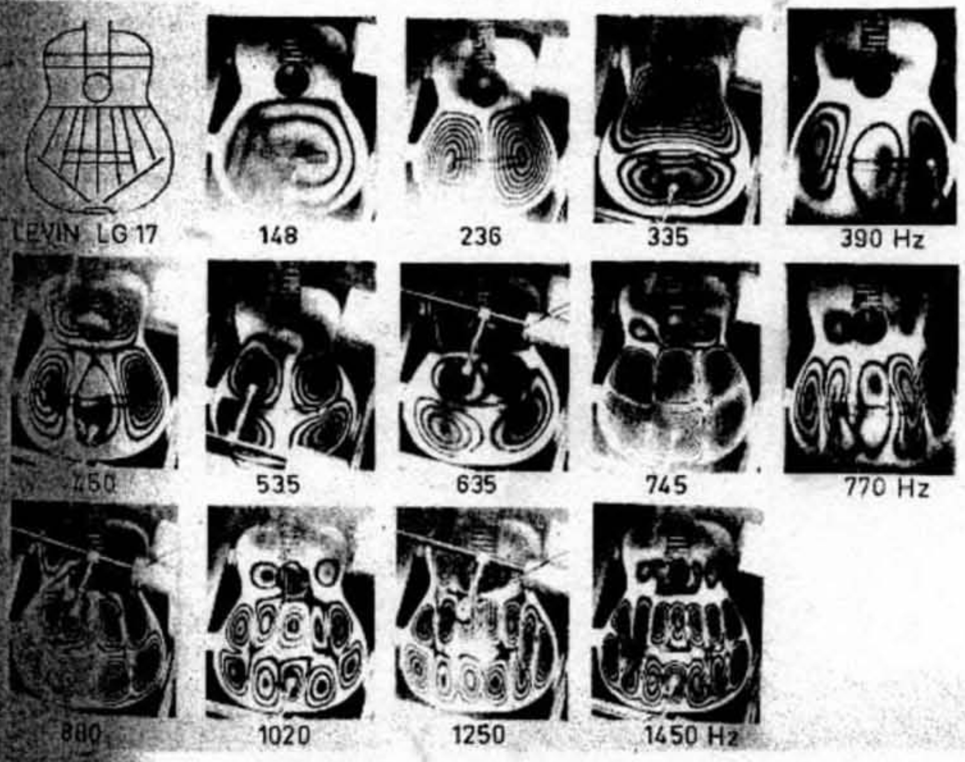
The soundboard is essentially a plate of wood, so light and thin (sometimes down to about 2 mm in thickness) that it could not possibly withstand the pull of the strings, were it not for the support of a number of wooden braces (or struts) glued to its underside, and of the bridge, glued to the top. The most active part of the soundboard is the wider portion, with the bridge roughly at its centre. A major problem of guitar construction is that of bracing the plate in such a way as to give it the necessary support while still allowing this portion around the bridge to vibrate freely.

From an acoustical point of view, the plate, struts and bridge together make a single vibrator. Now we have already seen, in sections 2.2 and 2.4, that a stretched string (essentially a one-dimensional vibrator) has a number of resonant frequencies which depend on the length, mass and tension of the string. Similarly, a plate has resonant frequencies which depend on its size and shape (in two dimensions), its mass and its stiffness. The struts and bridge add both mass and stiffness to the parts of the plate to which they are attached, and this is why adjustments to the bracing can cause such marked changes in the soundboard's response.

As in the case of a string, each resonant frequency of a soundboard corresponds to a definite vibrational shape or mode. Fig 3.1 shows the first thirteen modes of a certain guitar soundboard whose bracing pattern is also shown. These photographs were taken by Dr. Ian Firth of St. Andrews University, using the recently-developed laser technique of time average interference holography[2]. In each case the soundboard has been forced to vibrate at a single mode frequency, and the light and dark fringes may be thought of as contour lines showing the displacements of the soundboard in that mode. (The displacement from one dark fringe to the next is of the order of ten millionths of an inch, which gives some idea of the sensitivity of this technique.) Mode 1 has a frequency of 148 Hz and has a single area of strong excitation, centred on the bridge; mode 2 has a frequency of 236 Hz and two areas of strong excitation, one each side of the bridge. Thus, when the soundboard is vibrating in mode 1, the whole bridge area moves in and out, perpendicular to the plane of the board. In mode 2, the bridge rocks about its centre, one side moving in as the other moves out.

It is not difficult to see the parallel that exists between these two modes and the first two modes of a string (see Fig 2.1). The single area of strong excitation of the soundboard's mode 1 corresponds to the single loop of string mode 1; and, just as string mode 2 has two loops and one node, so the soundboard's mode 2 has two areas of strong excitation and one *nodal line*, along which no vibration occurs, coinciding approximately with the line where the two halves of the soundboard are joined. In general terms, the correspondence holds also at the higher resonant frequencies: like the string, the soundboard vibrates in progressively smaller portions, with nodal lines separating the areas of strong excitation. However, there are several important differences.

Fig 3.1 Modes of vibration of a soundboard



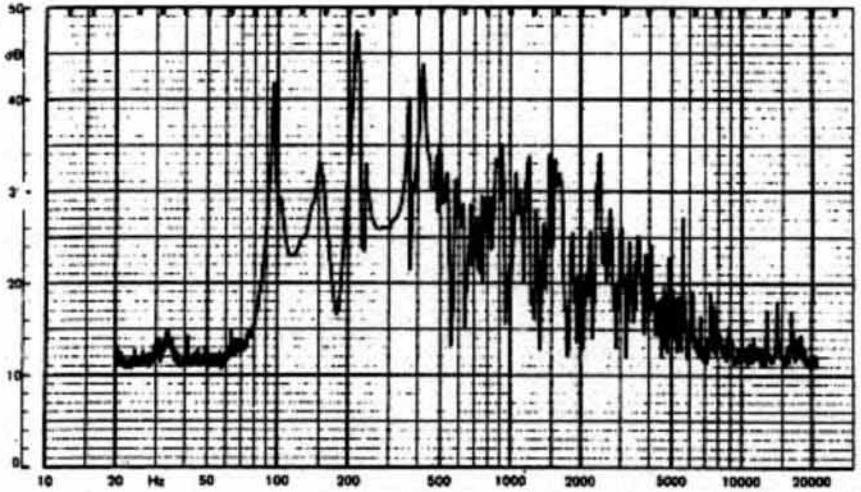
In each case the vibrations are *transverse*, i.e. the string moves in a direction perpendicular to its line, and the soundboard perpendicular to its plane. However, the string has two degrees of freedom for transverse vibrations, whereas the soundboard has only one. In other words, while the soundboard can vibrate only perpendicular to its plane, the string can vibrate either parallel or perpendicular to the soundboard, or indeed in any intermediate direction. For the present, we need only note this as a general principle, but its implications for the player will occupy us for much of the rest of the book.

Another difference may be seen by comparing the mode frequencies of a string (Figs 2.1 and 2.2) with those of the soundboard shown in Fig 3.1. The string modes all have frequencies which are whole-number multiples of the fundamental frequency, and this is why a string makes a musical sound of clearly identifiable pitch. The mode frequencies of a soundboard are not harmonically related, except by rare coincidence (e.g. modes 9 and 10 of this particular soundboard have frequencies 770 Hz and 880 Hz respectively), and therefore a soundboard does not give such a definite note when struck. Indeed, this is just as well, since the response of a soundboard with harmonically-related resonances would vary wildly from one note to another. As it is, the soundboard resonances do give rise to more or less pronounced variations in both volume and quality of different notes, since any partial of a note which happens to lie close to a soundboard resonance will be emphasised. For example, one would expect the soundboard of Fig 3.1 to respond strongly to the open D (147 Hz), not simply because the fundamental frequency of this note is very close to that of the soundboard's mode 1, but also because its sixth, seventh and tenth partials lie close to the soundboard's modes 10, 11 and 13 respectively. Another strong note should be the open A (110 Hz), whose third, fourth, seventh, eighth and thirteenth partials all lie near soundboard resonances, besides which the fundamental would probably be close to the main air resonance. On the other hand, the third string Bb (233 Hz) would not necessarily be particularly strong, even though its fundamental is close to the soundboard's mode 2, because none of its higher partials coincide with resonances.

The above examples should help to explain why the soundboard's resonances do not prevent the body from functioning tolerably well as a broad-band amplifier. Every note on a guitar will have *some* partials lying fairly near resonances. Furthermore, the natural damping of a soundboard prevents its vibrations from building up to a very large amplitude, even at resonance. (Compare the very strong response of a string when another happens to be vibrating at one or more of its mode frequencies — a resonance effect which adds greatly to the richness of guitar sound, but which can be troublesome when clean lines are desired.) To some extent, then, a soundboard's damping is useful since it tends to even out the response, albeit at the expense of power. This is one reason why it is difficult to make a guitar which is both loud and even throughout its range. Another pair of conflicting qualities are volume and sustain, since at resonance the soundboard will absorb vibrational energy from the string relatively fast. All this supports the statement made earlier, that no guitar body can come near the perfection of a good audio amplifier. Rather, a luthier has to aim for a happy compromise between the various conflicting factors.

Fig. 3.2 shows the frequency response of a soundboard, measured by Bernard Richardson at University College, Cardiff, on a guitar of his own construction. The guitar was placed in a room with heavily-padded walls to prevent reverberation, and the soundboard was driven by a vibrator placed near its perimeter, diagonally below the bridge. A microphone above the soundboard was used to measure the sound intensity as the driving frequency was varied from 20 to 20,000 Hz^3. It can be seen that the response is very weak below about 80 Hz and above about 6,000 Hz. The first peak, at 95 Hz, is due to the main air resonance, and the next two, at 154 Hz and 216 Hz, to the soundboard's modes 1 and 2 respectively. The impact of these, and of the many closely-spaced higher resonance peaks, can be estimated by noting the very wide range over which the response varies between the peaks and the troughs. Variations of the order of 30 decibels, which are common here, would be disastrous for an amplifier or loudspeaker, but are part and parcel of the guitar sound. It is not surprising that the frequency, height and sharpness of each resonance peak are so critical in determining the sound of each individual guitar, and therefore that no two guitars ever have quite the same sound.

Fig 3.2 Frequency response of a soundboard



The normal job of the soundboard is, of course, to respond to the continuous vibrations of a string, at the frequencies of the string modes. However, an *impulse* to the soundboard will set it vibrating in a mixture of its own modes, in much the same way as the string modes are excited by plucking. The sound is relatively brief, owing to the heavy damping; and, as we have already noted, it has no clear pitch, since the mode frequencies are not harmonic. Nevertheless, striking the soundboard in the region of the bridge (lightly, with a knuckle rather than a nail, and with all the strings damped) gives a deep sound in which one can usually identify the pitch of the main air resonance. When the soundhole is covered, the air resonance disappears and the sound seems to rise in pitch. Still higher pitches are heard when the soundboard is struck near its perimeter, for the same reason that the higher modes of a string are favoured by plucking near one end (see sections 2.6 and 2.7). The principle of gradual release of a string, introduced in section 2.8(b), also has its counterpart here: a soft object, whose impact is spread over a relatively long time, suppresses the higher modes and so produces a "thud", while a harder object, whose impact is more abrupt, emphasises the higher modes to give a "tap".

The fact that the sound varies according to where and how the guitar body is struck is, of course, well known to players, who obtain many different percussion effects in this way. Not so obvious, but significant nevertheless, is the fact that any note played on the guitar has a certain percussive element, as we shall see in section 3.5. In the meantime, let us turn our attention to the main subject for discussion in this chapter: the means by which energy is fed from a vibrating string to the soundboard.

3.4 Coupling between string and soundboard

When two vibrators, each with its own natural frequencies, are coupled together, the composite system behaves in a complicated way which depends on the properties of each vibrator and on the nature of the coupling. A guitar string and its soundboard form one such vibrating system, and the details of their interaction are far from being fully understood. However, in one respect the coupling between them is very simple.

The guitar bridge, which is glued to the soundboard and indeed functions as a part of it acoustically, really does no more than determine the end of the vibrating length of the strings (at the saddle) and provide an anchor for them. Therefore, to a first approximation, the strings may be considered as being attached directly to the soundboard. This being the case, any force exerted on the string will tend to move the soundboard in the same direction. Thus, if the string is pushed down towards the soundboard, the latter is displaced slightly downwards; if the string is pulled up, the soundboard moves up slightly. It follows that a continuous up-and-down movement of the string will tend to produce a corresponding up-and-down movement of the portion of the soundboard in the bridge area.

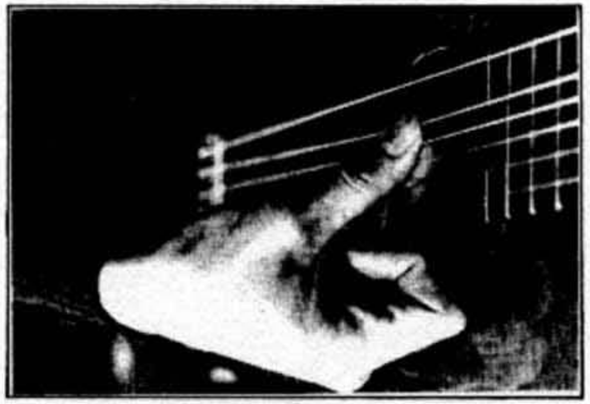
In principle, the same would apply to movements of the string parallel to the plane of the soundboard, which would tend to move the soundboard in that direction. However, as we saw in the last section, the soundboard is free to vibrate only perpendicular to its own plane. The most direct means of exciting the soundboard's transverse modes is therefore to make the string vibrate in a plane *perpendicular to the soundboard.*

As it stands, this last statement may be hard to accept. For one thing, it appears to recommend a practical impossibility, since a very awkward hand position would be required to make the strings vibrate exactly perpendicular to the soundboard. For another, it runs counter to the common teaching, accepted implicitly by many guitarists, that the only sensible direction in which to make a string vibrate is parallel to the soundboard[4]. As to this latter idea, the evidence presented below should be sufficient to refute it. The first objection, however, is a valid one. It is indeed impractical to restrict a string's vibration to the perpendicular plane, but at any one time the vibration will have *components* parallel and perpendicular to the soundboard respectively. Even if the player aims to set the string vibrating from side to side, he will probably impart an appreciable perpendicular component too. It is this component which drives the soundboard directly, and it matters relatively little whether the concomitant parallel component has large or small amplitude. Incidentally, it probably matters still less whether the components are in phase, so that a given point of the string vibrates in a straight line, or out of phase, so that it describes an ellipse.

The discussion so far has been somewhat over-simplified, for the straightforward pushing-and-pulling action is not the only way in which the string can excite the various modes of the soundboard. Since the force of the string acts at the saddle, which is a certain distance above the soundboard, parallel vibrations of the string will produce a very slight rocking of the bridge – tending to excite mode 2, for example. (It is interesting, in this connection, to compare the guitar bridge with the high bridge of a bowed string instrument. The latter is specially designed to produce this kind of rocking motion, from one foot of the bridge to the other, when the string is bowed nearly parallel to the top plate.) Another consideration is that the extra stretching of a string during vibration causes the tension to fluctuate – tending to excite mode 3, for example. This fluctuation occurs at double the frequency of the string's vibration, since the tension increases whichever way the string is displaced. However, the reader need not make any special effort to understand these other coupling mechanisms, since they are relatively insignificant on the guitar[5]. Let us instead return to more practical matters with a simple experiment.

Experiment 3 Try to make the open fifth string vibrate as nearly as possible (a) parallel (b) perpendicular to the soundboard. This is *not* easy to do, and it is quite useless for this purpose merely to pluck the string in the normal way, aiming the fingertip or nail across towards the next string or down towards the soundboard. (The reason for this will emerge in the next chapter, where the plucking action will be considered in more detail.) The best method I have found is to grasp the string between thumb and finger and to draw it out, bow-and-arrow style, in the desired direction before releasing it. In case (a) the finger may be slid underneath the strings, as in Fig 3.3(a). In case (b) the string is picked up as in Fig 3.3(b), and let go towards the soundboard, taking care to keep the amplitude small enough to avoid a slap against the frets. (This restriction does not apply so stringently in actual playing, as will also be explained in the next chapter.)

Fig. 3.3 Experiment 3



(a) Setting string into vibration parallel to the soundboard

(b) Setting string into vibration perpendicular to the soundboard

With a little practice, aided by looking carefully at the string's vibration after release, one can make the string vibrate very nearly in the desired plane. It is worth taking the trouble, for the results are quite startling. The more nearly the vibration is restricted to the parallel plane, the closer the sound approximates to an ineffectual buzz. By contrast, the perpendicular vibration produces a deep, full sound, and a response which can actually be felt in the body of the instrument.

The open A was chosen for this experiment because its fundamental frequency lies fairly close to the main air resonance on most guitars. It therefore gives a particularly striking contrast, but much the same applies also to the other open strings.

Experiment 4 Repeat the last experiment on each open string in turn, this time listening to each note until it dies away. The contrast in fullness and volume is there in each case, but it lasts only for the first part of the note. Towards the end there is little to choose between the sounds, whether the vibration *began* parallel or perpendicular to the soundboard. This suggests that the polarisation of a string's vibration (i.e. the relative amplitudes of the parallel and perpendicular components) may change with time.. Another observation is that, whereas the initial sound of a parallel vibration is merely weak on the bass strings, on the treble strings the contrast with the perpendicular vibration is increasingly one of *quality* as well as volume of sound. On the first string, while the sound of the parallel vibration still lacks the "body" of the perpendicular, it seems to have almost as much brilliance. This suggests that the direction of the string's vibration matters less at the higher frequencies.

Let us investigate this last idea further by trying the same experiment at the highest possible frequencies. In section 2.11 we saw that these may be excited by plucking the first string rather less than an inch from the bridge. If the plucking point is one-thirtieth of the way along the open string, for example, those modes around the fifteenth, with frequencies in the region of 5,000 Hz, are favoured.

Experiment 5 Repeat the last experiment, on the first string, close to the bridge. It is now difficult to see which way the string is vibrating, and one has to rely on the feel of the bow-and-arrow technique. Making the amplitude the same in each case, clearly essential for a fair comparison, is also no easy matter. However, I have tried this test on a number of guitars, and in each case the result has been roughly as follows.

The perpendicular vibration gives a generally louder sound, with an obtrusive "thud" at the start of the note; with the parallel vibration this noise is absent and the note has a very thin quality, seemingly lacking none of the brilliance which the perpendicular vibration gives.

Although this appears to confirm our earlier suspicion, it must be admitted that an "experiment" so difficult to control, and relying so heavily on subjective impressions, is hardly worthy of the name. Being aware of the need for a properly-controlled experiment, I was fortunately able to turn to Bernard Richardson, who had devised an ingenious set-up for this very purpose at University College, Cardiff. The essential feature of Richardson's method is the use of a cotton thread to pluck the string automatically, which enables not only the direction of plucking, but also the position along the string and the plucking force, to be determined exactly. The sound of the note is recorded in a heavily-padded room, and the recording analysed by playing it through a filter connected to a pen recorder, which gives a visual record of each of the first few partials of the note. Alternatively, the intensity of sound in each each octave over the audio frequency range may be plotted.

Using guitars he has built himself, Richardson has obtained a large number of such records, and they leave no doubt that at the lower and middle frequencies (below about 1,500 Hz) considerably higher sound intensities are produced by perpendicular than by parallel plucking. (For example, the technically-minded may like to know that on the open first string the peaks are typically 10 dB higher.) The peaks are also much *sharper* for perpendicular plucking, the sound intensity reaching its maximum value very quickly and then immediately falling away; for parallel plucking the sound can take a considerable fraction of a second to reach its peak intensity, after which the decay is usually similar to that following perpendicular plucking. All this is consistent with the hypothesis that the string vibration gradually loses its initial polarisation, but that it is always the perpendicular component which drives the soundboard directly at the lower frequencies.

At frequencies above about 1,500 Hz there seems to be no consistent difference between the two directions of plucking. The results of the experiment I requested suggest that some of the higher partials may be favoured by parallel plucking and others by perpendicular. Overall, it does seem that the initial direction of the string's vibration is far less significant at the higher frequencies than at the lower. A likely explanation is that much of the sound radiated at the highest frequencies does not come from the guitar body at all, but directly from the string. (At 5,000 Hz, for example, the wavelength in air is only 6.9 centimetres, compared with which a string's diameter is still small, but by no means negligible.) One piece of evidence to support this view is that the "bodiless" guitar, mentioned at the beginning of this chapter, although pathetically feeble at the lower frequencies, proved almost a match for my Ramirez when played very near the bridge on the first string!

Whatever the reason, it is certainly true that the bass and mid-range sounds may be suppressed without losing the extreme treble, by making the string vibrate parallel to the soundboard. In the next section we shall see why this can sometimes have positive benefits. However, deliberately to vibrate the string parallel to the soundboard must remain the exception rather than the rule. Whenever a full sound is required, the guitarist will not go far wrong by concentrating on the perpendicular component, without thought of the parallel.

If this appears to turn a familiar rule on its head, which indeed it does, we must not jump to the conclusion that everything which is taken to follow from that rule is also wrong. To be more specific: the notion that the string should always be set vibrating parallel to the soundboard has been cited as a reason for making the apoyando (rest stroke) and tirando (free stroke) as nearly as possible identical, working from the same hand position and making the nail only just clear the next string in tirando[6]. That this turns out, in fact, to be perfectly sound advice, is a remarkable instance of two theoretical "wrongs" making a practical "right". The confusion arises from a misunderstanding of the nature of the plucking action, as we shall see in the next chapter.

3.5 The starting transient

In section 1.5 it was stated that the non-musical sound heard at the beginning of a note is an important characteristic of any instrument, and the origin of this *starting transient* was briefly explained. Now we know enough about the behaviour of the two parties involved, the string and the soundboard, to understand a little more about this phenomenon. In the process we shall take the opportunity of drawing on a number of ideas from the first three chapters, which will make a fitting end to this mainly theoretical section of the book.

Imagine a string drawn aside, in a direction diagonally down towards the soundboard, and about to be released. As we saw in section 2.6, in effect the string is now held ready to vibrate in the mixture of modes corresponding to the shape of its displacement. But in the last section we also saw that any force put on the string causes a force in the same direction to be put on the soundboard. The latter is, of course, relatively immobile in the parallel plane, but the perpendicular component of the force causes the soundboard to be deformed slightly. Thus the soundboard is also held ready to vibrate in a mixture of *its* modes corresponding to this deformation.

When the string is released, the soundboard is in turn released from its deformed condition and two separate vibrations take place: that of the string, in its own harmonic modes, and that of the soundboard, whose mode frequencies generally bear no harmonic relation either to each other or to those of the string. This latter vibration is therefore a noise, quite distinct from the musical sound of the note, and because of the soundboard's heavy damping, it soon dies away – hence the name "starting transient". Meanwhile, the string continues its vibration and forces the soundboard to vibrate with it. Therefore the musical sound due to the string is also heard from the beginning and persists long after the starting transient has gone, provided that the string is left to vibrate freely.

The reader may have noticed a similarity between this description of the starting transient and the discussion, at the end of section 3.3, of the sounds produced by striking the soundboard. Indeed the two have a lot in common: the release of a string has much the same immediate effect on the soundboard as a light blow delivered to the bridge. An impulse in the bridge area, it will be recalled, tends to emphasise the lower-frequency modes of the soundboard, and especially the main air resonance. The starting transient therefore usually sounds like a faint "thud"at the beginning of a note. However, the manner of playing the string will presumably affect the transient sound, just as it does the musical quality of a note. The more abrupt the release, the sharper will be the impulse at the bridge, and the more the transient will sound like a "knock" or a "tap". Also, the transient is very sensitive to the direction of plucking, since it is due mainly to the perpendicular component of the string's displacement before release. If the string is set vibrating parallel to the soundboard, the low-frequency transient noise disappears, as may be verified as follows.

Experiment 6 Damp the strings with a soft cloth stuffed between the strings and the fingerboard. This will not cut out their vibrations completely, but it can make them at least as short-lived as those of the soundboard. Whichever string is plucked, it is now quite easy to hear the same transient "thud" of the soundboard, mingled with the brief vibration of the string itself. The prominence of the main air resonance may be demonstrated by covering the soundhole, and noting how much lighter the transient sound becomes. Now compare the sound of any string when it has been drawn out (a) perpendicular, (b) parallel to the soundboard before release, as in Experiment 3 above. The deep thud heard in case (a) disappears in case (b).

If a string is plucked, perpendicular to the soundboard, with the same force at different points, it is heard that the transient becomes more and more prominent as the plucking point approaches the bridge. (This is simply because more and more of the plucking force is directed to the soundboard rather than the nut.) But we saw in section 2.7 (Fig 2.6) that the same force gives the string progressively *less* vibrational energy near the bridge. In other words, plucking near the bridge gives more noise for less musical sound.

The percussive sound obtained near the bridge can sometimes be used to striking effect, but it can also be a positive nuisance, as for instance when playing high harmonics on the treble strings. We saw in section 2.10 that, in order to bring out a fifth fret harmonic clearly, the string should be plucked within about three inches of the bridge; but if it is given a strong perpendicular component there, the noise of the transient will initially drown the delicate sound of the harmonic. Now, on the first string the fifth fret harmonic has mode frequencies 1319, 2637, 3956, 5274 Hz, etc. Since all except the first of these are in the high-frequency range where the sound seems to be radiated almost equally well whether the vibration begins parallel or perpendicular to the soundboard, there is little to lose and much to gain by minimising the perpendicular component in this case. The same is true whenever a very light, thin sound is required, in particular when playing near the bridge on the treble strings.

It is hoped that the present chapter has provided some useful background knowledge about how a guitar works. However, the main point to be carried over into the section of the book devoted to the techniques of sounding the strings may be summed up very briefly. We now know that the direction of a string's vibration has a marked effect on the quantity and quality of sound produced. Clearly, then, a guitarist must have techniques for controlling the direction of release over as wide a range as possible. In particular, the normal plucking action must impart an appreciable perpendicular component of vibration, since the soundboard is driven mainly by this component. These are the basic objectives, and we are now ready to consider how they may be achieved in actual playing.

4.1 The problem of fret-rattle

Most guitarists would agree that, while weak or thin sounds are only too easy to produce on the guitar, sounds with both body and volume are harder to come by. I hope that the arguments given in the last chapter left the reader in no doubt that these latter qualities are associated with the string's component of vibration perpendicular to the soundboard. Before considering how this component may be imparted in the normal course of playing, however, we should tackle what may appear to be a knock-down objection to the whole idea: how on earth is one to make a string vibrate towards and away from the soundboard without thereby causing it to buzz or rattle against the frets?

The answer my be found by looking again at the motion of an ideal string after release (Fig. 2.8) . It will be remembered that the first and last diagrams in this figure show the two extremes of the vibration. The displacement after half a cycle is the *reversed* mirror-image of the initial displacement; in other words, the vibration pattern is anti-symmetrical. Suppose now that Fig 4.1(a) represents a string drawn out, away from the soundboard, and about to be released. Then a glance at Fig 4.1(b) should constitute a dire warning of the slap against the frets which will certainly ensue unless the initial displacement is kept very small. (This technique is actually used sometimes in contemporary music. However, the *Bartok pizzicato*, as it is called, is among the most violent sounds available on the guitar, and where not prescribed it is definitely better avoided! An unintentional one serves as a rude reminder that the plucking action was faulty.) The danger of fret-rattle is considerably reduced if the string is pushed down *towards the soundboard* before release, as Fig 4.2 implies. After half a cycle the string will have risen, harmlessly, above the frets, and if fret-rattle occurs at all in this case, it will be only when the string returns to its initial shape at the end of a full cycle.

Fig 4.1 Two extremes of a string's vibration

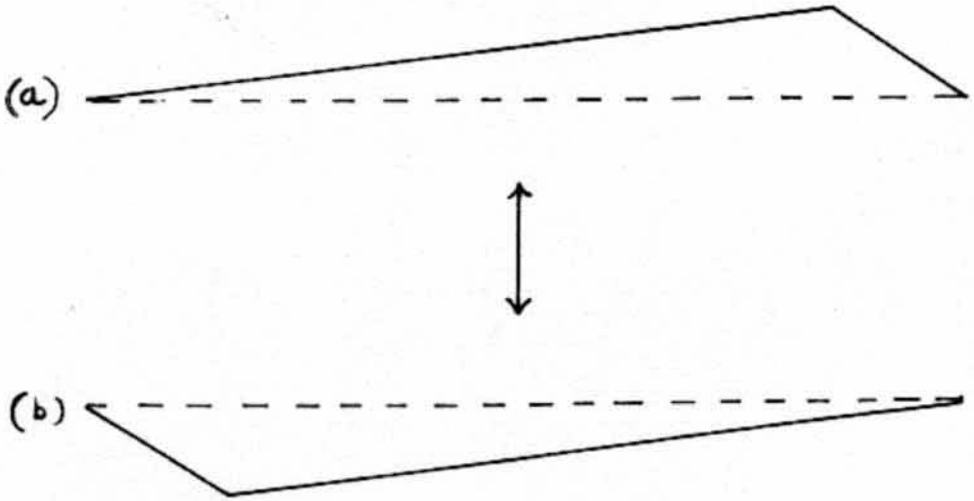
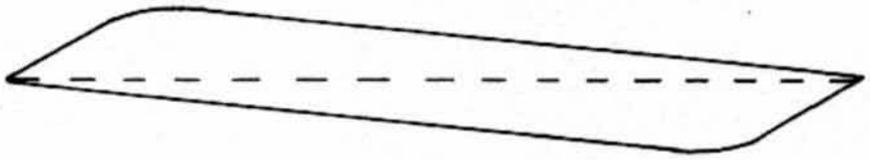


Fig 4.2 Envelope of a string's vibration



That guitar strings really do vibrate in this way may be verified quite simply, as follows:

Experiment 1 Slacken the sixth string a little, so that quite a large-amplitude vibration may be obtained without excessive force. Lay the guitar flat and draw the string out horizontally, between thumb and finger, near the bridge. Note the shape of the string and then release it. During the vibration, the same shape appears on the opposite side of the string, near the *nut*. The "envelope" of the vibration, seen as a haze of course, looks like a parallelogram with rounded corners, roughly as in Fig 4.2.

It is also worth trying the following test, which shows one of the more surprising consequences of this vibration pattern.

Experiment 2 Try to make a Bartok pizzicato on any string – using thumb and finger to draw the string away from the guitar and release it – (a) near the bridge, (b) near the nut. In case (a), it is found that even a slight lifting of the string away from the soundboard will cause a loud slap against the frets. But in case (b), when the string is lifted above the frets themselves, and let go towards them, it proves quite difficult to cause a slap at all! Indeed, unless the string is pulled up with considerable force near the nut, the sound of the note is pleasantly full and warm, similar to that of an apoyando with the flesh of the thumb, played near the bridge. Given that a string's vibration is anti-symmetrical, this is, of course, just what one would expect. Similar reasoning explains why descending slurs (ligados) can be made to give a relatively full sound, without fret-rattle, if the left-hand finger plucks the string steeply *upwards*, away from the fingerboard.

Returning now to the right hand, we can see that the closer the plucking point is to the bridge, the greater is the advantage of pushing the string down rather than pulling it up. Halfway along the string, the danger of fret rattle is the same in either case – except that the fingerboard gets in the way if one attempts to push the string too far down. At a point one-fifth of the way along, however, the string may be pushed down about four times as far as it could have been pulled up before release, without causing fret-rattle; and one-tenth of the way along, it should be possible to push down about nine times as far. Since the force required to displace a string through the same distance increases rapidly towards the bridge, this reasoning suggests that one should be able to press a string down very hard near the bridge, and so produce very loud notes, without any fret-rattle. Up to a point this is indeed possible, at least on a good guitar, but we have left an important factor out of the discussion so far.

In section 3.5 we saw that pushing a string down also causes the soundboard to flex inwards slightly, especially if the plucking point is near the bridge. When the string is released, the soundboard springs outwards, and may send a "shock wave" down the string sufficient to cause some fret-rattle. In fact, the two-way interaction between string and soundboard continues throughout the vibration; it is presumably at the bottom of such anomalies as the occasional note which seems to swell or waver, even without vibrato, and the buzz which comes shortly *after* the start of a note, even though the player did nothing to provoke it. This is one of the complications which we studiously avoided in the last chapter, and which we shall pursue no further here. Suffice it to say that a guitar's tendency to buzz is related not only to the height of its action (i.e. the clearance between the strings and the frets), but probably also to the springiness of its soundboard.

Be that as it may, the main point of this section remains valid: that, provided the string is pushed down rather than being pulled up before release, a considerable amplitude of perpendicular vibration is possible without causing fret-rattle. Nevertheless, fret-rattle remains a problem which, given the absolute necessity of a perpendicular component of vibration, is inherent in the construction of the instrument. The amplitude of that component which will just cause fret-rattle sets a limit to the volume and fullness of sound available on any given note of a guitar. This is why a classical guitar needs a higher action than an electric (whose feeblest string vibrations may be made quite deafening with amplification) – and incidentally, it is also why the policy of some manufacturers to make student guitars with "easy" actions is so inimical to good tone production.

Given a well-adjusted instrument, a guitarist need not tolerate any unwanted fret-rattle, so long as his plucking action is correct. A string should *never* be lifted away from the soundboard in the course of normal playing; nor, for that matter, should it be driven down towards the soundboard excessively. But any attempt to circumvent the whole problem by restricting the strings' vibrations to the parallel plane would be about as sensible as deciding never to eat in future, for fear of being poisoned.

4.2 Projecting the string towards the soundboard

We now have a clear objective which applies whenever a strong, full sound is required, without fret-rattle. The string must be projected down towards the soundboard (but not excessively), and released from a point *below* the plane of the other strings. Now it is not difficult to see that an apoyando stroke, in which the fingertip or nail pushes through the string and, after releasing it, comes to rest on the next one, can hardly fail to achieve this objective. The "deeper" the apoyando, the further the string will be projected down before release.

Let us now look more closely at the motion of a string during and immediately after an apoyando stroke. Suppose that a finger nail shaped to a curve is used, in such a way that the downward slope it presents to the string is not too steep. (The details of how this may be done will be discussed in the next chapter.) Fig 4.3 shows a "shallow" apoyando with such a nail, the fingertip moving directly across to the next string rather than down towards the soundboard. As the nail moves across, it not only draws the string aside horizontally, but also pushes it down. At the instant of release, the string is at a point diagonally below its original position, and therefore it moves off in an upward diagonal.

Fig 4.3 Apoyando stroke

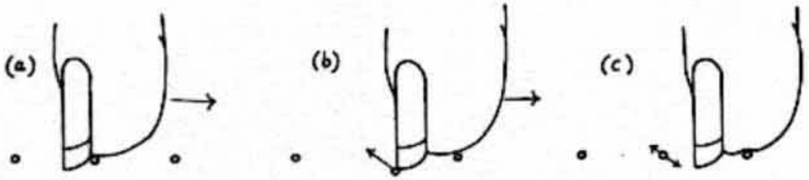
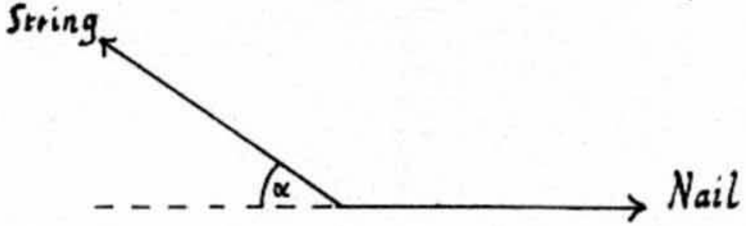
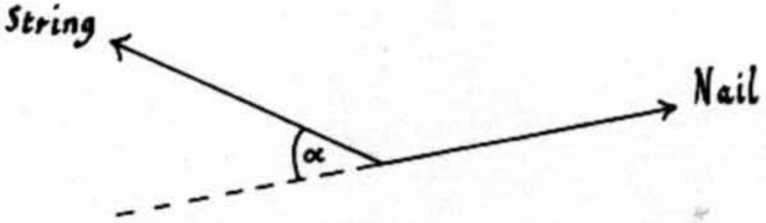


Fig 4.4 Direction of string's release in apoyando



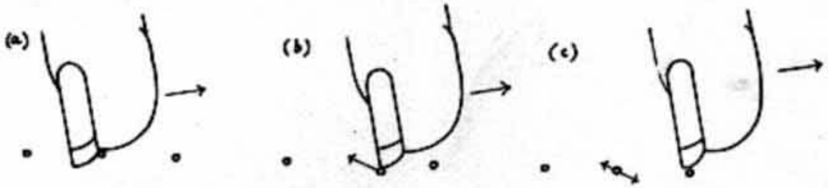
The essential point here is that the direction in which the string moves off is not directly opposite to the direction of the nail's movement, but is inclined at a certain angle α, as shown in Fig 4.4. Given this fact, we may go on to ask what will happen if, instead of moving horizontally across, the nail moves slightly upwards, just enough to clear the next string. Other things being equal, the direction diagram will simply be rotated slightly, as in Fig 4.5. The string still moves away *upwards*, albeit at a less steep angle.

Fig 4.5 Direction of release in tirando



Here we have used a little geometrical trick to arrive at a seemingly paradoxical conclusion. Fig 4.5 represents a nail making a *tirando* stroke (i.e. rising clear of the next string) and yet releasing the string from a point *below* its original plane! However, Fig 4.6 shows that there is no paradox – it is indeed possible for a nail to project a string downwards, release it, and *then* come clear of the next one. This is, in fact, the proper technique of tirando, which is in essence no different from apoyando. Both strokes have the same objective, to project the string downwards, and in tirando this is done most effectively if the stroke is as "flat" as possible, differing as little as possible from the apoyando action.

Fig 4.6 Tirando stroke



Once this principle is understood, the development of a full tirando sound becomes much easier. This is another phenomenon, like the anti-symmetrical vibration of a string, which is not yet common knowledge among guitarists and teachers[1], and which is all the more useful to understand because it goes against intuition. Incidentally, the reader may now find it interesting to re-read the last paragraph of section 3.4 and to spot the fallacy in the argument which leads from a false premise (that the string should vibrate parallel to the soundboard) to a correct conclusion (that the tirando stroke should normally be as "flat" as possible). In this fallacy can also be found the germ of another: the belief that any guitarist who uses long nails could improve his tone by filing them shorter. As we shall see later, the optimum length of the nails depends on a number of factors which vary from one individual to another, and is not susceptible to hard and fast rules.

Another interesting point is that Sor, who approached technique in a very analytical way, was well aware of the tendency of a rounded fingertip (for Sor did not use the nails) to impart a perpendicular component to a string's vibration, and said so explicitly in his Method of 1830[2]. However, he did not realise the beneficial effects of this component, seeing in it only the danger of fret-rattle. If only Sor had taken his reasoning one step further, then he and not Tarrega might have been the one to revolutionise right-hand technique by cultivating the apoyando.

4.3 Controlling the direction of release

Up to now in our discussion of apoyando and tirando, we have only considered one example of each stroke, viz. the "shallow" apoyando and the "flat" tirando. These two strokes are almost identical in action, and they can both be executed from the same hand position. However, it is possible to obtain a variety of different sounds by emphasising the difference between apoyando and tirando.

The essential difference is in the angle at which the string is released. Apoyando tends to set the string vibrating at a steeper angle, with a stronger component perpendicular to the soundboard, and therefore gives a fuller sound than tirando, other things being equal. Associated with this fullness is the slight "thud" of the starting transient, which is always present in the apoyando sound to some extent, becoming quite prominent near the bridge (see section 3.5). Tirando gives a lighter sound, and is generally more suitable than apoyando when playing near the bridge and for harmonics, at least on the treble strings.

As we have already noted, for the highest harmonics and for the lightest, thinnest sounds it is desirable to cut out the perpendicular component altogether, making the string leave the nail horizontally. Fig 4.7 shows that this will require a tirando stroke in which the nail moves upwards rather more steeply than usual. (Note that it is perfectly possible to pluck upwards more steeply still, but not without risking an ugly slap against the frets.) The action of this steepest useful tirando is shown in Fig 4.8.

Fig 4.7 Direction of release in steepest tirando

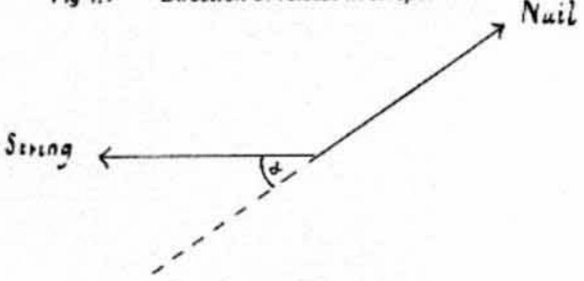
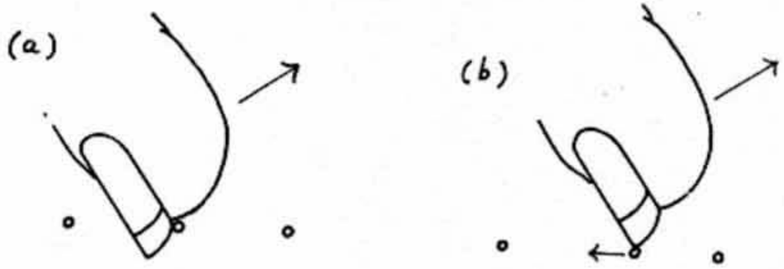


Fig 4.8 Steepest tirando stroke



For a comprehensive control of the angle of release, a guitarist also needs to be able to go to the other extreme – a very deep apoyando which will make the string move off vertically (see Figs 4.9 and 4.10). Such a stroke can occasionally be useful for playing single notes, when a very full, warm sound is required.

Fig 4.9 Direction of release in deepest apoyando

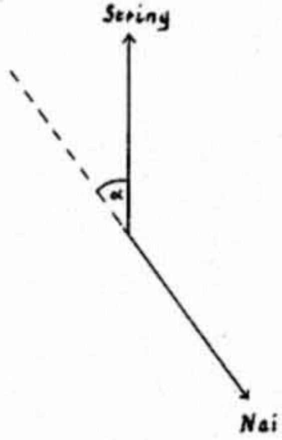
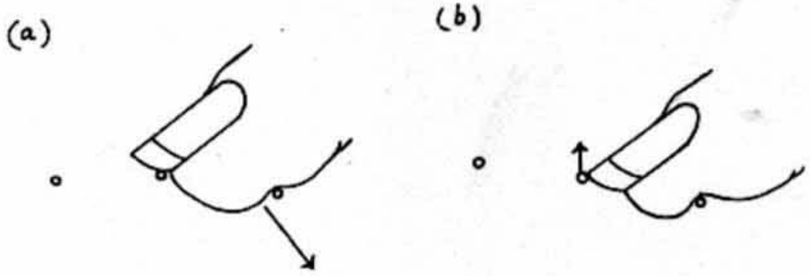


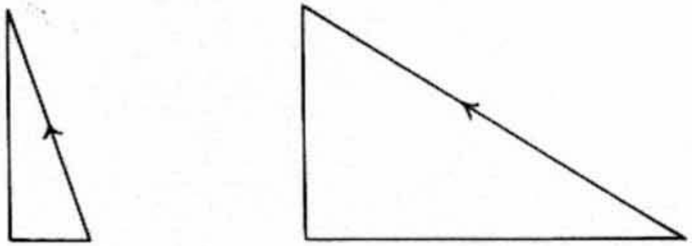
Fig 4.10 Deepest apoyando stroke



These two extremes both need modified hand positions, and are suitable only for special tonal effects. Most of the time a guitarist will be varying the direction of release well within these limits, using either apoyando or tirando from a normal hand position. Particularly important in determining a guitarist's characteristic sound is the extent to which he can project the string down in a flat tirando; Fig 4.5 shows that this depends on the angle α, which in turn depends on such details as the length and shape of the nail. Given the variability of these details, it is not surprising that some players seem unable to get a full sound at all without using apoyando, while others only rarely have to resort to it, their tirando sound being already remarkably strong and full.

In this section it has been convenient to think in terms of the direction of the string's release, but this idea can be misleading if taken too far. Although it is the perpendicular component of vibration which drives the soundboard directly, it does not follow that a *steeper* diagonal of release will always give a *stronger* sound. There is, as we know, a limit to the amplitude of the perpendicular component which may be imparted without causing fret-rattle. Using apoyando, it is only too easy to exceed this limit, without necessarily aiming the nail downwards at all; indeed, with skill (or, at the other extreme, with a gross lack of it) a string may even be made to rattle on the frets using tirando! In other words, different amplitudes of the parallel component may be imparted along with the maximum downward component, and the direction of release will vary accordingly. Fig 4.11 shows two different directions of release, corresponding perhaps to a deep and a shallow apoyando respectively, each having the *same* perpendicular component. Clearly, the string's initial displacement is much greater in the latter case. Far from giving a weaker sound than the deep apoyando, the shallow stroke will give just as much body, and, in addition, a brighter quality with a crisper attack, since the same nail will release the string more rapidly in this case (see section 2.8). Moreover, if it is true that the polarisation of the vibration can change with time, as was suggested in section 3.4, then some of the extra energy put into the string by the shallow apoyando stroke may eventually be radiated as sound.

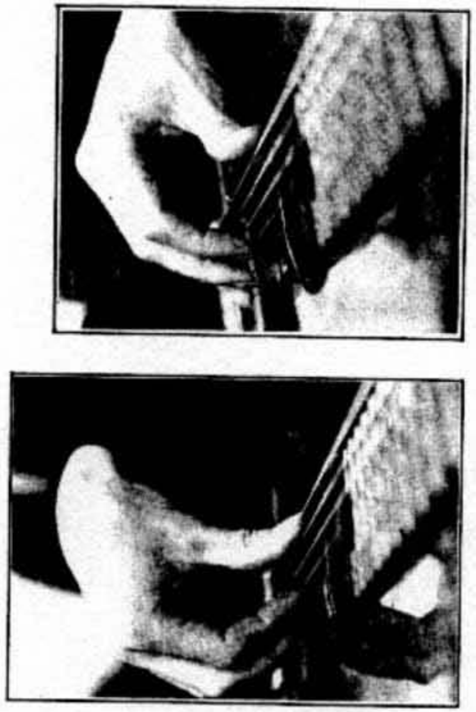
Fig 4.11 Two directions of release



(a) Deep apoyando *(b) Shallow apoyando*

All this goes to show that there is generally nothing to be gained by adopting a downward-sloping attitude of either fingers or thumb. Fig 4.12(a) shows a hand position which, far from helping the fingers to produce loud notes by projecting the strings downwards, actually restricts them in the force they can use without causing fret-rattle – to say nothing of the thumb, which is left without a hope of making a full sound in the bass. Fig 4.12(b) shows an equally unbalanced position, in which the fingers are condemned to pluck steeply upwards, while the thumb is in danger of driving the strings downwards excessively. Either one of these positions may well be useful for a special effect, but for normal playing they are both disastrous. Most players would agree that a good "normal" position will allow both fingers and thumb to change easily between apoyando and tirando, with little or no movement of the hand. This makes a useful criterion for setting the height of the wrist.

Fig 4.12 Two extreme hand positions



(a) Excessively low wrist

(b) Excessively high wrist

4.4 Applying the general principles

In this chapter we have made some progress towards understanding how the physical principles underlying tone production apply to the actual techniques used. However, there are pitfalls in moving from theory to practice, especially when diagrams are used to show the action of playing a string. Figs 4.3, 4.6, 4.8 and 4.10 all show a particular fingertip and nail, moving always in a straight line perpendicular to itself. The diagrams take no account of the fact that fingers and nails come in an endless variety of shapes, sizes and textures, nor of the subtleties of action which their owners use to draw different sounds from the instrument. For example, in a tirando stroke the nail will describe some sort of curve rather than moving in the straight line shown; and, although it is normally a good idea to move firmly through the string, the finger and nail need not be quite as unyielding as they have been portrayed. The "give and take" between finger and string is, no doubt, at the root of that mysterious phenomenon known as a guitarist's "touch". In short, these diagrams, and all similar ones throughout the book, should be taken only for what they are – rather crude illustrations of general principles.

In moving from the general to the particular, a wonderful variety of different sounds, and different means of producing them, becomes available. It would be futile to attempt here a detailed survey of these sounds and techniques, since they are ultimately the products of each player's imagination and skill. Viewed in another way, however, they are all ultimately governed by a few basic principles, a knowledge of which can help the guitarist, not only by suggesting ways of obtaining the sounds he has in mind, but also by feeding his imagination with new possibilities. Before starting on the last two chapters, which further explore the practicalities of playing, the reader may therefore wish to take stock of the major influences on the sound of a single note which are under the player's immediate control. These are:

(a) the fractional distance along the string of the plucking point,
(b) the magnitude and direction of the string's displacement on release,
(c) the manner in which the string is released, and
(d) the vibrato applied, if any.

Leaving aside certain special effects, these are the basic parameters which a guitarist can adjust in order to produce different sounds. Of the four, the first and last have already been discussed at some length, and are in any case obvious enough. The more interesting and difficult problems of tone production lie under the headings (b) and (c), and it is these which will claim most of our attention from now on.

The emphasis on what is interesting is also my reason for assuming that the strings are played with the nails rather than with the flesh alone. This is not merely because the current fashion is overwhelmingly on the side of nail-playing, nor would I wish to discount the very attractive features of a flesh tone. It is simply that most of the variations in the manner and direction of a string's release to be discussed are scarcely possible at all unless the nails are used. Furthermore, it is largely a waste of time to compare different shapes of fingertip (which will, however, be done briefly in section 6.2), since in the end every flesh-player has to make do with his own. The same is indeed true of one's nails, but at least their length and profile can be adjusted without resorting to mutilation!

The advantages of using the nails are often bought at a high price: hours spent shaping and polishing them, weeks spent waiting for a broken or botched one to grow. Finding the optimum length and shape for each is no easy matter, and even experienced players sometimes go wrong in filing their nails. The next chapter, devoted to the use of the nails to produce a good basic sound with the additional possibility of wide variation, contains a section on their shaping. It is hoped that some of the suggestions given there will prove helpful, but they are mostly no more than common-sense applications of the principles already explained. The main thing is to understand those principles; then it takes only a little imagination to see how they apply to any particular case.

CHAPTER 5 USE OF THE NAILS

5.1 The nail as a ramp

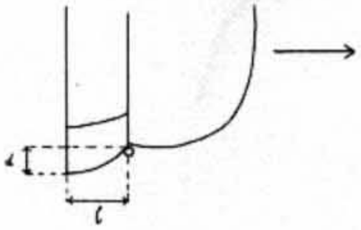
We can now bring together some of our earlier ideas to obtain a more detailed picture of the way in which a nail sets a string vibrating. One aspect of the plucking action, the principle of gradual release, was introduced in section 2.8(b). There we found that any abruptness in the initial motion of the string tends to give a hard edge to the sound. For a smoother sound, the string's initial acceleration must also be smooth. In practice, this means that the nail must launch the string as from a ramp, the effective ramp length being a certain fraction of the string's initial displacement. As we now know, the nail also has another ramp-like function, at least as important as the first, which is to project the string down towards the soundboard and release it from a point below the plane of the other strings.

Roughly speaking, a well-shaped nail performs this double function as follows. One side of the nail engages the string (most players lead with the left), and at first the string moves across with it. However, as the string is drawn further away from its original position, the restoring force due to its tension increases to the point where the string begins to slide down the slope presented by the nail. If the nail is shaped so that this slope becomes progressively less steep towards the bottom, the string continues to accelerate, shooting smoothly downwards and off. This latter phase of the action, beginning at the instant when the string begins to move with respect to the nail, is the important one in producing the sound; and, provided that there is no "catching", it takes place very rapidly. Since this is true regardless of the speed of the earlier phase of the action, we need not consider at this stage whether the nail approached and drew the string across quickly or slowly. In either case, the essential features of the plucking action are the same.

Ideally, then, the nail behaves like a smooth downward ramp, whose slope gradually levels out at the bottom. The ramp has two important dimensions: its length l and its depth d. Fig 5.1 shows these dimensions in the case of a particular nail used in a particular way. However, we have already noted the versatility of a nail in laying out a string's path in advance. More specifically, we shall presently see that the details of the ramp presented to the string depend not only on the length, shape and texture of the nail itself, but also on the hand position and finger action used.

This fact leads to the possibility, which we shall investigate in the next two sections, of varying sound of a note by using the same nail in different ways. Conversely, it also begins to explain the wide divergence of hand positions and nail shapes which different players use to obtain broadly similar results in terms of sound. A nail shaped to suit one hand position may be quite unsuitable for another – and for this reason the question of nail shaping, that most critical aspect of tone production, will be left till the end of the chapter.

Fig 5.1 Dimensions of nail as a ramp

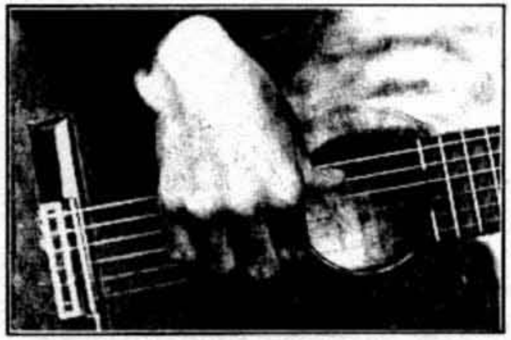


5.2 Varying the ramp length

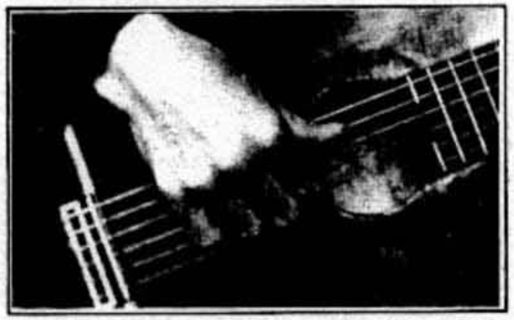
If the right hand is placed with the line of knuckles parallel to the strings, as shown in Fig 5.2(a), so that each fingernail plays directly across the string's line, the chances are that the sound will be hard, twangy and thin. If, however, the hand is turned slightly off the parallel, so that each nail comes across diagonally, the sound gains warmth and loses its hard edge. Fig 5.2(b) shows the hand turned so as to lead with the left-hand side of the nail, but some players prefer to turn the other way, and lead with the right; the effect is much the same in either case.

Fig 5.2 Two settings of the right hand

(a) Line of knuckles parallel to strings

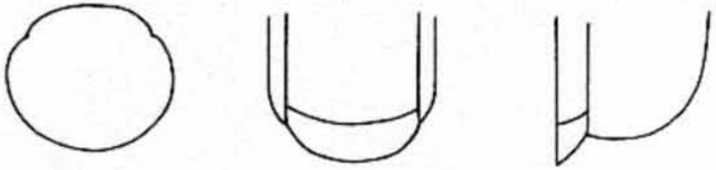


(b) Leading with left side of nail



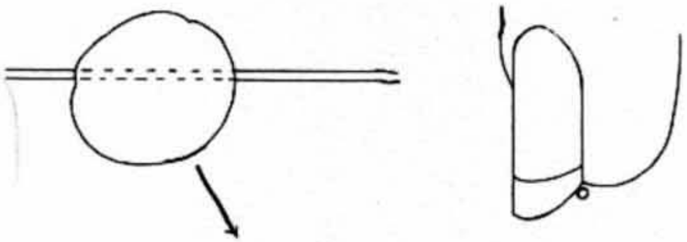
In order to understand this phenomenon, let us take a particular nail as an example. Fig 5.3 shows our model nail, viewed from three different directions. The side view (c) shows the ramp which the nail will present to the string if it plays directly across; but if the nail is turned as in Fig 5.4(a), the ramp it presents looks like Fig. 5.4(b). Thus, turning the nail with respect to the string has the effect of lengthening the ramp without changing its depth. The string therefore gets a longer, gentler ride and the sound has none of the harsh "twang" associated with an abrupt release. (Incidentally, neither the nail length nor the angle of turn shown in these diagrams should be taken as "recommended". Both are, if anything, exaggerated for clarity.)

Fig 5.3 Model nail



(a) Cross-section *(b) Profile* *(c) Side view*

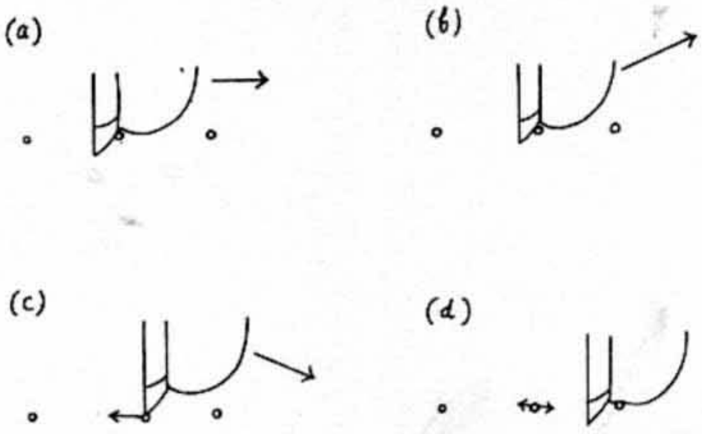
Fig 5.4 Nail turned with respect to string



(a) Angle of attack *(b) View along string*

The above explanation may be correct as far as it goes, but it is essentially no more than a repeat of that given at the end of section 2.8. Now we can go much further, and in particular, we can discover why the sound changes from "thin" to "warm" when the nail is turned at an angle. A closer comparison of Figs 5.3(c) and 5.4(b) reveals that, in the latter case, the ramp is not only less steep overall, but its slope also levels out progressively towards the bottom. The turned nail will therefore have no difficulty in projecting the string smoothly downwards and off, so giving plenty of body to the sound. Used straight across, however, the nail presents such a steep slope that the string may be unable to slide down it, no matter how far it is drawn aside. In other words, the string may simply get "stuck" on the nail, which therefore fails to work as a ramp at all. In this case, the only way of releasing the string is for the fingertip to yield, either by bending back or by moving upwards. Let us leave aside the first possibility for the time being, and assume that it does the latter. Then a shallow apoyando stroke will look roughly like Fig 5.5.

Fig 5.5 Apoyando using nail directly across line of string

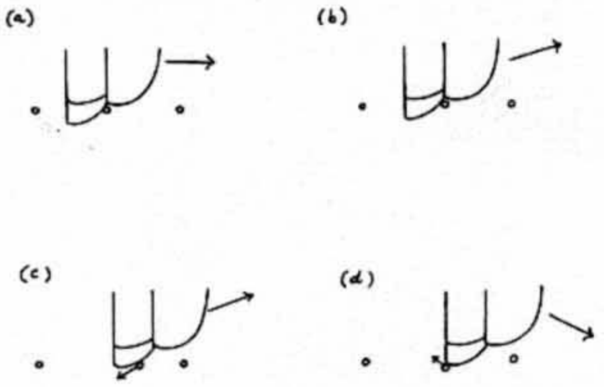


Here we see an interesting reversal: instead of pushing the string down, the nail is obliged to ride over it. An apoyando this certainly is, since the fingertip comes to rest on the next string, and yet the string is hardly projected downwards at all! It is not surprising, then, that the sound of a nail used in this way is thin and lacking in body. In fact, the effect is much the same as if only the extreme tip of the nail had been used, like a plectrum.

This example also gives us an insight into the cause of thin sounds in general. These are a perennial bogey; every guitarist knows that turning the hand is no guarantee against them, and every teacher comes to expect them whenever a student uses the nails without bothering to shape and polish them correctly. We already know that the sound will be thin (meaning "lacking in body" rather than "edgy", though it may well be both) if the nail fails to project the string downwards appreciably. The reason for this failure may simply be that the nail presents too shallow a ramp to the string, perhaps because it is just too short. Now we can add a second possibility, which applies equally to longer nails: the string may be tending to get stuck, or "catching", somewhere on the nail, so that the nail has to ride up over the string to let it through. In either case, the remedy is to ensure that the nail works properly as a smooth ramp of sufficient depth.

Returning to the angled nail shown in Fig 5.4, we can now see that there is no reason why the nail should not yield to some extent in this case too; indeed, this is a natural way of controlling the volume of a note. Fig 5.6 shows a shallow apoyando stroke in which the nail rises up slightly instead of pushing straight through. The string is thus allowed to begin its descent from a point lower down the nail, where the slope is less steep. Diagram (c) shows the instant when the string begins to slide down the slope, and diagram (d) the instant of release, which follows very shortly afterwards. Clearly, the nail still functions as a ramp in this case, but one of smaller dimensions. The sound will therefore have much the same quality as if the nail had pushed firmly through, but less volume. (Note that as the string moves downwards, the finger experiences a brief upward force which suddenly disappears on release, the finger then coming down with a slight "bump" on the next string. In tirando, the finger has to be held with sufficient tension to resist this downward reaction at the end of the stroke, and in this sense tirando is inherently less "relaxed" than apoyando.)

Fig 5.6 Light apoyando using nail turned with respect to string



(Note that nail moves into the paper, in the direction shown in Fig. 5.4.)

We are now beginning to see how much the effective ramp length may be varied by using the same nail in different ways. When the nail comes straight across the string and only the tip of it is used, the "ramp" becomes so short as to be really no ramp at all. If we now try to imagine the *longest* ramp which could be made with our model nail, the answer must be to turn it right round, as shown in Fig 5.7. This presents the string with a very long, gentle slope – too long, in fact, for the whole of it to be used unless the string is first drawn very well aside. More usually, the nail *glides* over the string instead of pushing firmly through. The foremost exponent of the gliding apoyando remains Segovia who, using a combination of flesh and nail, produces with it a "liquid" sound of great fullness and volume. The gliding apoyando is only suitable for playing relatively slow melodic lines, because the direction of movement shown in Fig 5.7(a) necessitates a rotation of the whole hand from the wrist.

Fig 5.7 Gliding apoyando

(a) Angle of attack

(b) View along string

As always, neither of the two extremes is satisfactory for normal playing. Most players find that, so long as the hand is turned off the parallel through a certain minimum angle, a sound is obtained which has all the necessary ingredients of volume, body, brilliance and clarity. Presumably, this minimum turn corresponds to the point where each nail begins to function as a ramp, pushing the string down rather than itself having to ride over the string. The angle at which this occurs varies from one player to another, and indeed from one nail to another. Some players, whose nails already have a "deep" cross-section, as in Fig 5.8(a), can make them into long enough ramps without turning any more than is necessary to ensure that only one side of the nail leads into the string. Others, whose nails have a "flat" cross-section similar to that shown in Fig 5.8(b), have to turn further round before the sound acquires any body. However, once this minimum angle is reached, there is no point in turning much further still, as a general rule. If the ramp is *too* long, it may hold the string back unnecessarily, muffling the higher partials and reducing the clarity. Moreover, turning the hand at all must be seen as a departure from the most efficient plucking direction – directly across the string.

Fig 5.8 Two cross-sectional nail shapes

(a) "Deep"

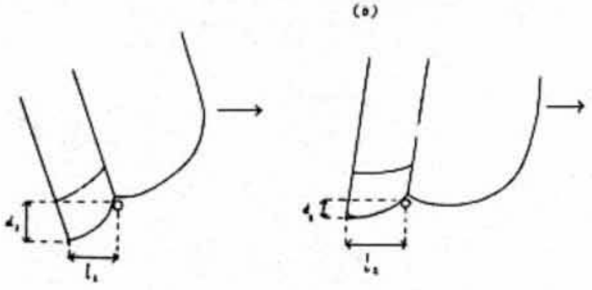
(b) "Flat"

Before leaving this section, it is worth pointing out a shift of emphasis which has occurred in the course of it. In section 2.8 the effect of turning a nail with respect to the string was discussed as a means of suppressing the higher string modes. Indeed, at that stage we could only understand it in those terms; subsequently, however, we have discovered a more positive effect – that of projecting the string down towards the soundboard and thereby giving body to the sound. With hindsight, we can now recognise this latter effect as being the more important in producing a good "normal" sound. It is true that using the nail as a long ramp (e.g. with a gliding apoyando) tends to suppress the higher partials, making the sound "warm" or "round"; equally, it is true that using the nail straight across like a plectrum tends to give a thin sound, because in this case the soundboard is driven only weakly, thus effectively suppressing the lower partials. However, these extremes are useful only as special effects. Generally speaking, it is better to aim for a sound rich in partials over a wide frequency range, without deliberately suppressing anything. This is why a good normal position has the hand turned just enough for each nail to do its job as a ramp, without detaining the string any more than necessary.

5.3 Setting the height of the wrist

In the last section we investigated, at some length, the effect of varying one angle of attack; now let us briefly consider another. Up to now, all the diagrams showing a "shallow" apoyando (Figs 4.3, 5.5 and 5.6) have had the fingertips standing up vertically throughout the stroke. However, this is not always necessary, nor must the fingertip always move perpendicular to itself. Fig 5.9 shows the same fingertip set at two different angles, but moving horizontally across in each case. Clearly, changing this angle has a marked effect on the dimensions of the ramp presented to the string. In case (a) the ramp is short and deep; in case (b) it is long and shallow.

Fig 5.9 Dimensions of ramp with nail set at two different angles



(Note that the direction of movement is the same in each case)

This fact has implications for several aspects of right-hand technique. The two diagrams (a) and (b) may be taken to represent two stages of the *same* stroke, in which case they show what happens when the fingertip yields to the string by bending back as it moves through. (Whether or not it is advisable to let this happen at all is one of the controversial issues to be discussed in the next chapter.) If, on the other hand, it is assumed that the fingertip remains firm throughout the stroke, then the diagrams (a) and (b) represent two different hand positions. More precisely, provided that the overall curvature of the fingers is kept the same in each case, the angle of attack shown in diagram (a) may be obtained by setting the wrist high (arched), and that in diagram (b) by keeping it low (flat). The reader may find it helpful to check this.

Adjusting the height of the wrist therefore offers yet another means of varying the sound – within limits. In practice, a guitarist has to shape his nails to suit a particular wrist height, and once this has been done, there is not a great deal of scope for variation. For example, the ramp shown in diagram (a) would probably prove too steep, except for producing a very strong, impulsive sound. If this angle of attack were adopted as "normal", then either the fingertip would usually have to yield, by moving up or bending back during the stroke, or the nail would have to be filed shorter, with a flatter profile. Conversely, the ramp shown in diagram (b) would tend to give a soft sound, perhaps lacking in clarity. With the fingertip set at this angle, better results would be obtained by growing the nail longer and filing it to a steeper curve; otherwise the nail would have to be aimed downwards to give any body to the sound.

These examples are intended to show some of the implications, as regards nail shape and finger action, of adopting a particular height of the wrist. However, the most useful criterion for setting the wrist height remains that given at the end of section 4.3: the normal hand position should be more or less equally suitable for apoyando and tirando, with both fingers and thumb. Neither of the angles of attack shown in Fig 5.9 looks very promising in this respect; as usual, some intermediate position makes the best compromise. Nevertheless, there is considerable variation, even among the best players, in the normal height of the wrist. The general tendency is for the treble sound to be bright and crisp, and the bass strong, when the wrist is set fairly high. A lower wrist tends to give a softer, rounder treble and a lighter bass.

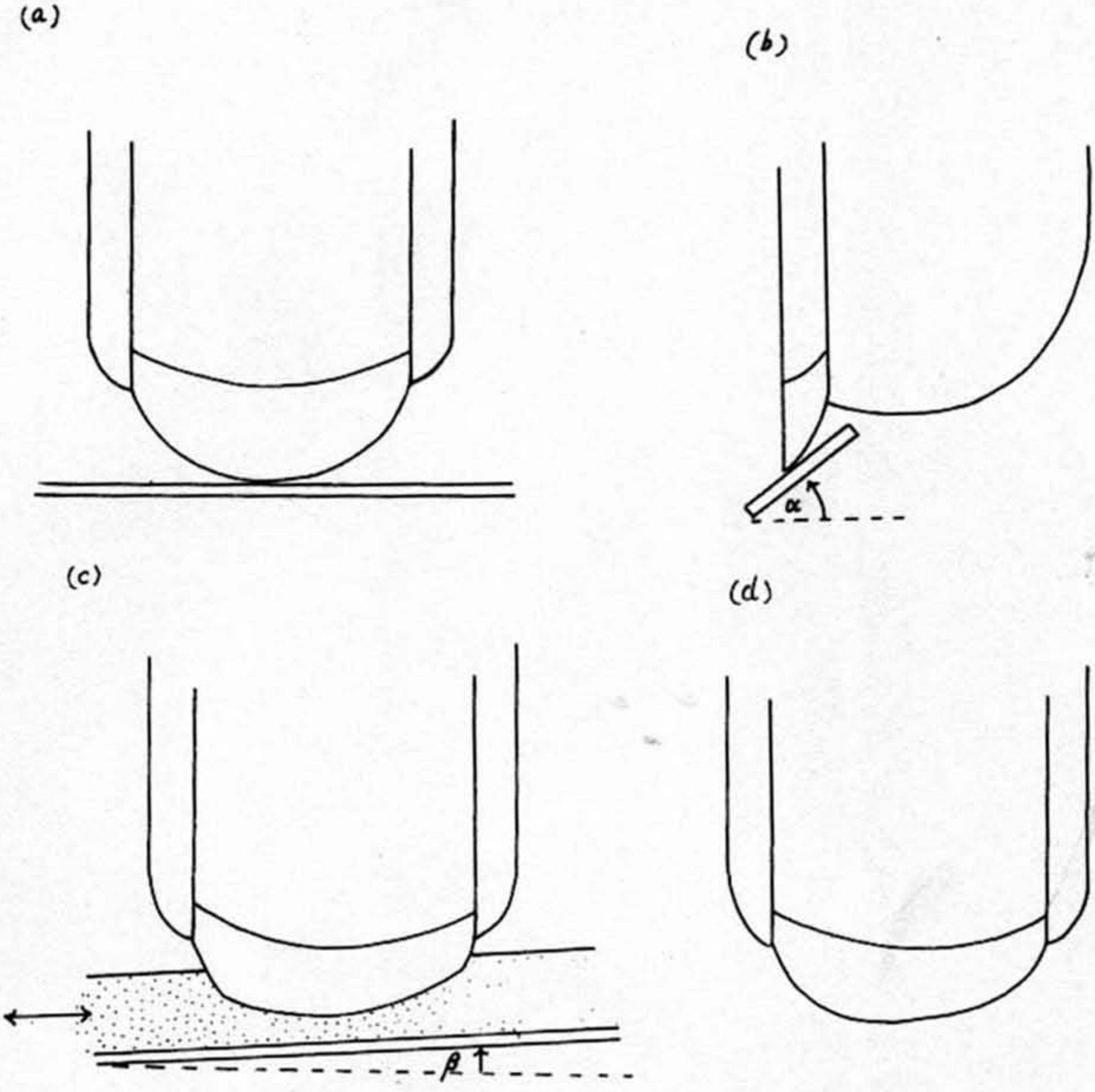
5.4 Shaping the nails

At the beginning of this chapter, it was stated that the optimum shape of each nail depends on all the other details of right-hand technique, especially the hand position adopted and the finger action used. The other side of the coin is that, if a player has a good idea of how he is going to place and use his fingers and thumb, and of the sort of sound he can expect to obtain with this placing, then the actual shaping of the nails is relatively straightforward. This is why we have delayed our discussion of it until now.

Once the "normal" hand position has been chosen, each nail has to be filed individually to give a satisfactory sound using either apoyando or tirando. At this stage it makes sense to aim more for evenness than for variety of sound. Although one must bear in mind that each nail will be used in different ways to produce different sounds, it is perhaps even more important to ensure that all three fingers give the *same* sound when used in the same way from the same hand position. An obvious case where this is desirable is the tremolo (*p a m i p a m i* etc.), which will not sound even unless the three fingers produce matching tone and volume. More generally, any gratuitous changes of colour from one note to another within the same phrase can obscure the sense of the music, as well as robbing those contrasts which *are* intended of their full impact. Of course, it is not essential for the matching to be exact. There are inevitably some differences in sound due to the fact that the fingers *i*, *m* and *a* lie at different positions along the string, and this can indeed be troublesome when playing near the bridge (where *i* may be well over twice as far along the string as *a*, and the thumb, of course, further along still); however, these differences may be made virtually imperceptible, during normal playing, by shaping the nails carefully.

The problem has thus been reduced to that of shaping the three finger nails to function as *equal* ramps. It would be quite mistaken, however, to imagine this to be a simple matter of filing them all to the same profile. For one thing, each nail is likely to have a different cross-sectional shape, and must be filed to suit it. For another, each finger will come into the string at a different angle, whatever hand position is chosen. In particular, if the third finger *a* stands perpendicular to the string, as viewed

Fig 5.10 "Straight-line" method of filing nail

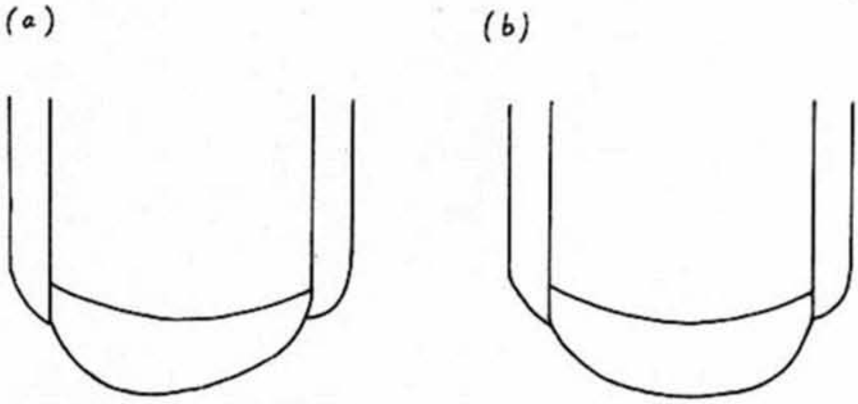


by a rough nail surface. Since the string is in contact mostly with the *inside* surface of the tip, this needs particularly careful polishing, especially on the leading side. However, towards the point of release it is the outside surface which contacts the string and which therefore needs special attention.

(b) The advantage of the straight-line method just described is that it gives reasonably good results whatever the natural shape of the nail and its angle of attack may be – provided, of course, that the angles α and β are correct. These have to be chosen according to the depth and steepness of slope required, taking into account the points mentioned in section 5.3. Beyond that, β depends mainly on the angle at which the finger comes into the string (as viewed from below the wrist), and α on the depth of the nail's cross-section. (If the nail is rather shallow, α may well prove too steep for the actual filing to take place in a straight line, since too much underfiling will obviously weaken the nail tip. In this case, the essential feature of the method may be retained by using the flat surface of the file as a template to check for straightness, while shaping the profile to a curve without tilting the file.) Getting both angles correct is no easy matter, and generally involves some trial and error; the method is therefore no panacea, but it can provide a useful starting-point towards finding the optimum shape for each nail.

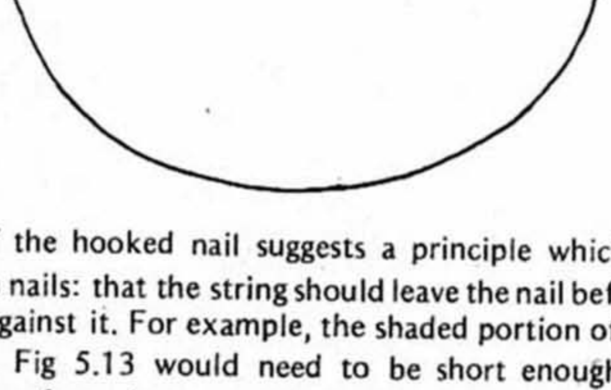
A small change in one of the angles, especially β, may have a radical effect on the final profile. The nail shown in Fig. 5.10 would probably work well for a finger which stood up perpendicular to the strings. If, however, the finger happened to lean one way or the other, so that β had to be changed by, say, ten degrees, then the final profile would look nothing like Fig 5.10(d); rather, it might resemble Fig 5.11(a) or (b). This one example shows how difficult it can be to judge whether a nail will work well, just by looking at it – and it also explains why other people's nails often look so peculiar. Certainly, it is futile to copy another player's nail profiles, and worse still to criticise them, without trying to understand exactly how each nail is used.

Fig 5.11 Profiles obtained by changing the angle β



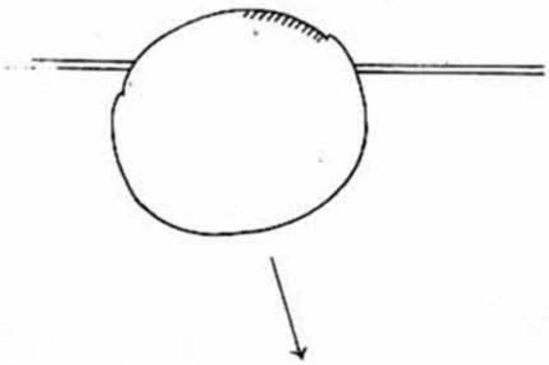
(c) A nail which hooks over near the middle, as shown in Fig 5.12, is particularly difficult to fashion into a ramp. In fact, the nail will tend to function as two separate ramps: a string moving from A to B will get stuck again at C before finally moving off at D. Clearly, this makes one ramp too many and the best solution is to file the entire portion from B to D down, out of the string's path, so that the string "sees" only the first ramp, from A to B. An unusual alternative would be to use only the portion from C to D.

Fig 5.12 Hooked nail



(d) The problem of the hooked nail suggests a principle which applies equally to less troublesome nails: that the string should leave the nail before the latter's curve begins to turn against it. For example, the shaded portion of the nail used at the angle shown in Fig 5.13 would need to be short enough to miss the string completely. Apart from the support it provides, the extreme trailing side of the nail generally has no function other than that of keeping well out of the string's way.

Fig 5.13 Shaded portion of nail should miss string



(e) The shaping has to take account of the texture of the nails. There is no point, for example, in trying to make a steep ramp out of a soft nail. Instead of projecting the string downwards, the nail will simply bend back under the string's pressure. To function as a ramp at all, a soft nail must be kept fairly short, and shaped to present a gentle slope to the string. Even then, it may be difficult to set a string vibrating with a strong perpendicular component, especially in tirando, and this is why very flexible nails tend to make a thin sound, lacking in body and volume.

Hard nails also have their problems. The "click" due to the initial contact between string and nail becomes increasingly prominent, the harder the nail is. However, this noise may often be reduced by adjusting the length of the leading side so that the soft flesh contacts the string just ahead of the nail, thus cushioning the impact. A hard nail also needs to be shaped very carefully into a smooth ramp, since it will not blanket out the effect of any slight imperfections in its shape by yielding. Ultimately, a hard nail can never give quite as smooth a ride as a nail with some "spring", and its sound will always have a certain hard edge.

Perhaps the ideal would be a nail with a firm leading side (to push the string down firmly) but a flexible trailing side (to release it smoothly). To have such nails growing naturally would require miraculous luck; but if a player feels the need to reinforce his nails, with tissue-paper and nail varnish or whatever, he may like the result of building up the leading side only.

(f) Most of the above points apply equally to the thumb. Obviously, the thumb nail must be shaped to suit its own natural angle of attack, which is quite different from that of the fingers. Normally, the string first contacts the nail somewhere near its centre and moves off from the bottom corner, although some players like to bend the thumb back far enough to use the nail as a ramp in the other direction. However, for most purposes, the part of the thumb nail used for playing need not be turned far off the line of the string – indeed, an unpleasant rasp can result if the nail comes too steeply across one of the wound basses. Like the finger nails, the thumb nail can be used in many different ways to vary the sound; or, unlike them, it can quite easily be excluded from the stroke completely, to give an especially warm bass or perhaps a fleshy six-string chord.

Although the thumb nail has been somewhat neglected in this chapter, it is certainly not unimportant. On the contrary, its shaping can have a profound effect, for better or worse, on the working of the right hand as a whole. For example, if the bottom corner of the nail tends to catch on the string (a very common problem), then not only will the bass sound thin and wiry, but it will also be difficult or impossible to play an apoyando with the thumb from a normal hand position. The hand is thus forced out of position whenever a thumb apoyando becomes necessary, and the instability so caused can undermine right-hand control generally, as well as making particular passages awkward (for copious examples, see the first two Preludes of Villa-Lobos). As if all this were not enough, the extra force required to push a catching nail through a string brings no reward in terms of tone quality, but only adds unnecessary tension. From every point of view, then, it is essential that the thumb nail be able to project the string firmly but easily under it, using apoyando or tirando, without disturbing the hand from its normal postion. If all three finger nails are able to do the same, then one has at least the basis of a sound right-hand technique.

CHAPTER 6 SOME CONTROVERSIAL ISSUES

6.1 The difficulty of being objective

Up to now an effort has been made to keep the discussion reasonably objective, but such an approach obviously has its limits. The further the argument moves from basic principles to the details of actual techniques, the more assumptions have to be made and the more difficult it becomes to resist the influence of one's own habits. Nor is it so easy to be objective even about the principles, since there is always the question of emphasis. The reader might be forgiven for feeling that there has been an over-emphasis in the last two chapters on the principle of projecting the string towards the soundboard – but I believe this to be *the* key idea in tone production which has hitherto been almost totally neglected.

Over and above these considerations, there remains the difficulty of being at all objective about the sounds themselves. For instance, no two people are likely to agree on exactly what constitutes the good "normal" sound which there has been so much talk of cultivating. Even the idea of having a "normal" sound, and a "normal" hand position to produce it, could conceivably be viewed as restrictive, favouring uniformity at the expense of diversity. In short, one could scarcely write anything definite about tone production without betraying certain preconceptions and offending some people's sensibilities. For this final chapter, therefore, I propose to give up the unequal struggle and indulge my own personal opinions, for what they are worth.

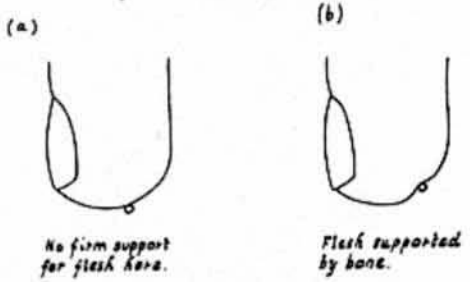
However, this chapter also has the more substantial purpose of showing that there is precious little objective basis for the more dogmatic statements which are frequently made about technique. It simply will not do to rule out of court a procedure which can be seen and heard to work perfectly well for some fine performer, but this happens all too often. When not due to plain ignorance of the basic principles, such contradictions usually arise either through a failure to allow for individual physical differences or through the use of objective terms (e.g. "correct" or "incorrect") where the question is really one of personal taste. It is hoped, therefore, to shed some light on a few much-disputed issues, and at the same time to give some idea of the scope there is, within the limits of "good technique", for each individual to find ways of producing the sounds he wants.

6.2 Nails or flesh or both?

The question of whether or not to use the nails at all is perhaps as old as the instrument itself. Pujol[1] has surveyed the history of this dilemma, and reviewed the arguments on either side, from the point of view of a confirmed "flesh-only" player. His discussion is, quite properly, mainly subjective; indeed, the non-use of the nails could hardly be defended in any other terms. Compared with a well-shaped nail, the average fingertip makes a crude tool indeed. It has none of the versatility of the nail, which can be turned at different angles to give sounds ranging from the round and silky to the spiky and metallic. With the flesh, real brilliance is virtually out of the question (since the higher partials tend to be suppressed), and playing near the bridge is almost self-defeating.

A fat or rounded fingertip like the one shown in Fig 6.1 will not project the string down very much, unless the string is engaged deeply enough for the bone to give the flesh some support, as shown in diagram (b). In this case, the string is faced with a long ride under the tip, which is indeed an advantage when playing apoyando at full volume. The problems arise when quieter sounds, which still have body and clarity, are required. A full tirando sound is especially difficult to produce with this kind of tip, because if too little flesh is used the string will slip off it without being pushed down appreciably, while to engage more flesh is to run the risk of drawing the string *away* from the soundboard before release, with the disastrous consequences mentioned in section 4.1.

Fig 6.1 *Rounded fingertip*



To be fair, it must be said that fingertips, like nails, vary considerably. The worst possible tip would be wide, bulbous and flabby, with perhaps a little dead skin to add to the unwanted noise. Fortunately, nature is seldom so unkind, and occasionally one comes across fingertips which might have been expressly made for guitar-playing. This type is firm but slender, and tapered down to the nail (see Fig 6.2). Such a tip makes an excellent natural ramp, with the nail itself for support. A matching set of such fingertips is rare, but probably more common among women than men.

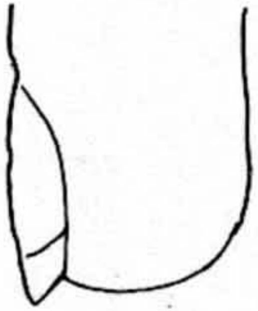
Fig 6.2 *Tapered fingertip*

Given suitable fingertips, the use of the flesh alone has much to recommend it. The player feels a closer contact with the strings, and the sound is unique – typically soft-toned and intimate, but sometimes virile and earthy. Some are prepared to sacrifice all the brilliance, clarity and variety of nail sounds for these qualities; but the vast majority of serious players today consider this too high a price to pay, a fact perhaps reflecting the general swing away from the romantic outlook, with its rather narrow conceptions of beauty in sound.

What, now, of the possibility of using both flesh *and* nail? In the case of a fingertip like the one shown in Fig 6.2, there is no reason at all why this should not work. The nail would have to be filed so that its leading side just protruded above the tip, thus making tip and nail into one continuous ramp. The player would then have the option of employing this composite ramp to produce a full apoyando sound with some of the quality of flesh tone; or alternatively, he could use the nail alone, perhaps by raising the wrist a little or by changing to tirando.

By contrast, the tip shown in Fig 6.1 above would be as troublesome when used in conjunction with the nail as it is by itself. Moreover, being rounded instead of tapered, this tip could not form the beginning of a composite ramp, leading the string smoothly on to the nail. Having passed the peak of the flesh, the string would be held up again by the nail, and would have to duck under this second obstacle before finally moving off (see Fig 6.3). Obviously, the flesh serves no useful purpose in this case, and a "nail-only" technique is the best solution. Accordingly, the nail has to be grown long enough to avoid more than a brushing contact of the string with the flesh. This light contact can be useful in giving the player the feel of the string, as well as reducing nail "click"; but some players prefer to do without it, literally using the nails alone.

Fig 6.3 *Rounded fingertip with nail*



6.3 Long nails or short?

Of all the differences between the techniques of accomplished nail-players, none is more striking than the variety of nail lengths used. However, this fact seems to have deterred few authors from laying down hard and fast rules. It is often recommended that each nail protrude about one-sixteenth of an inch beyond the tip of the finger (a reasonable length, admittedly), while Duarte, always at pains not to mislead by quoting measurements which fail to allow for personal differences, argues only for keeping the nails as short as practicable[2]. The trouble with unequivocal rules of this kind is that few experienced players find that it helps to pay the slightest attention to them. Finding the optimum length for each nail is largely a matter of experiment, and can take an inordinately long time if one begins with very narrow preconceptions.

Several of the factors which have a bearing on nail length have already been mentioned in passing; the following is a summary of them.

(a) A nail cannot work properly as a ramp, projecting the string well down towards the soundboard, unless it has a certain minimum length. If a nail is taken down too short, its sound becomes weak and thin, especially in tirando. Often a few days' growth is then all that is needed to bring about a marked improvement in fullness and volume.

(b) The finger nails have to be filed to suit the wrist height adopted. If the wrist is set rather low, the nails need to be longer than if an arched wrist is used.

(c) Similarly, the optimum length depends on the relative amounts of apoyando and tirando a player likes to use. If apoyando is employed only occasionally, the nails have to be long enough to give a very full tirando sound, while shorter nails are convenient if a lot of apoyando is used.

(d) Weak or flexible nails have to be kept fairly short, because the longer they are grown the more they will yield to the string instead of pushing it firmly downwards.

(e) Nails which hook over are generally less troublesome the shorter they are kept.

(f) If the fingertip is suitably tapered, the possibility arises of using a combined flesh and nail technique. In this case, the length of the leading side of the nail must be adjusted to allow a smooth transition from flesh to nail.

(g) If, on the contrary, the tip reaches a peak some distance away from the point of attachment to the nail, the latter needs to be long enough to be used without any interference from the flesh. If the nails grow strong and straight, and if a truly "nail-only" technique is adopted, then it matters relatively little how long the nails are, provided that they are not too short.

6.4 "Plucking" v. "Striking"

Before considering this rather difficult question, it may be worth mentioning that, according to the physicist's definition, the normal action of sounding a note is always one of plucking as opposed to striking, just as the quill of a harpsichord plucks the string (though usually moving through it at a high speed), whereas the hammer of a piano strikes the string. However, there are certain guitar sounds which *are* produced by an impulse, other than the obvious percussion effects of *golpe, tambora,* etc. One is the ascending slur ("hammer"), in which some of the second note's sound comes from the impulse of the new fret on the string. The action of the fret is similar to that of a clavichord's tangent, which has the dual function of setting the string vibrating and defining its vibrating length. Flicking a string with the back of a nail, as in *rasgueado,* though still essentially a pluck, also has an element of the clavichord action about it[3]. When the nail meets the string, it impulsively sets each of the two portions of the string on either side of it briefly into vibration. (If the nail is made to stop on the string instead of moving through it, these two notes may be heard quite distinctly, along with the inevitable noise.) Since the two notes are, in general, harmonically related neither to each other nor to the final note, they introduce some dissonance to the composite sound. The same is true, to a lesser extent, of all "clicks" due to the initial contact of string and nail.

However, these digressions have little to do with the distinction between plucking and striking which a guitarist might understand. In a "plucking" action, the fingertip or nail is considered to be initially at rest on the string, no matter how briefly; in "striking", it comes at the string from a distance and is already moving at the time of contact. Now, although these two actions may *feel* quite different, from the string's point of view there may be virtually no difference at all. In either case, the string finds itself first drawn aside and then sliding quickly under the nail and off; so the sound is unlikely to be affected much by the speed at which the nail approached the string, except perhaps in respect of the noise produced on contact.

What clearly does make a difference – and here we qualify the statement made in section 5.1 – is the speed with which the nail moves through the string after the first contact. Any tendency for the string to catch or get stuck will be reduced if the nail moves quickly through; similarly, a nail soft enough to "give" disastrously when pushed through slowly may work quite effectively if its stroke is quick. The action of tirando, moreover, simply does not work in slow motion, because of the danger of drawing the string away from the soundboard. In tirando, the nail has to project the string downwards, release it, and then rise clear of the next string; generally speaking, the more quickly all this is done, as one continuous finger movement, the better. None of these points, however, should be interpreted as an argument for "hitting" the string. Many good teachers and players (John Williams among them[4]) recommend beginning every stroke on the string, or when this cannot be done without destroying *legato*, as close to it as possible. There is no inconsistency here: it makes no difference how long in advance the initial contact is made, provided that the actual stroke, the movement through the string, is quick. On the other hand, there is nothing intrinsically "wrong" with striking either, except in so far as economy of movement is sacrificed. Starting a short distance from the string obviously makes it easier to move quickly through, and may even be found essential if the nails are very flexible. Yet again, it is a question of one man's meat . . .

The whole issue is further complicated by the difficulty of sorting out one sensation from another. For example, a player who thinks of the action as a quick "impulse" is likely to produce a stronger, more explosive sound than a player who thinks of pushing slowly through; but it seems to me that the real distinction here is less in the speed of the stroke than in its *firmness*. In the former case the finger is braced for a quick attack; in the latter it is likely to yield more to the string, giving it a gentler ride. Worth noting, too, is that the less firm the stroke, the more noticeable will be the effects of any small imperfections in the nail shape, because the string will find it easier to push the nail up than to slide under it wherever the slope it presents is not perfectly smooth and gentle. If the finger is held firm, however, such minor imperfections matter less: though perhaps a little rough, the sound will still be strong and full, for the string has no choice but to shoot under the nail.

The basic objective for a normal sound, that each nail project the string smoothly downwards without detaining it more than necessary (see the end of section 5.2), is therefore best achieved using an action which is both quick and firm. However, there is ample scope for varying tone quality and attack by using a different "touch". Slow, gentle strokes can often be effective, especially for drawing out the notes of a quiet melody – perhaps using the gliding apoyando. Nor, for that matter, would every player want his normal sound to be *too* powerful and incisive. This is a highly personal area of technique, where the most rigid teaching methods cannot prevent individuals from producing their own sounds in their own ways. Of course, a teacher should encourage a good basic action, and show the student how to vary his attack; but there will always be some who are "pluckers" at heart, and others who are "strikers".

6.5 Tip joints: firm or relaxed?

One of the odder ideas in guitar teaching, which had quite an influence some years ago, was to seize on a particular aspect of right-hand technique – the fact that some players sometimes allow the fingertips to bend back during the stroke – and to make it the corner-stone of the method, with the attractive principle of *relaxation* invoked to support it[5]. Not for the first time (and with what implications for our own ideas?) we are reminded that "men may construe things after their fashion, clean from the purpose of the thing itself." Relaxation is one thing; letting a joint which is supposed to be transmitting force to the string go completely flaccid is surely another. Moreover, as Duarte points out, it is both mechanically inefficient and unduly complicated to have the fingertip bending back while the rest of the finger moves forward[6].

make sense of a line punctuated with arbitrary changes of colour. A much more satisfactory use of apoyando is to separate melody from accompaniment, or one voice from another, by this colour contrast. Using apoyando for an entire line, rather than just for occasional notes, not only makes the line itself sound more coherent, but also sets it clearly in relief from the rest of the musical texture.

Of course, this idea is all very well in theory, but in solo guitar music it is rare to find any line, in treble or bass, which can be played apoyando throughout. (Obviously apoyando is ruled out whenever the next string has to be sounding simultaneously.) For this reason it is a good idea for any guitarist to cultivate a tirando sound which is sufficiently solid and full to be almost indistinguishable from apoyando when used as a substitute. Some players follow this line of development further still, and by making their nails work as deep ramps, they are able to produce sounds with tirando which others fairly struggle to obtain with apoyando. This enables them to command as wide a range of colour and dynamics as they normally need without having to resort to apoyando, and thus without having constantly to inquire whether the next string is supposed to be vibrating. Needless to say, such players are not getting "something for nothing": they have to work just as hard with their tirando to get the power for which others use apoyando. Indeed, they may even have to work harder, because in tirando the finger has to resist not only the upward force of the string as it moves under the nail, but also the downward reaction following its release (see section 5.2). This is, therefore, only one possible solution, open only to those with nails strong enough to be grown rather longer than average, and with strong fingers to keep them under firm control. Many of the finest players prefer to use a lot of apoyando, and accordingly to keep their nails quite short.

In teaching beginners, the choice is rather different. To produce a full sound with tirando requires some skill and, preferably, a well-shaped nail; with apoyando, by contrast, neither is needed. Almost any complete beginner can make a strong sound of acceptable quality, provided that the flesh only is used and that the fingers play only firm apoyando strokes. (The thumb meanwhile has to be restricted to tirando, since few people can manage simultaneous apoyando with finger and thumb at first; and, if they could, the bass would tend to overpower the treble on most guitars.) An increasing number of teachers are now introducing apoyando as the *only* stroke for the fingers at first, which not only encourages good tone production from the start, but also allows the right hand to be more relaxed than if tirando were introduced immediately. The music has to be restricted to two-part solos with the parts carefully spaced, or single-line ensemble music, which is excellent for sight reading and time-keeping in any case. By the time the student has gained enough finger control to make a proper attempt at tirando – when, that is, he can make a tirando stroke which is almost identical to apoyando, neither clawing the string upwards nor causing the hand to bounce – he will already be accustomed to producing a full-bodied guitar sound and will be unwilling to settle for less. There will certainly be a tendency for the sound to weaken when tirando is introduced, as also when the nails are first used, but not to the extent of that anaemic scratching at the surface of the strings, so common among students who have never been taught apoyando. On the debit side, it must be said that this method of teaching severely restricts the beginner's choice of music, indeed ruling out almost everything that a guitar can do most easily and effectively. (Of the vast early 19th century student repertoire, based as it is on an all-tirando technique and making free use of chords, arpeggios, etc., only a handful of pieces are suitable.) Besides, for all its advantages of power and security, apoyando can become irksome if insisted on too rigidly, for the tirando action undoubtedly feels more natural. The question of how soon, and in what order, to introduce each of the two strokes, is really a question of priorities. If the aim is