STUDIES OF MUSIC PERFORMANCE

(J. Sundberg, editor)

Papers given at a seminar organized by the Music Acoustics Committee of the Royal Swedish Academy of Music

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PREFACE

On October 23, 1982, the Music Acoustics Committee of the Royal Swedish Academy of Music arranged the eighth full day public seminar which was devoted to various aspects of analyis of musical performance. Two foreign speakers, Manfred Clynes from the New South Wales Conservatorium of Music, Sydney, Australia, and Christopher Longuet-Higgins, University of Sussex, England. Also, professor Ingmar Bengtsson and docent Alf Gabrielsson of the Uppsala University and myself reported on our works in this area. Written versions of these papers are now published in the present volume. As with previous issues in this series of books published by the Academy on various topics in the field of music acoustics we are fortunate enough to offer sound illustrations on the grammophone records enclosed, which still remains a remarkably rare arrangement in books dealing with sound.

The different articles in this book attack questions raised by music performance in different ways. Longuet-Higgins uses a theoretically oriented approach. Bengtsson and Gabrielsson focus on measurements of tone durations in music performance. Frydén and myself apply the method of analysis by rule synthesis. Clynes has a special background in his "sentics", which can be regarded as a sort of science of human emotional gestures. The different articles can be said to reflect the fact that music performance research represents a rather new research field. For instance, the reader will find indications of the need for a further exchange and development of thoughts and experiences within this field and even between the authors. It is pertinent to recall, however, that the word "seminar" is derived from a Latin word for sowing. I am convinced that the present volume will efficiently fulfill its purpose to sow thoughts and ideas of music performance, some of which will certainly be further developed in the future.

The responsibility for producing the grammophone records was assumed by Bertil Alving. Mervi Moisander-Webster typed the manuscripts.

KTH, July 1983

Johan Sundberg
Editor
Chairman of the Music Acoustics Committee

The Rhythmic Interpretation of Monophonic Music

H.C. Longuet-Higgins & C.S. Lee
Laboratory of Experimental Psychology, University of Sussex

1. Introduction

When a listener hears a tune played or sung without accompaniment, he does not merely perceive the relative pitches and durations of the notes; he becomes aware, to a greater or lesser extent, of the tonal and rhythmic relations between them - for example, whether the tune is in a major or minor key,and whether its rhythm is that of a march or a minuet. In assigning a rhythmic interpretation to a particular passage, the listener will generally be influenced by clues of many different kinds. The notes of the passage may be differentely accented; some of them may be played staccato and others legato; rhythmic clues may be supplied by the tonal relations between the notes; and in vocal music the words themselves may exert a dominant effect. But there is one source of evidence that is always available, even when there are no words, when the notes are of indefinite pitch, and when the performance is devoid of accent, phrasing or rubato: even in such impoverished conditions the listener may still arrive at a rhythmic interpretation of the passage, based solely on the relative durations of the notes. It was, we believe, Simon (1968) who first recognised the need for an account of how listeners perform this lowly perceptual task, and since that time Longuet-Higgins and Steedman (1971), Longuet-Higgins (1976), Steedman (1977), and Longuet-Higgins & Lee (1982) have suggested partial solutions of the problem. In this paper we take a step back and consider the criteria which might lead a listener to favour a particular rhythmic interpretation of a given sequence of notes.

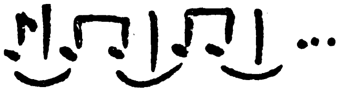
The paper falls roughly into three parts. In Sections 2 and 3 we develop a generative theory of musical rhythms in the same spirit as the work of Lindblom and Sundberg (1972), but focussing particularly on the rhythms of individual bars, and their relation to the underlying metre. We pay special attention to the concept of syncopation, and in Section 4 - the middle part of the paper - we suggest that in assigning a rhythmic interpretation to a sequence of notes the listener tends to avoid interpretations which demand either syncopations within bars or syncopations across bar lines. Section 5 sketches some hypotheses about the perception of higher-level rhythmic structure, and in Section 6 - the last main part of the paper - we consider the role of the performer in clarifying for the listener what might otherwise be rhythmically ambiguous sequences; in this section we pay special attention to the grouping of notes into phrases by the device of slurring together adjacent notes.

Our data and predictions, like those of Lindblom and Sundberg (1972), refer in the first instance to written music, just as the data and predictions of the theoretical linguist usually refer in the first instance to printed text. The reader may feel that this restriction evades a number of important issues connected with the live performance of real music, but the expressive qualities of live performances vary so widely that we have felt it essential to restrict the discussion in some way, and we have done this by concentrating on those directions about a performance which a composer customarily indicates in a musical score, such as whether a particular note is to be played staccato or legato. Our appeal is therefore not to the auditory sensibilities of the reader but to that part of his musical intuition which is engaged when he reads a musical score which indicates the values of the notes and the way in which they are meant to be phrased; in a sense we appeal to him as a potential performer, who has to decide how the musical listener is likely to interpret the music if it is performed according to the composer's directions.

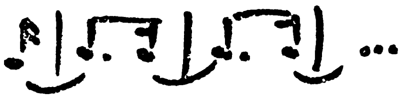
We start, then, by considering unadorned sequences of note values, and how a listener might assign them rhythmic interpretations. The following examples may convince the reader that the problem is more subtle than it might seem:

(a) An isochronous sequence of notes such as the chimes of a clock has no obvious rhythmic structure, in that the notes might be felt to be grouped in twos or in threes, with or without "upbeats":

But, at least if heard in isolation, the sequence is most unlikely to receive any of the following (theoretically possible) rhythmic interpretations:



(1)



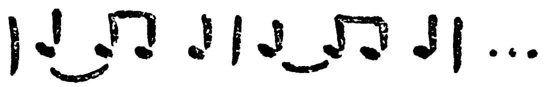
(2)

(3)

(b) If the relative values of the notes are as shown in (4)

(4)

then the sequence has the obvious rhythmic interpretation (5), rather than, say, (6) or (7):

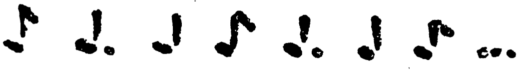


(5)

(6)

(7)

(c) If, on the other hand, the relative note values are as shown in (8), then the obvious interpretation is (9) rather than, say, (10) or (11):



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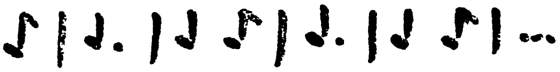

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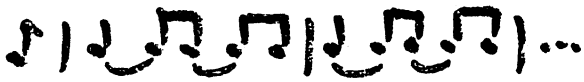


(10)

(11)

These particular facts (assuming the reader to accept them as such) are, of course, uninteresting in themselves; what is of interest is whether they exemplify any generalisation about the perceptual propensities of musicians. We suggest that they do, and in the following paragraphs we attempt to formulate such a generalisation as precisely as possible, and to show that its implications accord with common musical intuition.

2. The Theory of Metrical Rhythms

In recent years it has been recognised (Martin 1972, Lindblom & Sundberg 1970, 1972, Longuet-Higgins 1976, 1978) that there is a close parallel between metrical rhythms (as opposed to the "free" rhythms of plainchant or recitative) and the syntactic structures of sentences. A metrical passage is one which could be assigned a "time signature" such as 4/4, 3/4 or 6/8; what such a signature specifies is actually a grammar consisting of a set of context-free realisation rules such as the following:

4/4 -> 𝅝 or 𝄻 or (2/4 + 2/4)
2/4 -> 𝅗𝅥 or 𝄼 or (1/4 + 1/4)
1/4 -> ♩ or 𝄽 or (1/8 + 1/8)
1/8 -> ♪ or 𝄾 or ....

In such a set of rules the symbols 4/4, 1/8 etc. (which have been adopted here for their appeal to musical intuition) are not themselves notes or rests, though they may be realised as such; they correspond to entities such as bars and beats, and may be said to designate "metrical units" at various levels in a metrical hierarchy. In the commonest metres each bar or shorter metrical unit is divisible into either two or three metrical units at the next level down; if this is the case the metre may be described as a "standard" metre, and represented by a list consisting entirely of 2's and 3's. Thus the 4/4 metre specified above would be represented by the list (2 2 2...1), indicating that the bar - the top-level unit - is divisible into 2, the half-bar is also divisible into 2, and so on.

The time signatures 3/4 and 6/8 indicate metres with different realisation rules namely

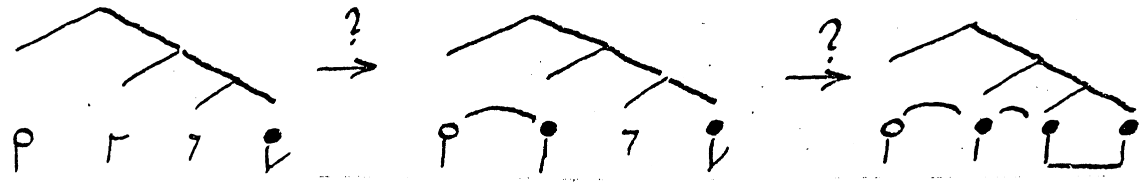
3/4 -> 𝅗𝅥. or 𝄼. or (1/4 + 1/4 + 1/4)
1/4 -> ♩ or 𝄽 or (1/8 + 1/8)
1/8 -> ♪ or 𝄾 or ....

and

6/8 -> 𝅗𝅥. or 𝄼. or (3/8 + 3/8)
3/8 -> ♩. or 𝄽 𝄾 or (1/8 + 1/8 + 1/8)
1/8 -> ♪ or 𝄾 or ....

The time signature commonly used for specifying such metres usually imply only the first one or two divisions of the bar; in the notation that we are proposing the 3/4 and 6/8 metres would be symbolised as (3 2) and (2 3) respectively. (We shall not enter here into the detailed description of "context-sensitive" metres, in which, for example, the first beat of a bar is divisible into 2 and the second into 3; or of "variable" metres, in which the bar, or any subunit thereof, is optionally divisible into either 2 or 3 units at the next level down.)

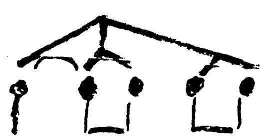
By the progressive application of the realisation rules of a given metre we generate a "tree" structure, in which the "root" node represents the whole bar, and the other non-terminal nodes represent lower-level metrical units. At this point the terminal nodes of the tree are all either (sounded) notes or rests; in order to allow for tied notes (notes that are tied back to their predecessors, rather than being separately sounded), a further rule is now invoked: if any note N, sounded or tied, is immediately followed by a rest R, then R may be replaced by a note that is tied back to N:



Finally, in order to avoid meaningless sequences of rests or tied notes, it is stipulated that any divided metrical unit consisting entirely of rests, or of notes that are tied together, is replaced by an undivided unit composed of a single beat, or of a single note that is sounded or tied according as the first note of the replaced unit was sounded or tied:

Any tree that results from the application of a set of metrical realisation rules, and the metre-independent replacement rules just stated, is a possible rhythm which accords with the given metre. The relation between the rhythm and the metre may be simply stated: the former is one of the structures that is generated by the grammar associated with the latter. On this view, a rhythm is much more than just a sequence of note values; it is a syntactic structure in which the note values are implicit in the terminal symbols, but do not by themselves define the rhythm; if they did, then no sequence of note values could be rhythmically "ambiguous" - open to alternative rhythmic interpretations - as such sequences undoubtedly are.

To show that the formal theory just described accounts quite naturally for the phenomenon of rhythmic ambiguity, one example should suffice. A bar consisting of a dotted crotchet (quarter-note) followed by three quavers (eighth-notes) might be, in common parlance, "in either 3/4 or 6/8." In the terms of the present theory, such a bar is generated both by the metre (3 2) and by the metre (2 3):



The relative note values are the same for both, but the structures to which they belong are quite different, and it is the existence of these alternative structures that constitutes the rhythmic ambiguity of the sequence.

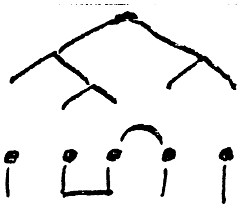
This example might suggest that rhythmic ambiguity is a merely sporadic occurrence, like syntactic ambiguity in sentences; but in fact it is an all-pervasive musical phenomenon. As the reader will already have noticed in inspecting examples (a), (b) and (c) of section 1, even the most innocuous sequences of note values permit an unlimited number of rhythmic interpretations. Hence, insofar as listeners agree on the rhythms of given sequences of note values, we can infer that the process of rhythmic perception must be tightly constrained by some tacit assumption as to what counts, or does not count, as a "natural" interpretation. In the following sections we are largely concerned with the uncovering of just such an assumption; but in order to state the assumption precisely, it is first necessary to clarify another rhythmic concept - that of syncopation.

3. Syncopation

Informally, most musicians would agree that the rhythms (12) and (13) are syncopated, whereas (14) and (15) are not; (16) is perhaps a marginal case:

(12)

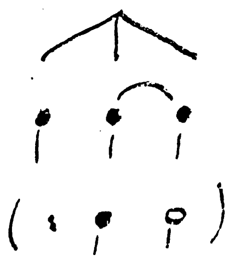
(13)



(14)

(15)

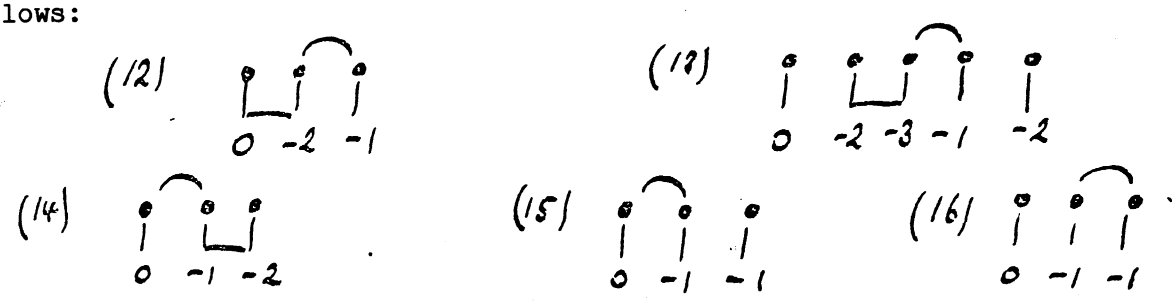
(16)



What is the difference? Surely that, in (12) and (13) at least, a "heavier" note is tied back to a "lighter" sounded note, whereas in (14) and (15) the "heavier" note is the first of the tied pair. This observation suggests that in order to pin down the concept of syncopation we need to define the "weight" of a note or a rest; the following definition seems to accord with intuition:

The weight of a given note or rest is the level of the highest metrical unit that it initiates. (The level of the topmost metrical unit is arbitrarily set equal to 0, and the level of any other unit is assigned the value n-1, where n is the level of its "parent" unit in the rhythm.)

On this definition, the weights of the notes in (12) to (16) are as follows:



We are now in a position to define a syncopation:

If R is a rest or a tied note, and N is the next sounded note before R, and the weight of N is no greater than the weight of R, then the pair (N,R) is said to constitute a syncopation. The "strenght" of the syncopation is the weight of R minus the weight of N.

Thus in (12) and (13) we have syncopations of strength 1 and 2 respectively, and in (16) a syncopation of strength 0; but (14) and (15) contain no syncopations - as musical intuition demands.

So far our discussion of rhythmic structure has been confined to the individual bar, for which the entire rhythm descends from a single node, the level of this node being arbitrarily set to zero. But many monophonic passages consist of sequences of bars which may or may not be grouped into higher metrical units. The concepts of level and weight may nevertheless be applied to such passages: the level of any metrical unit in a sequence of bars can still be defined as zero if the unit is a full bar, and can otherwise be assigned the value that it would have if the bar containing the unit were considered in isolation. The same applies to the concept of weight: the weight of a note or rest can still be defined as the level of the highest metrical unit that it initiates. Then it will be appropriate to describe a sequence of bars as syncopated if and only if one of the bars contains a syncopation, or some bar begins with a rest or a note that is tied back to a sounded note of lesser weight.

4. Regular Passages

At this point the reader is invited to reconsider the note sequences (a), (b) and (c) of Section 1. In each case, the "natural" interpretations of the sequence are the only ones that are entirely unsyncopated; in all the alternative interpretations there are notes that are tied back to sounded notes of equal or lesser weight. We may suspect that this is a general characteristic of "natural" interpretations: that when a sequence of notes can be interpreted as the realisation of an unsyncopated passage, then the listener will interpret the sequence in this way. But the question immediately arises: if a note sequence is indeed the realisation of an unsyncopated passage, how can the listener arrive at such an interpretation of it, using no more information than the relative durations of the notes? This is the problem to which we now turn.

We define a regular passage as a sequence of bars satisfying the following conditions:

(i) Every bar, except possibly the first, begins with a sounded note (this ensures that there are no syncopations across the bar lines);
(ii) all the bars are generated by the same standard metre;
(iii) there are no syncopations within any of the bars.

We now show that if a sequence of notes is indeed the realisation of a regular passage, then the durations of the sounded notes (defined as the times between their onsets) supply useful evidence about the rhythmic structure. More precisely, we show that if D is the duration of the metrical units at level L, then the sounded notes whose durations exceed D must be spaced by time intervals which are multiples of D', where D' is the duration of the units at level L+1. So by considering notes of progressively greater duration we can, as it were, build up the metre from the bottom, until we reach the lowest metrical unit that accomodates the longest sounded notes. We will now present the steps in the demonstration as a series of lemmas with accompanying proofs.

Lemma 1. Let N be a sounded note, and let U be the highest metrical unit that N initiates. Then the duration of N cannot exceed that of U.

Proof. Let N be any sounded note except the last one in the sequence, and let S be the next sounded note after N; let U be the highest metrical unit that N initiates. Suppose, contrary to the Lemma, that the onset of S occurs later than the end of U. Then the end of U must coincide with the onset of a rest or tied note R; let V be the highest metrical unit initiated by R. Since the beginning of V coincides with the end of U, the level of V must be at least as high as the level of U. Hence the weight of R is no less than the weight of N, and so (N,R) constitutes a syncopation. But by hypothesis the rhythm is unsyncopated, and so the onset of S must occur no later than the end of U, as the lemma asserts.

Lemma 2. If D is the duration of the metrical units at level L, then every sounded note of duration greater than D must be of weight at least L+1.

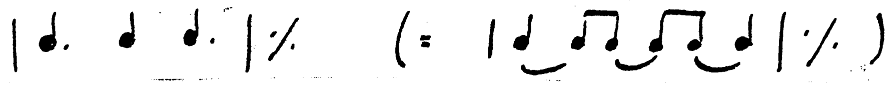
Proof. By Lemma 1, no sounded note of weight L can have a duration greater than D. Therefore any sounded note of duration greater than D must be of weight at least L+1.

Lemma 3. If L is any level in the metre, and if D is the duration of the units at that level, then the time intervals between the onsets of sounded notes of weight L or greater must be multiples of D.

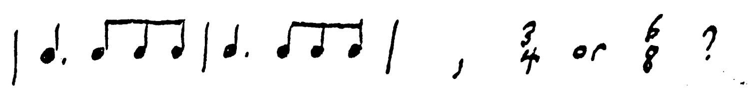
Proof. The duration of any metrical unit of level higher than L must be a multiple of D, because when a metrical unit is divided, its daughter units are of equal duration. But the sounded notes under consideration all initiate metrical units of level L or greater, so the lemma follows.

The task of determining the metre of a regular passage, and thus revealing its rhythmic structure, may therefore be broken down into the following steps:

First one must locate the shortest metrical units, and these will have the same durations as the shortest sounded notes. (This is not true for syncoped passages, such as



where the crotchet does not delimit the shortest metrical unit, which is at the quaver level.) The next step is to consider the set of all sounded notes of duration longer than the shortest metrical unit. By Lemma 3, the times of onset of these notes must be spaced by multiples of the next shortest unit. So if the shortest metrical unit is of duration D, and the highest common divisor of the spacings between sounded notes longer than D is D', we shall find that D'/D is an integer whose only prime factors are 2 and 3. (This conclusion rests, of course, on the assumption that the metre is standard.) If D'/D turns out to be a power of 2, then we can conclude that the metrical unit at the next level is of duration 2D, and if D'/D is a power of 3, the duration of the unit must be 3D. But if D'/D is a multiple of 6, then the next unit up might have a duration equal to either 2D or 3D; in this case the metre, and consequently the rhythm, will be ambiguous:



If D'/D has any other value, such as 1/2, 1, 3/2, 5, we can infer that there is no interpretation of the sequence as the realisation of a regular passage.

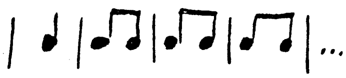
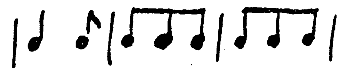
The remaining stages in the determination of the metre follow exactly the same lines. D is multipled by 2 or 3, as the case may be, and we form the set of all sounded notes whose durations are greater than the new value of D. If at any stage there is just one such note in this set, then the procedure fails to provide a regular interpretation of the sequence, since we need at least 2 notes of duration greater than D in order to determine D'. But if, for a given value of D, there are no sounded notes of duration greater than D, then the process comes to an end, and the metrical units of duration D can be identified as the bars of a regular passage.

To show how the procedure works in practice, we can apply it to the note sequence (4) of Section 1. The shortest notes are the quavers, and these reveal the lowest level of the metre. The sounded notes which exceed a quaver in length are the crotchets and the dotted crotchets; the highest common divisor of their spacings is a crotchet, so that D'/D = 2. The next metrical unit above the quaver is therefore a crotchet unit. The only notes longer than a crotchet are the dotted crotchets, and their spacing is a dotted minim, equal to three crotchets, so that the duration of the next metrical unit is a dotted minim. There are no notes longer than a dotted minim, so the process terminates, and we obtain a rhythmic interpretation of the sequence as the realisation of a regular passage in which the value of each bar is a dotted minim, and the metre is (3 2). This is the interpretation given in (5).

The note sequence (8) of Section 1 supplies another example. The shortest notes are the quavers, and the notes longer than a quaver are spaced by dotted crotchets, so that the quaver units must be grouped in threes forming dotted crotchet units. There are no notes longer than a dotted crotchet, so the process terminates, yielding an interpretation of the sequence as the realisation of a regular passage consisting of dotted crotchet bars as shown in (9). The associated metre is simply (3).

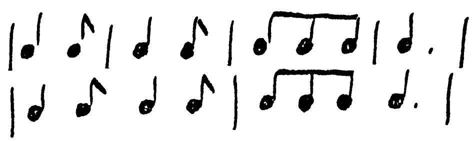
For the isochronous sequence discussed in Section 1 (a) the procedure finds the shortest metrical unit - of value, say, one crotchet - but as there are no sounded notes longer than a crotchet the process immediately halts, implying that every bar contains just one note. Though this interpretation is rather uninteresting, it does at least preclude the implausible interpretations shown in (1), (2) and (3).

As a final example we may consider the note sequence which consists of a single crotchet followed by several quavers. The quaver immediately establishes itself as the shortest metrical unit, but now there is only one note longer than a quaver. The presence of this note indicates that if the passage is regular there must exist metrical units above the quaver level. But we need at least two notes longer than a quaver to delimit this higher metrical unit, and only one note is available. This shortage of evidence corresponds to the fact that the quavers might indeed be grouped in either twos or threes:

 or 

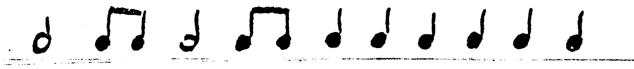
In short, there exists a parsing algorithm for note sequences which, when it succeeds, delivers an interpretation of the sequence as the realisation of a regular passage. When the algorithm fails at any stage, its failure is evident from the fact that either D' is not computable (because there is only one sounded note of duration greater than D) or the computed value of D'/D is not a power of 2 or a power of 3.

We can now return, with a clearer insight, to the question why listeners regard some rhythmic interpretations of note sequences as so much more plausible than others. We propose the following answers: that if the parsing algorithm just described succeeds in interpreting a note sequence as the realisation of a regular passage, then this interpretation will be implicit in the listener's interpretation of what he hears. We may describe one interpretation as being "implicit" in another if all the metrical units of the former are present in the latter; thus an interpretation which specifies the rhythmic structures of all the bars of a regular passage is implicit in a richer interpretation which goes further, and groups the bars together in twos or threes. Thus of the two interpretations shown below, the first is implicit in the second:



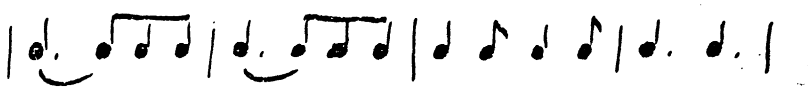
We close this section with a pair of real musical examples, to illustrate how the rhythmic ambiguity inherent in the first few notes of a sequence can be resolved by later notes, on the assumption that the sequence is the realisation of a regular passage. The examples are taken from the second movement of Beethoven's Piano Sonata Op. 109 and the second subject of the first movement of Brahm's Symphony No. 2. The relative note values (which in the first example disguise the rhythmic structure) are as shown in (17) and (18) below, the first six notes having the same relative values in both passages:

(17)



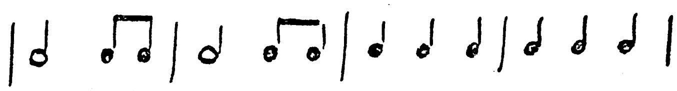
(18)

For both sequences the parsing algorithm yields a quaver as the shortest metrical unit; the question then arises how the quavers are grouped. In example (17) the notes longer than a quaver are spaced by the following numbers of quavers: 6, 6, 3, 3 and 3; the highest common divisor of these numbers is 3, so the next metrical unit is of value 3 quavers, equal to one dotted crotchet. There are two notes longer than a dotted crotchet, and these are spaced by two dotted crotchets, so that the highest metrical unit accessible to the algorithm has a value of one dotted minim. In decreasing order of size, the metrical units are therefore a dotted minim, a dotted crotchet and a quaver, and the metre is (2 3); parsing the sequence according to this metre we obtain the regular passage shown in (19), which agrees with Beethoven's score.



(19)

In example (18) the notes longer than a quaver have the following spacings: 6, 6, 2, 2, 2, of which the highest common divisor is 2, so that the quavers must be grouped in pairs, forming crotchets. There are just two notes longer than a crotchet, and these are spaced by three crotchets, so that in descending order the metrical units must be a dotted minim, a crotchet and a quaver, yielding the metre (3 2). The sequence is thus interpreted as the realisation of a regular passage in 6/8 time, namely (20):



(20)

It will be noted that our analysis of the Beethoven example differs somewhat from that of Simon (1968), but he also made the point that the full metre of monophonic sequence may not become clear until after a few bars have been heard.

5. Higher-Level Rhythms

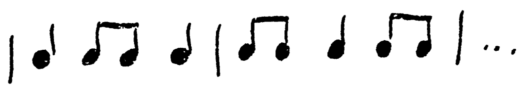
Our discussion has so far been confined to monophonic passages in which all the bars are generated by the same standard metre, but the bars are not necessarily grouped together into higher-level metrical units. In many passages, however - particularly complete melodies - higher-level groupings are musically apparent: in most folk tunes, for example, there is rhythmic structure at all levels, so that the whole passage may be assigned a rhythmic structure with a single root node (Lindblom & Sundberg 1972). In this section we consider how such higher-level rhythms might be perceived by the listener on the basis of the durations of the notes.

The problem of discerning higher-level structure arises, in the present context, from the fact that if every bar (except possibly the first) begins with a sounded note, then the bar itself is the highest level metrical unit that is accessible by the parsing algorithm described in Section 4. The reason is that no note can then have a duration longer than a single bar, so that if D is the duration of a bar, the duration D' of the units at the next level up cannot be computed from the highest common divisor of the spacings of notes with duration greater than D. For example, if the note durations are as shown in (21)


(21)

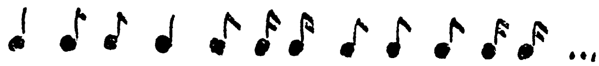
only two metrical levels can be discovered by the algorithm, namely the crotchets and the quavers; this <u>impasse</u> corresponds to the fact that both (22) and (23)


(22)

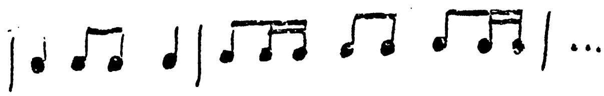

(23)

are possible regular interpretations of (21), satisfying the three conditions listed in Section 4, but in these two interpretations the crotchets are grouped in different ways. One does feel, however, that (22) is a more natural interpretation than (23); one therefore looks for perceptual reasons why this might be so.

An obvious property of (21) is that the notes of duration greater than a quaver are spaced by minims (1/2 notes), so that D'/D = 4, and since this is a power of 2, the algorithm adopts 2D as the duration of the metrical unit at the next level. But it might seem more natural to adopt D' itself, namely 4D, as a higher metrical unit. If this idea is in fact adopted, then one obtains not merely a grouping of the quavers into crotchets but also a grouping of the resulting crotchet units into minim units, with the result shown in (22), and perhaps this is one reason why (22) seems a more natural higher-level interpretation than (23). The resulting rhythmic repetition will undoubtedly reinforce this interpretation, as against (23), but repetition cannot be the whole story because for the note sequence (24) the natural interpretation is still (25) rather than (26).


(24)

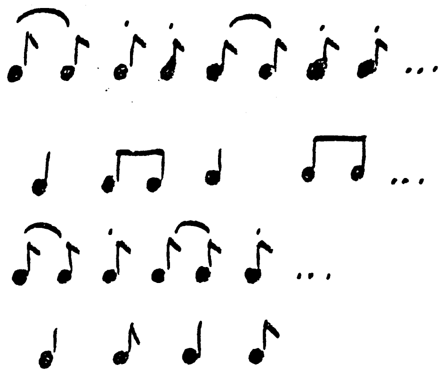

(25)


(26)

We are suggesting, in short, that although higher-level rhythms cannot be inferred from the regularity assumption as it stands, the listener may nonetheless perceive such higher-level groupings even if the notes of duration greater than D are quite widely spaced, provided that D'/D is still a power of 2 or a power of 3. But we must stress that this conjecture is logically independent of the assumption that the passage is regular in the precise sense defined in the preceding section.

6. The Role of the Phrasing

So far our discussion has been confined to extremely impoverished musical material, in which the only information accessible to the listener is that which can be derived from the times of onset of the notes. In real musical performances, however, the performer will not be content merely to sound the notes at appropriate moments; he will accent some notes more than others, advance or delay the onsets of some of the notes, and play some notes *staccato* and others *legato*. In this section we shall sketch a theory of the communicative function of such devices, and will suggest that in some cases at least they supply essential clues to the rhythmic structure. In particular we shall be concerned with the device of "slurring", though doubtless similar considerations would help one to understand the effects of accent or *rubato*.

In a musical performance of any interest there will be occasional gaps between consecutive notes. If, in a given sequence of notes, the offset of every note conincides with the onset of its successor, then we may describe the sequence as "slurred" or as constituting a single "phrase"; it follows that any sequence whatsoever can be partitioned into phrases, with a gap between the end of each phrase and the beginning of the next. We propose that phrasing, so defined, is not merely an ornamental device but can serve an essential function in making clear to the listener the rhythmic structure of a passage; the following examples should make clear the basis for this view:

(27)

(28)

(29)

(30)

Thus a sequence of quavers phrased as shown in (27) is likely to be assigned the same metre as the unphrased sequence (28), whereas if the quavers are phrased as shown in (29), the natural rhythmic interpretation will be closely related to that of (30). The effect of the phrasing seems to be to create "virtual" notes of duration equal to the individual phrases; if these durations are sufficiently long they may reveal metrical units of duration greater than the longest notes of the unphrased sequence. To illustrate the role that phrasing can play in the rhythmic clarification of note sequences, we may consider just one simple rule for phrasing the notes of a passage, whether regular or not:

If any metrical unit is divided (into 2 or 3), then slur together all the sounded notes which belong to it except those which descend from its rightmost node.

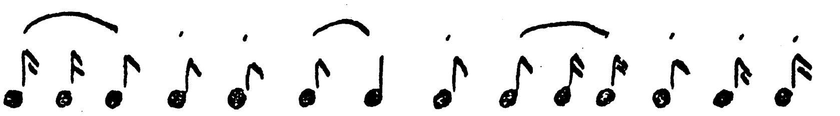
For a passage in which every bar begins with a sounded note, the effect of this phrasing rule is to replace the sounded note by virtual note which lasts for at least half the bar, or two-thirds of the bar, if the metre is ternary at the highest level. It is not difficult to see, furthermore, that the resulting sequence of virtual notes will be regular even if some of the bars of the unphrased sequence were originally syncopated:

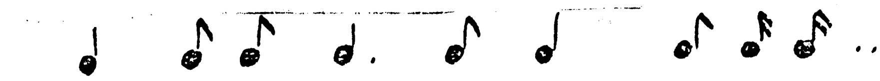
So if a passage is phrased according to the rule in question, then the resulting sequence will be amenable to the parsing algorithm of Section 4, and it becomes possible for the listener to establish its metre on the basis of the virtual sequence, and to use this metre (assuming it does not change from bar to bar) for parsing the individual notes of each phrase and thereby arriving at a rhythmic interpretation in which not necessarily all of the bars are unsyncopated.

To illustrate the use of phrasing for revealing the rhythmic structures of even syncopated passages we may consider a final pair of examples (derived from the opening of Bach's d Minor Klavier Concerto). The note values are as shown in (31)

 (31)

and if the passage is slurred according to the given phrasing rule, the result is as shown in (32); the corresponding virtual sequence is given in (33), and leads to the rhythmic interpretation indicated by (34), which is of course the interpretation that Bach intended.

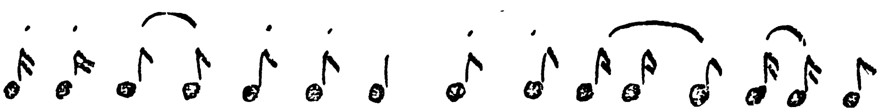
 (32)



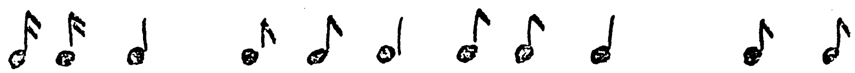
... 33)

... 34)

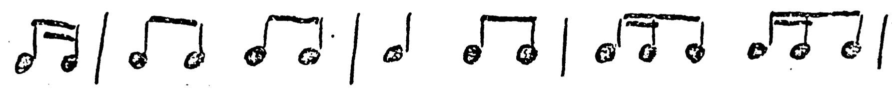
If, however, Bach's own bar lines are moved forward by one quaver, then the application of the phrasing rule leads to the slurring given in (35), corresponding to the virtual sequence (36); applying the parsing algorithm to this sequence we obtain the quite different rhythmic interpretation indicated in (37).



(35)



(36)



(37)

The reader will, perhaps, agree that such an inappropriate phrasing of the passage in question is liable to quite mislead the listener as to its rhythmic structure. The phrasing rule which we have used for illustration is not, of course, intended as an infallible guide to musical performance, but merely an illustration of our thesis that phrasing is not merely an ornamental device, but can have a crucial role to play in the elucidation of rhythmic structure.

7. Conclusions

i) Any given sequence of note values is in principle infinitely ambiguous, but this ambiguity is seldom apparent to the listener.

ii) It appears that in choosing a rhythmic interpretation of such a sequence the listener is guided by a strong assumption: that if the sequence can be interpreted as the realisation of a regular passage in the sense of Section 4, then that is how it is to be interpreted.

iii) The listener may well group the bars of this passage into higher-level metrical units, for reasons of the kind discussed in Section 5.

iv) Phrasing can make as important difference to the way in which the listener perceives the rhythm of a sequence, and even syncopated sequences which would otherwise be difficult to interpret can be rhythmically clarified by slurring the notes appropriately.

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ANALYSIS AND SYNTHESIS OF MUSICAL RHYTHM

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Abstract

After stating some basic premises for empirical rhythm research, the performance of musical rhythm is discussed with special reference to various duration variables in the performance. Several examples are given from analyses of music performances. These are taken as starting points for an interplay between analysis and synthesis in the investigation of musical rhythm. This is illustrated by means of examples taken from Mozart, the Vienna waltz and Swedish tunes (sound examples are included).

Introduction

A presentation of our research on musical rhythm through the mid 1970:s was given at an earlier seminar in Stockholm (Bengtsson & Gabrielsson, 1977). Here we will only briefly repeat some basic premises of this research and then proceed to demonstrations concerning analysis and synthesis of musical rhythm.

A general frame of reference for this work is provided by the following chain of events:

MUSIC PERFORMANCE $\longrightarrow$ SOUND SEQUENCES $\longrightarrow$ RHYTHM RESPONSE

Feed-back

Performance of music on various instruments produce sound sequences, which may elicit a rhythm response in the listeners (including the performers themselves). Thus, rhythm is regarded as a response to certain kinds of sound sequences. This response includes experiential, behavioral and psycho-physiological aspects in complex interactions. We may thus talk of rhythm as (a) experience (Swedish: "upplevelse"), (b) overt behavior, and (c) as psycho-physiological response, depending on the actual purpose and context.

Research on muscal rhythm addresses three basic questions:

1. What distinguishes rhythm from non-rhythm?
2. What distinguishes different rhythms from each other? and
3. How should music be performed in order to elicit the intended-/desired rhythm response?

These questions were discussed in our paper mentioned above, and only some comments are made here to provide a background for the following demonstrations.

As regards the second question, it was shown that rhythms differ experientially in various structural aspects (such as meter, accents, degree of complexity etc.), various motional aspects (such as tempo and an abundance of various motion characters described by expressions as "driving forward", "retarding", "swinging", "walking", "dancing", "jumping" etc.), and various emotional aspects ("vital vs. dull", "excited vs. calm" etc.). Usually the structural aspects of rhythms are discussed much more than the motional and emotional aspects. There are reasons to believe, however, that the last-mentioned aspects are at least as important as the structural aspects, and should be given more attention than is usually the case.

The emphasis in this paper will be on the third question, i. e. concerning the performance of musical rhythm. How do you play in order to bring about the adequate rhythm response in the listeners? The stimuli reaching the listeners' ears are sound sequences generated by the performer(s). Depending on the instrument(s) in question the performer is able to manipulate various properties of the sound sequences: durations, amplitudes, frequencies ("pitches"), spectra, onsets, decays etc. There are many reasons to believe that the durational characteristics of the sound sequences are of primary importance for the rhythm response. In the present article we will therefore concentrate on various durational variables. This does not mean that other variables will be neglected, only that we make a simplification to facilitate the analysis at the present stage of knowledge.

Different concepts of duration

When dealing with sound sequences there are (at least) three duration variables to be considered, see Fig. 1:

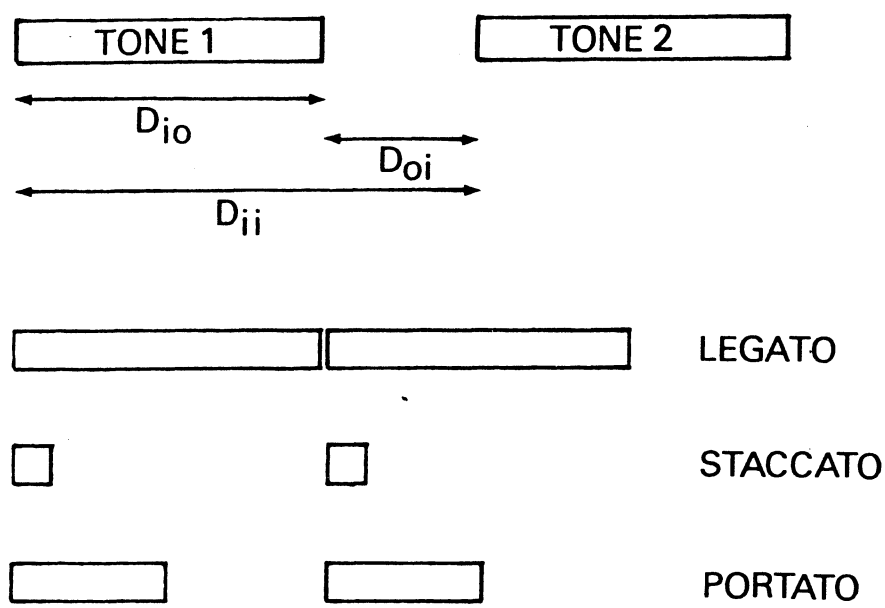


Fig. 1. Upper part: Schematical representation of a two tone sequence illustrating the meaning of the duration variables Dii, Dio, and Doi, see text.

Lower part: Deviations from mechanical regularity at the measure (M) level of the same tune.

1. the duration from the onset of a tone to the onset of the following tone, labelled Dii here ("duration in-in"),
2. the duration from the onset of a tone to the end of the same tone, Dio ("duration in-out"), and
3. the duration from the end of a tone to the onset of the following tone, Doi ("duration out-in").

With regard to rhythm, Dii is, of course, of fundamental importance), and this is also generally acknowledged in rhythm research. However, the proportion of Dio and Doi, that is, of sound and non-sound within Dii, is also a crucial factor. This fact has not been much discussed much in previous research. In musical notation such aspects are reflected in the use of articulation signs as legato, staccato and portato. In extreme legato Dio=Dii (in fact Dio may bd even longer than Dii, as when the tone is not released until the next tone has actually begun) and Doi=0. In staccato Dio is "short" and Doi "long", and portato is a kind of midway position between legato and staccato (see Fig. 1).

It should be realized, however, that these three types of articulation represent categories, within which there is a wide range of variation. There are different "degrees" of legato as well as of staccato and portato, and there are no well-defined limits between the categories. The proper use of these articulation possibilities is of extreme importance in music performance and is probably one of the most important ways of affecting the experienced motion character of the rhythm in question. Some examples of this are given below.

The SYVARD Hypothesis

With regard to Dii a basic hypothesis is that live performance of musical rhythm is usually characterised by certain systematic variations (SYVARD) as regards the duration of the sound events (SE) in relation to strict mechanical regularity. Rhythm performance may then be described in terms of such deviations from mechanical regularity. The deviations may occur at different levels: at the SE level (that is, for single tones or groups of tones within a beat), at the B (beat) level, the M (measure) level etc. Further the deviations are different for different types of music and may be different for different performers.

Some examples of SYVARD in Vienna waltzes and in Swedish folk music were given in our 1977 paper. Since then, a much bigger material of monophonic performances has been analysed as described in Bengtsson & Gabrielsson (1980) and Gabrielsson, Bengtsson & Gabrielsson (1983). Different types of SYVARD are found in all analysed cases. Only a few glimpses of the results can be given here; for more detailed accounts the reader is referred to the above-mentioned papers.

A simple and instructive example is provided in Fig. 2 referring to performances of the Swedish tune "Sorgeliga saker hända". The notation of the tune is shown in the figure. The majority of the available performances (38 in all) conformed to the SYVARD pattern shown in Fig. 2. Mechanical regularity is represented by the straight horizontal line marked 0 in the figure. The deviations from this mechanical regularity for the different tones in the melody are indicated by the filled circles; these circles are connected by a solid line, which may be called the "performance profile" for this melody. It can be seen that all filled circles referring to half-notes have negative deviations, i. e., the half-notes are performed shorter than in a completely mechanical performance. For the quarter-notes the situation is the opposite: they show positive deviations, i. e., they are lengthened as compared with a mechanical performance. The consequence is that there is no 2:1 ratio between the half-note and the quarter-note within each measure; the ratio is rather about 1.75:1 but varies between measures. Further it is seen that the dotted half-note in measure no. 8 (M8) is lengthened considerably, thus signalling the end of the first half-period.

The deviations at the M level for most performances are seen in the lower part of Fig. 2 (one filled circle for each of 15 measures; the final measure is omitted because of measurement difficulties). The performance profile shows a "slow start" (positive deviations for M1-M2), a marked lengthening in M8 as mentioned above, and a retardation towards the end in M14-M15, while the remaining parts of the melody are performed more rapidly (negative deviations).

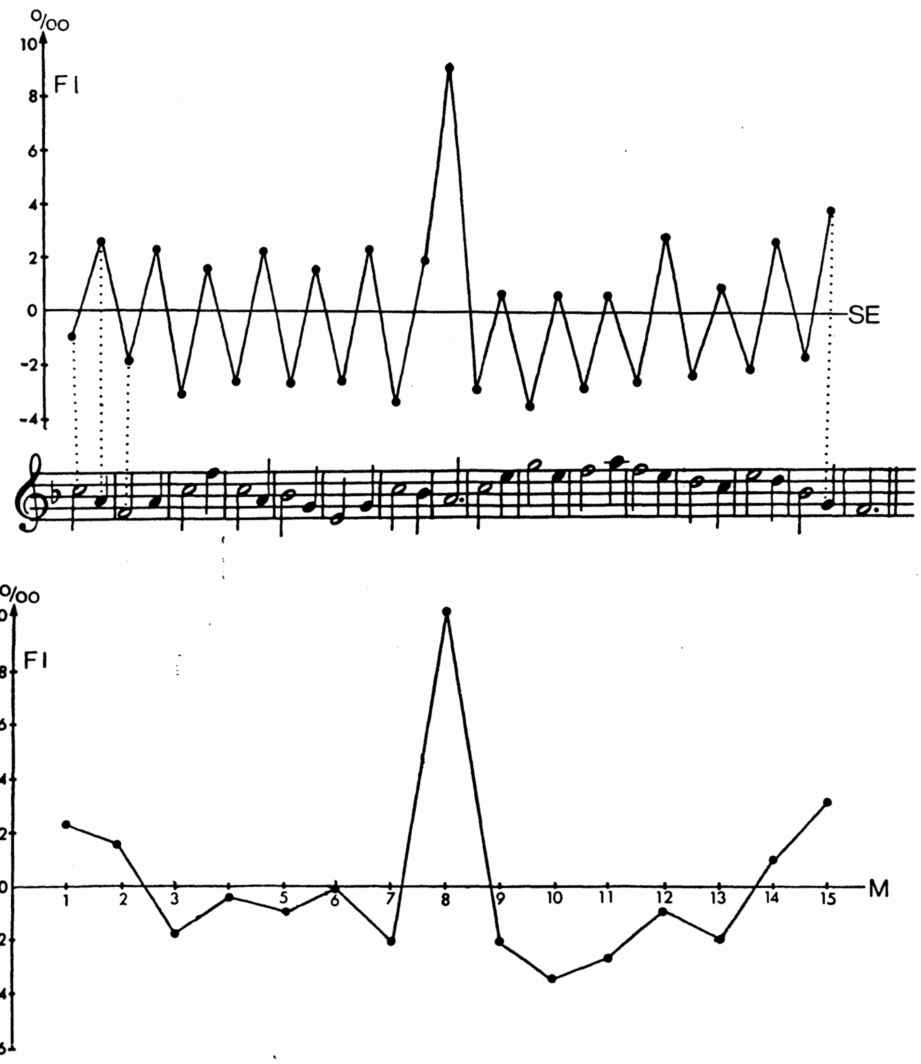


Fig. 2. Upper part: Deviations from mechanical regularity in the performance of the tune "Sorgeliga saker hända". The deviations are expressed in thousands of the total duration of the tune.

Lower part: Deviations from mechanical regularity at the measure level (M) of the same tune.

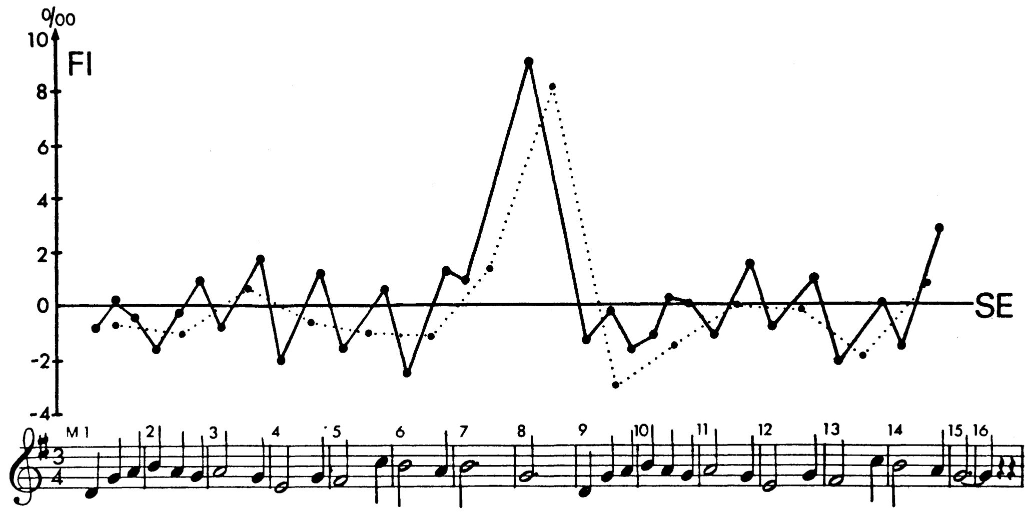


Fig. 3. Deviations from mechanical regularity at the SE level (solid line) and at the M level (dotted line) in a performance of the tune "Dansen går på Svinnsta skär". The deviations are expressed in thousands of the total duration of the tune.

A related example is given in Fig. 3. In this melody, "Dansen går på Svinnsta skär", many measures are composed of half-note + quarter-note, just as in the previous melody. The performance profile for these measures (M3-M6 and M11-M14) shows the same "zig-zag" profile as in Fig. 2, i. e., the half-notes are shortened and the quarter-notes are lengthened as compared with mechanical regularity. There is a marked lengthening of the dotted half-note at the end of the first half-period (M8) and a retardation towards the end. The performance profile at the M level is shown by the dotted line.

However, even for the simple melodies in Figs. 2-3 there were many individually different ways of performing them. The correlations between all performances of a given melody were therefore subjected to so-called factor analysis so as to map different types of performances. There are, in fact, two more profiles for the melody in Fig. 2 and three more for that in Fig. 3, which should be shown in order to attain some degree of completeness. These are presented in the above-mentioned papers, together with the results from 15 other melodies. Most of these are more complex than the melodies mentioned here, and the SYVARD patterns are sometimes quite intricate.

Timing in music is an extremely complex phenomenon, and although we know its importance from general musical experience, it is not until recently that we have been able to study it in a truly empirical way.

Interplay between analysis and synthesis

It is not enough to describe performance of musical rhythm in terms of SYVARD or other types of physical variables. We have to relate the characteristics of the performance to the experience of the musical rhythm. To do this, ideally we should have good measurements both of various performance variables (duration variables as well as other variables) and of variables concerned with the experience of rhuthm. Today, however, we still have only rather crude and approximate measures in both of these respects.

One way of approaching these problems is by means of an interplay between analysis and synthesis. We start by analysing live performances of musical rhythm. The data resulting from such analyses can provide us with hypotheses about which features of the performance may be of special importance to the listeners' impression of rhythm. We can then try to use different performances of the same piece of music and study the listeners' responses and judgments of these different performances. Usually, however, any two (or more) real performances of the same piece differ not only in one characteristic (say, a kind of SYVARD) but differ in other characteristics as well (such as tempo, amplitude envelopes, spectra etc.). Consequently, you cannot draw any safe conclusions regarding the effects of each separate variable.

The possibilities can be improved if a performance of the piece can be synthesized, e. g. by electronic means. That is, a synthesizer is used for obtaining adequate control over all relevant variables. Specific variables can be selected (for instance, a certain SYVARD pattern) and varied systematically in synthesised examples, which are presented to listeners for judgment. Then one can proceed to another variable, and so on. Depending on the amount of variables this may be a very big undertaking.

The planning and calculations required for the generation of the syntheses are in themselves very instructive. Often one finds that the synthesised version does not at all meet your expectations. These procedures can only be hinted at here by means of some demonstrations, which are included in the sound examples in this volume.

Mozart's Piano Sonata in A major

The first example refers to the variation theme of Mozart's Piano Sonata in A major (K. 331). The notation appears in the upper part of Fig. 4.

By means of factor analysis on the correlations between some 25 performances by five musicians, the two most common performance profiles were found to be as is shown in the lower part of Fig. 4 (Dii values). In the first profile (called F I) we note a kind of V-shaped profile for the pattern appearing in the beginning of M1 and M5, meaning that the initial dotted eighth-note as well as the final eighth-note of this pattern are both lengthened (positive deviations) at the expense of the sixteenth-note in the middle. For the sequence , which appears once or twice in each measure, we see a zig-zag profile similar to that seen in Fig:s 2 and 3. Here it means that the quarter-note is shortened and the eighth-note is lengthened in relation to a mechanical performance (the average proportion quarter-note/eighth-note was about 1.7:1, while the mechanical would have been 2:1). Further there is a retardation at the end of the first half-period (in M4) as well as towards the end of

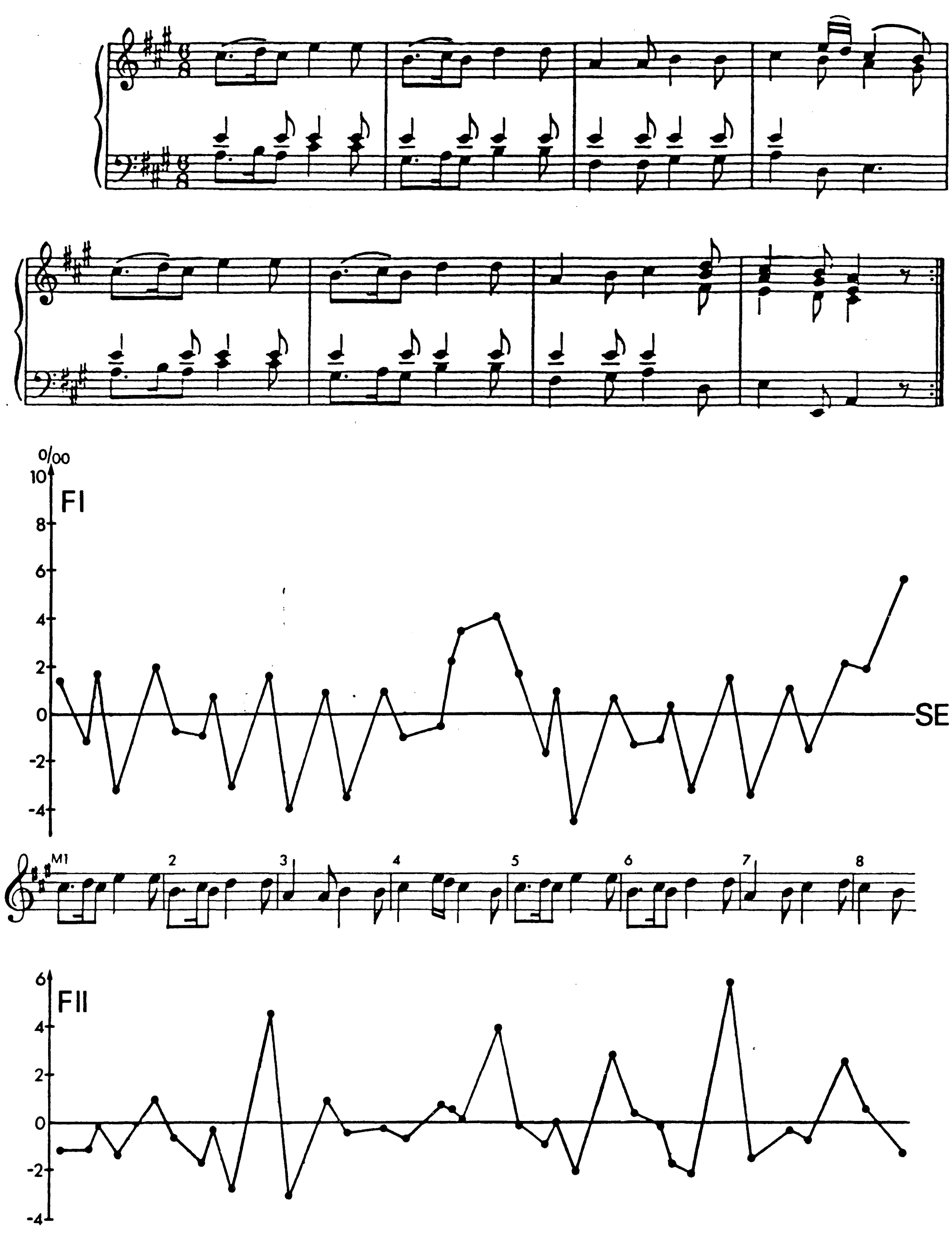


Fig. 4. Upper part: Notation of the theme in Mozart's Piano Sonata in A major.

Lower part: Deviations from mechanical regularity in two different types of performance of this theme, see text.

the theme. In the second profile (FII) there are also tendencies to V- and zig-zag profiles but not as consistent as in F I, and there is no retardation towards the end. There are "peaks" for the last note in M2, M4, and M6, which indicate a phrasing in groups of two measures; in fact, these "peaks" include a short breathing rest before starting the next phrase (these were actually performed on the flute).

Sound Example 1 presents three synthesised versions. The first is truly mechanical. The second follows the F I profile for Dii values shown in Fig. 4. The articulation is legato (Dio=Dii) except for the quarter-notes in the ♩♪ pattern in M1-M3 and M5-M6; for these quarter-notes there is slight "non-legato", so that Dio is about 90 % of the Dii values in the melody part, 95 % in the lower parts. This also applies to the last chord in M4 (i. e. the end of the first half-period). These Dio values approximate those found in the actual performances according to F I. The third version reflects the F II profile for Dii values in Fig. 4. The articulation is legato except for the last tone in M2, M4 and M6, in which the Dio value is about 75 % of the Dii value, reflecting the breathing rests mentioned above. This version is monophonic.

It is adviceable to listen to these examples several times in succession and at the same time to look at the F I and F II profiles in Fig. 4. (The "profile" for the mechanical version would simply be a straight line.) Much could be added and elaborated concerning various details, but these examples may be sufficient to give a first idea of the effects of varying only Dii values (and to some extent Dio values), holding everything else constant.

There are, of course, other ways of performing this theme than those given here. We will report on that elsewhere. As some anecdotal evidence we may mention that the American pianist Lorin Hollander performed this theme upon our Synclavier II keyboard with some different musical intentions. His different performances all showed characteristic SYVARD patterns, partly similar to those described above, partly different. When we finally asked him to play as mechanically as possible, the result was that his SYVARD diminished - but it was still there!

"Vårvindar friska"

The next example is the well-known Swedish tune "Vårvindar friska" as notated in Fig. 5. This melody comprises four phrases of 4M (four measures) each. Three of these phrases are almost identical (M1-M4, M5-M8, and M13-M16), while one is different (the third phrase, M9-M12).

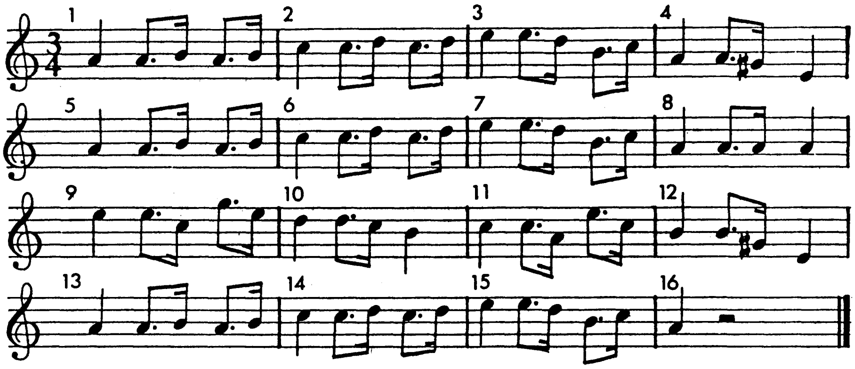



Fig. 5. Notation of the tune "Vårvindar friska".

A total of 15 performances of this melody were analysed, and many different SYVARD patterns were found at different levels, from the SE level to the phrase level (see Gabrielsson, Bengtsson & Gabrielsson, 1983). We use these results to generate a series of syntheses. The series starts with a completely mechanical performance. Then various modifications are added successively beginning at the SE level, proceeding to the B level, the M level and the phrase level. Further there are examples of different articulations. The process is "cumulative", that is, the specific features of each new synthesis are added to those of the earlier syntheses.

All examples appear in sound Example 2. To save time, only some of them contain all 16M of the melody, the others are reduced to M1-M8 (see below).

The syntheses appear in the following order:

2a. Mechanical performance. Tempo MM ♩ = 111. Legato. All 16M.

2b. The mechanical ratio of 3:1 between the two SE:s in the pattern, which mostly appears twice in each measure, is modified to 2:1, which would in fact correspond to a notation like . When comparing this example with the mechanical version in 2a, one notes a considerable difference in the perceived motional character. The reason for this modification is that the average proportion between the two SE:s in the notated pattern was in fact around 2:1 in most of the analysed performances. - The example contains M1-M8 only.

2c. The pattern is modified still more, being 2.11:1 on the second beat and 1.95:1 on the third beat of each measure, in which it appears. These values approximate those found in the performances. The pattern is thus performed differently on different beats, somewhat "softer" on B3 than on B2. Can you hear a difference between the examples 2b and 2c? - The example contains M1-M8 only.

2d. Still another modification of the pattern is made to make it dependent not only on its position on different beats (as in 2c) but also on its position in different measures within each 4M phrase according to the following proportion values:

		B2	B3
	M1	2.30:1	2.03:1
	M2	2.21:1	1.95:1
Phrase	M3	1.95:1	1.87:1
	M4	1.79:1	-

These proportions approximate the averages in the corresponding measures and beats of the analysed performances. The pattern is thus performed progressively "softer" during the course of the phrase. - The example contains M1-M8 only.

2e. The duration of the three beats within the measure is modified. In all earlier examples each beat occupied 33.3 % of the duration of the measure (=mechanical principle). In the present example, B1 occupies 32.1 %, B2 34.6 % and B3 33.3 %. This is an example of an short-long-intermediate (SLI) pattern of beats within the measure. This holds for all measures except those terminating phrases (M4, M8, M12), in which B1 occupies 28.4 %, B2 33.3 % and B3 38.2 % - thus a SIL pattern.

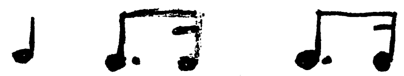
It was apparent in the performances analysed that B2 was expanded at the expense of B1. However, in the measure which terminates a phrase there was a successive retardation, so that B3 was the longest beat. (Actually this retardation must be considered in relation to the considerable expansion of entire measure terminating the phrase, as in the following synthesis, 2f. In the present synthesis, however, all measures are still equally long, and therefore the SIL pattern in the phrase-terminating measures is not perceived as a retardation but rather as a "rush" to B3.) - The example contains M1-M8 only.

2f. The duration of the four measures within each phrase is modified. In all earlier examples all measures were equally long. In this example the duration of the four measures within each phrase generally follows an LSSL (Long-Short-Short-Long) pattern, that is, M1 and M4 within each phrase are longer than M2 and M3. This pattern was apparent in the analysed performances, especially the lengthening of M4 in each phrase. Expressed in per cent of the phrase duration, the mechanical case would be 25 % for all of the M:s. In the present example, M1 occupies 24-25 %, M2 23 %, M3 23-24 %, and M4 28-29 %, with some variation between phrases. The prolongation of M4 is most pronounced in the third phrase, which is easily heard in this synthesis. Further the Dio value of the last tone in M4, M8 and M12 is set to 66-80 % of the corresponding Dii value to make a short break between the phrases. - The example includes all 16 M:s.

The remaining three synthesised examples illustrate various articulation possibilities which were found in the performances and which are somewhat exaggerated here in order to demonstrate how the variation of

Dio affects the perceived motion character. Until now Dio has been equal to Dii, that is, legato (except at the phrase endings in 2f). Examples 2g - 2i are all based upon 2f but are not cumulative as the previous examples. Thus 2g equals 2f with the addition of a certain articulation in B1 of each measure, 2h equals 2f with the addition of another articulation in B2 of each measure, and 2i equals 2f with the addition of another articulation in B2 and B3 of each measure. The differences in motional character as compared with all earlier examples, as well as between 2g - 2i themselves, are easily noticed.

2g. Dio of the quarter-note in B1 is set to 50 % of Dii, for all other tones Dio = Dii as earlier, that is

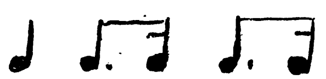


Dio: 50 100 100 100 100 % (only M1-M8)

2h. Dio of the dotted eighth-note in B2 is set to 40 % of Dii, that is

Dio: 100 40 100 100 100 % (only M1-M8)

2i. Dio of the dotted eighth-note in B2 is set to 40 % (as in 2h) and Dio of the dotted eighth-note in B3 is set to 60 %, that is



Dio: 100 40 100 60 100 % (All 16M)

We have made eight modifications since we started using the mechanical performance. The modifications have been based upon empirical data from analyses of performances, and it is instructive to listen to the various examples in order to learn about the perceptual effects of various manipulations. However, the present description should be understood only as a demonstration. A more strict experimental approach would require still more analyses and controlled listening tests to evaluate real performances as well as synthesised versions etc.

Most, or all, of the synthesised examples sound more natural than the original mechanical version. It is thus obvious that we have found some valid principles for the performances of this melody by the analytic-synthetic approach. But it is also evident that much remains to be done in order to get a satisfactory resemblance to a live performance. Only certain duration variables have been manipulated here. To continue, it would be necessary to treat the durational variables in a still more detailed manner, and to manipulate amplitudes, spectra (timbre), onsets and decays etc., features which have been kept constant here. The experience from analysing many performances is that one actually has to "shape" each single tone in all these respects (which is what the performer does!) in order to give the synthesis a "live impression".

Vienna waltz accompaniment

Some characteristics of the performance of the Vienna waltz were discussed in our 1977 paper (where also references to still earlier papers on this topic can be found). A well-known feature occurs at the beat level in the accompaniment: the first beat is shortened and the second beat lengthened. In other words, the second beat "starts too early" if compared with a mechanical performance. This effect can be studied by listening to the six accompaniment versions given in sound Example 3. The construction of the versions is explained in Fig. 6. The first version is truly mechanical, that is, each of the three beats in the measure occupies 33.3 % of the measure duration. In the following versions B1 is increasingly shortened and B2 lengthened correspondingly, so that B2 starts earlier and earlier, while B3 remains at 33 %. Listening to the versions with regard to how well they simulate the accompaniment in a Vienna waltz, one will probably find versions 4-5 to be the best; the duration of the first beat is then 25-27 % and that of the second beat 40-42 % of the total measure. This is indeed a considerable deviation from the mechanical values. Still more extreme deviations may occur, see below.

The above values refer to Dii. However, the Dio values are also crucial. In Fig. 6 the Dio values are represented by the rectangular areas within each beat (note that there is only one SE per beat). In B1 the Dio value is 90 % of the Dii value, in B2 it is only 15 % and in B3 it is 30 %. These values should not be taken as normative, just as examples in this context.

The importance of the Dio values are demonstrated in Sound Example 4. This contains eight versions as illustrated in Fig. 7. In all these versions B1 occupies 28 %, B2 39 % and B3 33 % of the measure duration. The parameter varied is the Dio value: it is either "long" (75-90 %) or "short" (30 %). With two Dio values and three beats we get $2^3=8$ possible combinations of "long" and "short" over the three beats: lll in the first version, lls in the second, and so on until sss in the eighth and last version.

Listening to these versions, one immediately notes the differences in the motion character between them. The perceived structure may be about the same in all cases, say "triple meter with a stressed first beat". Thus, the basic difference is rather in the perceived motion character. It would be a matter of personal taste to decided which versions are most similar to an ideal Vienna waltz accompaniment. Some versions are obviously impossible, e. g. version no. 1, others are better, but none of them is perfect. In fact, the purpose of this example was not to model a typical Vienna waltz accompaniment, but rather to demonstrate in a simple way how important different Dio values are to the rhythm experience, especially regarding the motional aspects of the rhythm experience. Realising that only two different Dio values were used here, it is easy to imagine the numerous possiblities associated with the use of additional levels of Dio values, e. g. from extreme staccato to extreme legato.

Sound Examples 3-4 were both first presented at the symposium "Gehirnvorgänge bei Ausübung und Wahrnehmung von Musik" arranged by Herbert von Karajan Stiftung, Vienna, May 1982; see Gabrielsson, 1982.

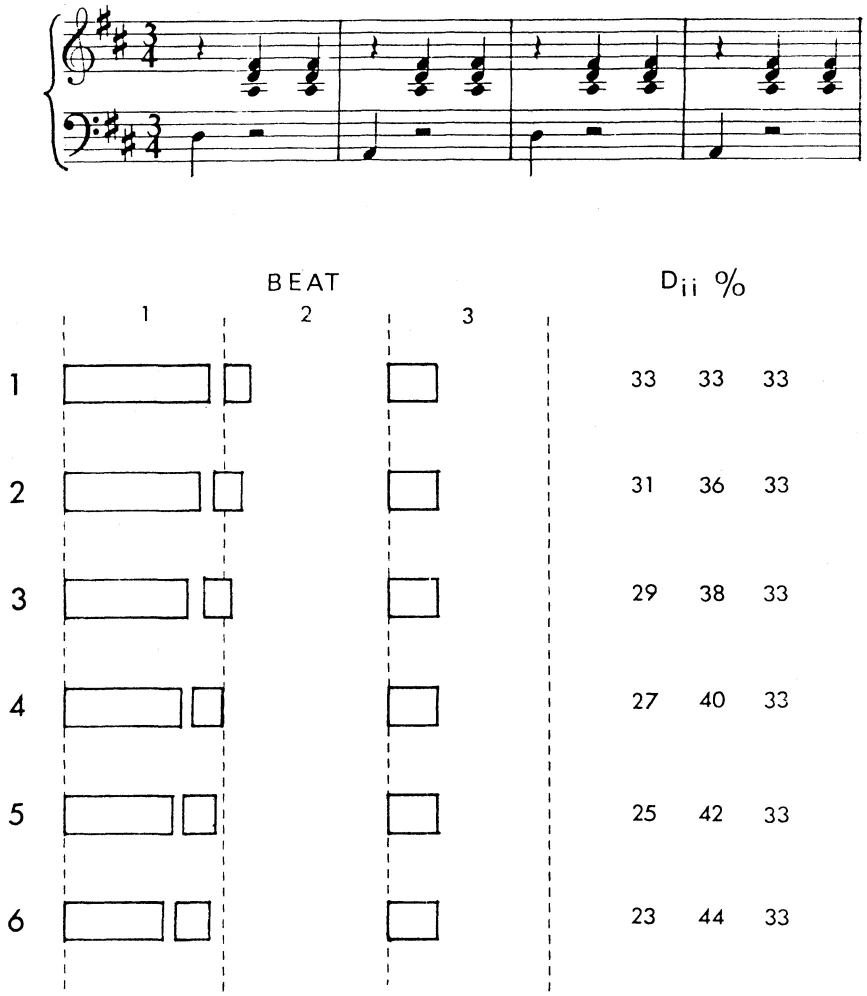


Fig. 6. Illustration of Sound Example 3. The four notated measures are performed in six different versions illustrated by the rows in the figure. The Dii values for the three beats within the measure are given in percentages to the right. The Dio values for each beat are represented by the lenght of the rectangles. The dashed vertical lines indicate the sub-division of the measure into three equally long beats. For further comments, see text.

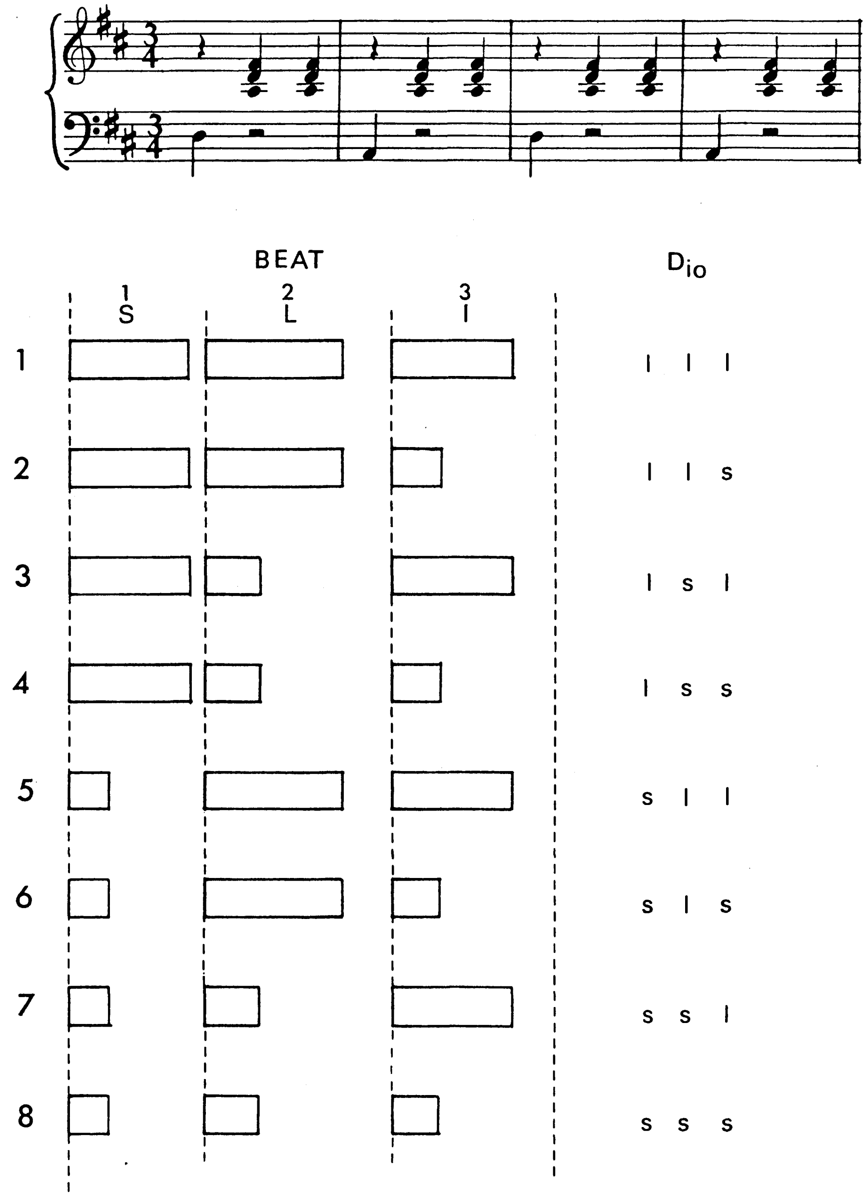


Fig. 7. Illustration of Sound Example 4. The four notated measures are performed in eight different versions. In all versions, the Dii values of the three beats constitute a short-long-intermediate (SLI) pattern of 28, 39, and 33 % of the duration of the measure. The Dio values within the beats are represented by the length of the rectangles, and are either long (l) or short (s) as shown to the right (lll+long-long-long, lls+long-long-short). For further comments, see text.

Synthesising the Bat Waltz

In order to have a try with a full-fledged piece of Vienna waltz, two sections, each comprising 16 notated bars, were chosen from the famous waltz in Die Fledermaus (=The Bat), composed in 1874 by Johann Strauss jun. (See Fig. 8.)

A good orchestral performance of a Vienna waltz is extremely complicated in terms of the acoustical parameters including chronometrical durations. Indeed, it is a sort of fine-meshed network, where everything fits together in a way that is at the same time well-structured and flexible, a true interplay between whole and parts. Changes made at one place immediately affect others. An improvement at one place might produce a chnage for the worse at another, maybe on another metrical level (or even in another parameter), and sometimes also in unexpected ways. Sound Example 5 presents a totally mechanical performance (MM NOT=164), which should be compared with the synthezised imitation of a live performance in sound Example 6.

The synthesis discussed here has some severe limitations which must be stated briefly. The timbre chosen is far from satisfactory and is the same through the example, and the same is true for the amplitude envelopes. The sound pressure level has been varied in a rather intuitive way according to recorded performances, mainly in order to incorporate some important accents. The main interest has been focused on the durational parameters. As regards dance movements the comments will be confined to a simple statement concerning the metrical size of a "full turn".

First of all it is necessary to make some statements about the overall metric structure, the most important rhythmetric entity, and the principal relationships between them in a Vienna waltz. (The term "rhythmetric" was introduced by I. Bengtsson in Sohlmans Musiklexikon 2nd ed. 1979. It means a rhythmic structure that at some level (or levels) is metrically definable in a way including some sort of experienced regularity at the same level.)

This sort of music, made for or at least derived from dancing and dance music, is structured according to a very regular hierarchical metric system. One can regard it in two ways: from the overall periodical structure down to the simplest entity, or the other way around. Neither

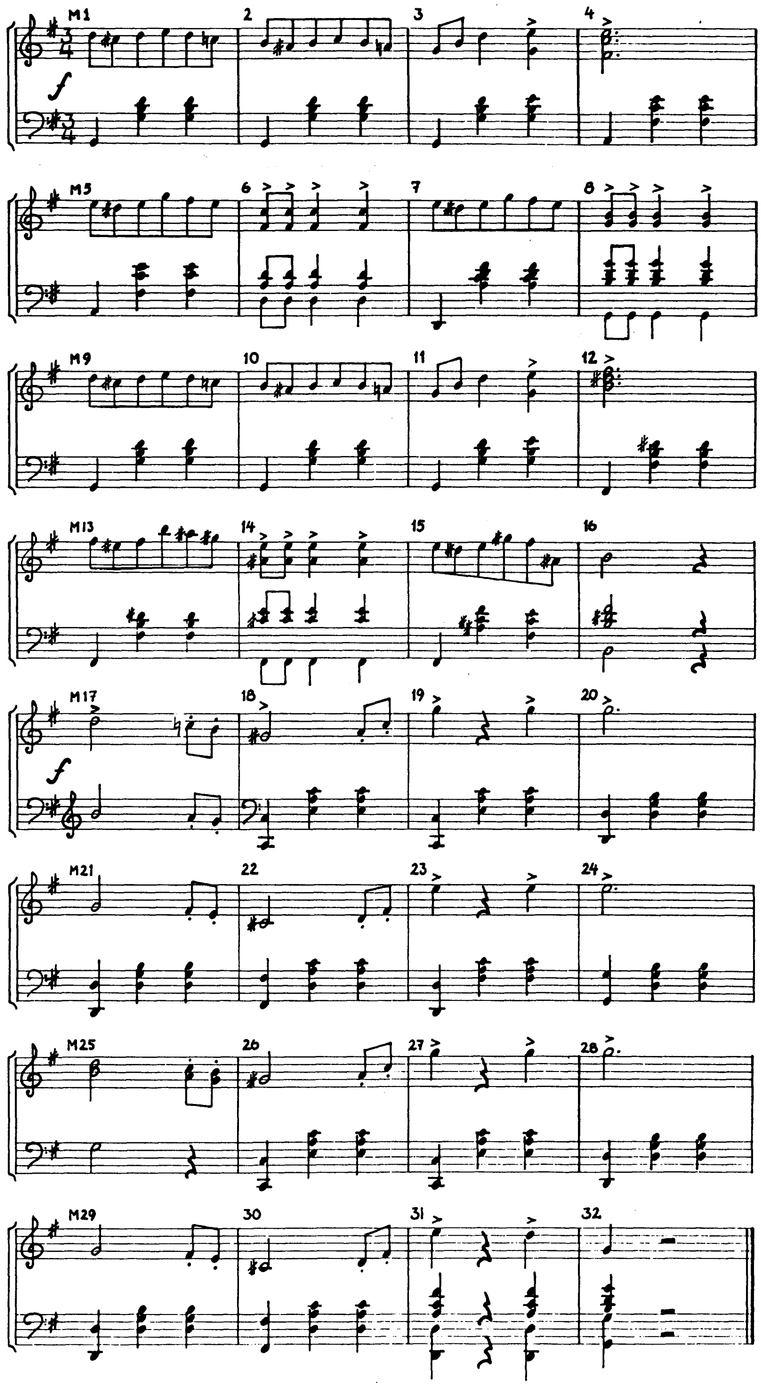



Fig. 8. The 32 measures from the Bat Waltz by J. Strauss jun. A simplified notation is used for the synthesis, which consists of three separate parts: melody, "accompaniment" (i.e. the after-beats), and bass.

way should be considered the "right" or "most important" one; they are thoroughly integrated. However, as it is not even quite self-evident what shall be considered to be the proper metrical entity, this is a good reason for starting from below.

Using ordinary notation as the point of departure, the bar or measure (M) with three regular beats (B) seems to be the self-evident rhythmical entity; it shall be labelled M_n. In dancing, however, this corresponds to the first half of the full choreographical cycle or turn, only, which comprises two such bars. These make a pair in succession and thus are not identical. The larger entity with 2 x 3 = 6 B shall be labelled M_b (b for overt behavior). In a rather important sense Vienna waltzes, and maybe most waltzes, are not in any "three beats in the bar" meter, but rather are based upon a 2 x 3 B structure. (See fig. 9. All examples analysed so far clearly show that the SYVARD pattern of the size $2M_n$ becomes obscured if averages were computed over both odd and even M_n.) Thus, 1 M_b = 2 M_n.

The overall hierarchical structure can be described as a result of replications of M_b. The most common scheme is a <u>period</u> of 8 M_b (16 M_n) consisting of two <u>half-periods</u> of 4 M_b (8 M_n), which, in turn, contain two <u>phrases</u> of 2 M_b (4 M_n) each; cf. fig. 9. All melodic and harmonic sound events are both distributed within and defining this hierarchical scheme, mostly in order to make it redundantly clear, sometimes in order to produce tensions, deviations and surprises.

Disregarding the limitations hinted at above, there are five major factors that influence the relationships between duration values (and any real values as well):

1) The basic D proportions within M_n and M_b, most conspicious as SYVARD at the B level;
2) Articulation in the sense of Dio/Doi-relationships within Dii;
3) Tempo and beat rate fluctuations and variations;
4) SYVARD at higher levels and some more randomly varying events at those levels;
5) Exceptions from exact synchrony between different parts, in this case between melody and accompaniment.

1. Many musicians have been told that in Vienna waltzes the second B per M_n should be played somewhat lengthened the expense of B 1, presumably implying that B 3 should be intermediate. This feature has been confirmed above in Fig. 6 and in Sound Example 3. Using, as before, S for short(er), L for long(er), and I for intermediate, the prevailing SYVARD pattern thus can be designated SLI within a M_n. The amount of displacement may differ between M_{odd} and M_{even}. Furthermore, a prolongation of B 3 may occur in certain situations, changing the SLI pattern to SIL.

As regards the SLI pattern, B 1 may vary from about 30 to 25 % or even less of a M_n, B2 between ca 34 % and 42 %, B 3 between ca 31 and 34 % or more, if there is a SIL pattern. The variations of the percentages depend quite a lot upon the structure of the composition as well as of different choices made during a particular performance (due to a lot of different circumstances which shall not be discussed here). An example of such a pattern is given in Bengtsson & al. (1969, p. 97). Typical averages for six B in a M_b are for M_{odd}: 30.2, 37.3, 36.5; M_{even}: 25.7, 38.6, 31.7 %; this shows a clear difference between odd and even M_n.

2. For all tones - long or short - one has to consider the Dio/Doi relationships discussed and exemplified in a previous section. The importance of this articulation factor must not be underestimated. We still know far too little about its roles as regards rhythm in all the three aspects stressed above. Sound Example 4 (cf. Fig. 7 above) clearly showed that in Vienna waltz, the basic rhythmic pattern would loose its life - or at least its energy and plasticity - if the accompaniment were performed almost legato. In this respect, already, there are characteristic SYVARD tendencies.

3. In many Vienna waltz performances the overall tempo variations are astonishingly large. In a group of recordings of the famous Danube waltz (An der schönen blauen Donau) the accelerando within the first 32 M_n varied between ca 40 and ca 80 %. The listener is apt to underestimate this difference, and it is often difficult to tell - with the exception of some clear instances - if the tempo changes occur continually, stepwise, or both.

However, tempo is a rather vague concept. In order to improve the precision, four different meanings of tempo should be distinguished: (a) the abstract mean tempo, calculated as the total duration of a music section divided by the number of beats in the same section, (b) the main tempo, being the prevailing (and intended) tempo obtained when initial and final retardations as well as more amorphous caesurae are deleted, (c) local tempi, maintained only for short periods but perceptibly differing, and (d) beat rate, an expression which, of course, could be used as a simple definition of tempo; here, however, we will use it exclusively for de-scribing minor fluctuations, which may not be perceptible as such.

In the Bat waltz the main tempo is accelerating slightly in both periods and somewhat faster in the second period than in the first one. Furthermore, there are changes of local tempo as well as of beat rate, depending mainly upon the melodic and harmonic structure. Good musicians use such structural components as cues for choosing those types of fluctuations in order to obtain the proper overall movement and thus to control the proper reactions as regards kinetics, imagined movement and feeling or mood. Here, too, the dialectics between the general and the particular becomes of central importance, and this fact pertains to all the parameters under discussion. Up to a certain point it is possible to state some rules or at least prevailing tendencies; beyond that point every piece of music must be treated as the singular instance, the quasi-individual, that it is. Both strategies have been used in the appended synthesised example.

4. At higher hierarchical levels SYVARD very much pertains to what musicians generally call phrasing. Here, too, prevailing tendencies are combined with singular and more "stretchable" variations, the latter partially due - on the acoustical side - to the interplay of different parameters, particularly intensity and duration, articulation included. "Stretchable" here means another sort of flexibility than that necessarily inherent in SYVARD. It is particularly a characteristic of many caesurae between phrases and half-periods as well as of transitions (see e.g. M_n 17). They are at the same time proper parts of the overall performed structure (and movement) and yet treated more freely - as a sort of instrumental counterparts to the interspacing of breathing pauses in singing, to "hesitations", and the like.

Therefore, this feature should not be considered as being just amorphous but rather as a valid sign of the performer's concepts and intentions, presumably also as an interpretable symptom of the relative importance, which is consciously or unconsciously allotted to structural, motoric/kinetic and emotional qualities or aspects. In the synthesised examples this type of events have often been treated by using an "addition factor" at proper places. (See Fig. 10.)

5. Among the most widely spread prejudices concerning musical rendering we find the belief, that tones appearing in different parts (e.g. in a melody and its accompaniment), which shall be played simultaneously according to the notation , are in reality performed with chronometrically exact simultaneousness. Measurements of live performances tell another story. In an analysis of the Kettenbrucke waltz (Bengtsson & Gabrielsson 1977, p. 34-38) it has been shown how the melody is often played in a way which is rather different from the perspicuous SLI pattern of the "afterbeat"-parts in the accompaniment, the attack time differences mostly being about 20-30 ms, in some cases about 40-50. In the synthesis of the Bat waltz this feature had to be dealt with, whereever the melody has six eighth-notes per measure. A good effect was obtained by making the SLI pattern less pronounced in the accompaniment and by permitting slight (i.e. imperceptible) non-simultaneousness. But this detail certainly calls for further and more systematic investigation.

Instead of giving a detailed description of the synthesised waltz section, a few topics and examples shall be selected, illustrated and commented upon. Fig:s 8 - 12 and Sound Examples 5 - 7 pertain to this discussion.

1. Choices and changes of tempo and beat rate. These choices can be seen from the table in Fig. 10. The prevailing tendency is an accelerando from MM 158 to MM 178. It is combined with changes pertaining to the $4M_n$-group and $2M_n$-group levels. Furthermore, "addition" factors are introduced (here expressed in fractions of a whole note). They are used to articulate phrasing, the values situationally conditioned by the structural context. In real time these additions vary between ca 5 and ca 30 ms.

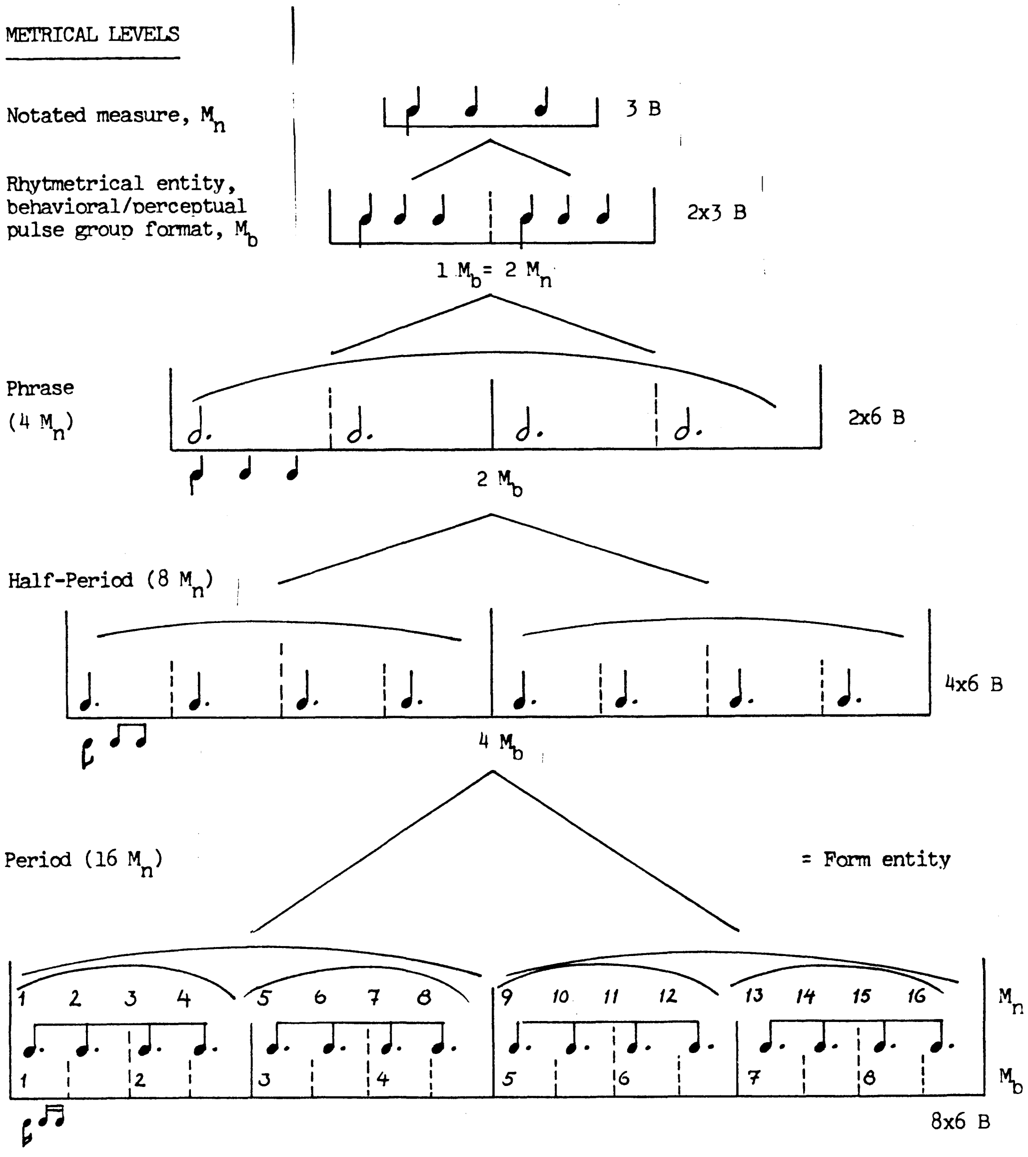


Fig. 9. Table showing the five metrical levels from the notated measure (M_n) to the full period. - diminished note values at the levels of half-period and periodmay look confusing at first sight. However, they represent a deliberate deviation from conventional notation made in order to elucidate the shifts of experienced group formats at these levels.

2. SYVARD at the beat level is dominated by more or less pronounced SLI-patterns. In the first period (M_n 1-16) the averages for the accompaniment are about 31 + 36 + 33 % in cases where there are six eighth-notes per measure in the melody part, and around 27 + 39 + 34 % elsewhere. The second period (M_n 17-32), which has a rather different character, lacks eighth-notes in the melody, and is more rapid; the average pattern is about 26 + 40 + 34 %. Furthermore, a certain amount of levelling occurs at starts and endings, for example 33.3 + 34.3 + 32.3 % with a starting addition of "1/40" at B 1 in M_n 1 , and 32 + 34 + 34 % in M_n 15.

It is always important to consider the proportions underlying these numbers rather than the mere values. A change by no more than 2 % from 27 + 40 + 33 % to 29 + 38 + 33 % means a change of the proportion between B1 and B2 from 0.68 : 1, or near 2:3, to 0.76 : 1, or near 3:4.

As regards the eighth-notes in the melody, a main tendency in most measures is a LS LS SL grouping of the three pairs of eighth-notes.

3. The prevailing articulation pattern (i.e. the treatment of Dio/Doi relationships) is, to put it roughly, "long-short-short", for example 100 or 90 % on B1 in the bass, from 20 to ca 40 % at the "after-beats" in the accompaniment. The values chosen vary according to the context, particularly with respect to melodic events and accents.

4. After the very beginning, where a particular starting effect must always be manifest, the tune starts as from the beginning in M_n 9-10. Fig. 11 shows the percentages and durations per M_n in this $2M_n$ group. The melody has a LS LS SL pattern at the SE level and at the same time a weak SLI pattern at the B level, a pattern that is furthermore modified by a minor prolongation of the starting B 1 and of the last eighth-notes group at B 6. The accompaniment in these bars has a more pronounced but yet not conspicuous SLI pattern, where B1 is made somewhat longer than B4, and B6 somewhat longer than B3. As part of the overall accelerando the MM value is changed from 174 to 176, which has the effect that all real time values are different within the frame of 1035 + 1023 msec for the two M_n. In the same table the articulation values are shown (in percent of Dii and msec) as well as the differences in attack time and

Tempo, beat rate changes, and addition factors

	M1			M2			M3			M4			M5			M6			M7			M8		
	B1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MM:	152, Acc. to 196 in 6 beats						168						174			168			176			170		
Add.:	+1/40 at the start								+1/24			+1/32												+1/40

Bass delayed 1/140 from the beginning and all the way

	M9			M10			M11			M12			M13			M14			M15			M16		
	B25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
MM:	178			180			176			174			178			168			180					
Add.:									+1/24			+1/40												+1/40

	M17			M18			M19			M20			M21			M22			M23			M24		
	B49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
MM.:	90			182			186						188								190			
Add.:												+1/40												+1/64

	M25			M26			M27			M28			M29			M30			M31			M32		
	B73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
MM.:	148			186					184				188					(188)	Ritard. to			160 in 6 beats		
Add.:																								

Fig. 10. Table of tempo and beat rate changes. The total duration is 33.5 sec. The addition factors are expressed as fractions of a whole note, the length of which varies according to beat rate. The sum of these additions is 356 msec. If calculated cumulatively, the mean tempo varies between MM ca 165 and ca 174. Its mean value is MM = 170.4 with the additions, 172.2 without them. Main tempo, however, is about 174 in the first period and about 186 in the second.

M e a s u r e s (M_n) 9 - 10

M_n 9: MM = 178. B_{mean}=337 ms, 3B = 1011 ms M_n 10: MM = 180. B_{mean}=333 ms, 3B=1000 ms

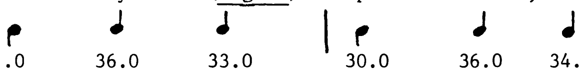
MELODY:

SE in %:	17.7	16.0	17.0	16.7	16.0	16.7	16.0	15.0	17.7	17.0	16.7	17.7
SE in ms:	179	162	172	168	162	169	160	150	177	170	167	177

B in %:	33.7	33.7	32.6	31.0	34.7	34.3
B in ms:	341	340	330	310	347	343

Articulation in the melody 100 % (legato) except 95% for SE 6, 90% for SE 12

ACCOMPANIMENT:



B in %:	31.0	36.0	33.0	30.0	36.0	34.0
B in ms:	314	364	334	300	360	340

Articulation in the accompaniment:

Dio in %:	100	20	30	90	20	30
Dio in ms:	314	73	100	270	72	102
Doi in ms:	0	291	234	30	288	238

The bass part is constantly delayed ca 10 ms in relation to the melody, the exact amour of delay being a simple function of the tempo value.

Onset differences between melody and accompaniment (in ms):

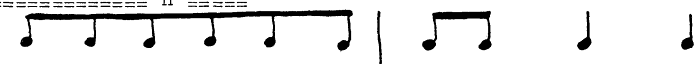
B1	B2	B3	B4	B5	B6
+10	-17	+6.5	+10.5	+0.5	+13.5

Duration differences between Dii per B in melody and accompaniment (in ms):

17	23.5	4	10	13	3

Fig. 11. Table of D values in percentages and msec. (ms) used in $M_{n\ 9-10}$ of the synthesis. Shown are also articulation (Dio in percent of Dii) and some values pertaining to the asynchronism between melody and accompaniment, the latter of coiurse including the bass. The bass notes are - independently of these differences - delayed ca 10 msec all the way in relation to the melody, the exact amount of this delay being a simple function of the local tempo.

SYVARD patterns of M_n 5 - 8

M_n 5-6: 

SE in %:	17.3	15.7	16.0	15.3	17.3	18.3	13.3	10.7	42.7	33.3
B in %:	33.0		31.3		35.7		24.0		42.7	33.3

Real time values. M_n 5 MM = 200, M_n 6 MM = 191

SE in ms:	156	141	144	138	156	165	126	100	402	314
B in ms:	297		282		321		226		402	314

M_n 7-8: 

SE in %:	17.7	13.3	17.0	13.7	19.0	19.3	14.0	9.0	38.7	38.3
B in %:	31.0		30.7		38.3		23.0		38.7	38.3

Real time values. M_n 7 MM = 202, M_n 8 MM = 191

SE in ms:	157	119	151	122	169	172	132	85	364	361
B in Ms:	276		273		341		217		364	361

Fig. 12. SYVARD values in percent and msec (ms) from an imitation of M_n 5-8 in the recording mentioned above. They give a fairly true picture of the real performance in these bars as regards tempo and duration relationships. The articulation values in M_6 and M_8 are around 45-55 % for the two SE at B1, around 20-25 % for B2 and B3. This means that all Dio values lie around 50-80 msec. Note the differences between the two M-groups, which are partially due to their different metrical position and other structural properties. Cf. Sound Examples 7a and 7b.

duration between melody and accompaniment. Interestingly, such differences of about 20-30 msec are readily accepted in a situation like this (maybe not even perceived), whereas differences around and just above 30 msec are unacceptable in a sequence of chords like the one first occurring in M_n 6.

5. In a recording of the Bat waltz by the Vienna Philharmonic Orchestra with Willy Boskovsky conducting (grammophone record Decca SPA 312) the rhythm  in M_n 6 and 8 and later on is performed in an extremely energetic way that contributes very much to the overall impression of forward movement, of gaiety and also of a proper "Viennese" performance dialect. With the aid of the available synthesizer (SYNCLAVIER II) a rather close imitation of the durational relationships in these bars was accomplished.

Durations are given in Fig. 12 in terms of percentage and msec . (The articulation values from the imitation are not reliable and are therefore excluded in the table.) The tempo is somewhat higher during the recording than in the synthesis presented here, and the deviations from mechanicality are even more pronounced in the former than in the latter. But the results of the imitation are rather revealing, and it is almost a shock to hear the performed pattern in 1/4 of the original speed. Therefore, after having studied the values in Fig. 12 one should listen to sound Example 7. Example 7a consists of M_n 5-6 in the recording with the orchestra. In Example 7b the same measures have been synthesised according to this rendering, but the music is played in 1/4 speed. - Of course, this might be called a rather extreme case of durational deviations from total mechanicality, but it shows in a rather striking way what SYVARD can be. Also it illustrates the considerable discrepances between a rhythmical live performance and what the notation is generally assumed to symbolize in this respect.

Another interesting detail in the example is that the substantially shortened B1 of M_n 6 and 8 is preceded by lengthening of B 3 in M_n 5 and 7. This lengthening is greater than in other contexts within the 32 bars. Thus, these beats (B 3 and B 4 of the six) are clearly contrasted. The average ratio between these beats is 1.57 : 1, and 1.38 : 1 between the neighbouring eighth-notes. However, this contrast at the same time means a compensation. The summed duration of the two beats under discussion is around 90 % of two mechanical beats. Compensations of this and similar types occur throughout and are an inherent constituent of the hierarchical layers of SYVARD phenomena.

Concluding Remarks

Although the title of this paper is "Analysis and synthesis of musical rhythm", it is clear from the above demonstrations and discussions that it deals not "only" with rhythm but also with many aspects of music performance in general and their effects on the experience of music.

In fact, rhythm cannot be studied separately from other components of music, as illustrated many times above, and the traditional separation of rhythm, melody, harmony, timbre etc. is a simplistic point of view, that may conceal important psychological realities in music.

The interplay between analysing performed music and using synthesis in order to single out and study the effects, that various performance features has on the experience, is a challenging and fascinating enterprise, which has been made possible only recently through important technical advances. We are only in the beginning of this enterprise, which offers so many possibilities but also poses many new problems. Among these problems are the difficulties to find adequate methods to study hopw music is experienced (Swedish: "musikupplevelsen") in all its richness and subtlety. We have to find new and better methods for this purpose in order to achieve a deeper understanding of the relationships between performance and experience. Many aspects of the musical experience, e.g. the motion character often referred to above, are elusive to verbal responses and probably require various non-verbal methods still to be developed. An interesting example is the so-called sentography described in the paper by Clynes in this volume.

Even with the present crude methods we note an interesting circumstance: performances which we judge as "good", "typical", "natural" etc. are often extremely complex when we describe them in terms of physical variables such as durations, amplitudes, envelopes and so on. On the other hand, physically "simple" sound sequences - mechanical duration relations, constant amplitudes, constant envelopes, spectra etc. - are usually experientially awkward. One is almost tempted to think of an inverse relation between physical and psychological "simplicity": the physically "simple" is psychologically "unnatural/not simple", and the psychologically "natural/simple" is physically complex. This admittedly stretches the meaning of "simple" in various ways and is also simplistic in other respects. However, it is evident that conventional physical measures are not adequate when studying the perceptual-experiential phenomena encountered here. The need for alternative descriptive systems is obvious, and the analysis-synthesis interplay may be a tool to approach these problems as well as many others.

Acknowledgements

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Numerous further references are given in the above papers.

Abbreviations

Add.	An "addition factor" added at a higher metrical level outside the basic SYVARD at a lower metrical level (cf. Fig. 10)
B	Beat. B1 means beat No. 1, B2 beat No. 2 etc.
D	Duration
Dii Dio Doi	Durational variables explained in the section "Different concepts of duration" and in Fig. 1.
LSSL	Long(er), Short(er), Short(er), Long(er)
M	Measure. 32M means 32 measures, M32 means measure No. 32 etc.
M_n	Notated measure
M_b	Behavioral measure or pulse-group
MM = x	Mälzel's Metronome value (x beats per minute)
msec	milliseconds
SLI	Short(er), Long(er), Intermediate. Other combinations used are such as LS, SL, SIL etc.
SE	Sound event (tone or rest)
SYVARD	Systematic variation(s) of duration parameter(s)

WHAT TELLS YOU THE PLAYER IS MUSICAL?
An analysis-by-synthesis study of music performance

J. SUNDBERG*, L. FRYDEN**, A. ASKENFELT*

Introduction

In musical performance, a string of note signs is generally converted into a sequence of tones. If this conversion is made in a simple-minded way, e g by applying a one-to-one relationship between the notation and the sound sequence by means of a computer, the result is musically a disaster. This fact raises a question: what are the ideal or acceptable relationships in music practise between the note signs and their corresponding acoustic signals? The present paper is an attempt to contribute to the answer to that question by formulating rules for the conversion of note signs into tone sequences.

Method

Two strategies are available in an investigation of this kind: measurements and/or synthesis-by-rule. Previous studies of musical performance have revealed an almost overwhelming complexity (see e g Seashore, 1938; Bengtsson & Gabrielsson, 1975), as expected. This suggests that the rules relating notation to sounding music can be assumed to be numerous and interacting. This implies the need for a large amount of measurements before any conclusions can be drawn regarding the underlying rules. Moreover, the pedagogical and artistic experience of one of the authors (LF) had generated a number of hypotheses regarding such rules. For these reasons the synthesis-by-rule strategy was preferred.

As in a previous study of musical performance focussing on singing (Sundberg, 1978) a computer-controlled vowel synthesizer was used ("MUS-

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SE", see Larsson, 1977). The synthesizer can generate one part only. In the present experiment the signal characteristics were adjusted so as to be similar to the timbre of a wind instrument and also a very small vibrato was used. The fundamental frequencies were in accordance with the equally tempered scale, but could be modified in steps of 7 cents, which is close to one difference limen for frequency in normal subjects (Rakowski, 1971). The amplitude was controlled in steps of 1/4 dB. The duration was controlled in steps of a time unit corresponding to .8 to 1.2 csec depending on the tempo, which is accurate enough according to measurements by van Noorden (1975). The computer programs used for controlling the synthesizer were (1) a notation program (Askenfelt, 1979) by means of which the melody can be written in ordinary music notation on the computer terminal display; and (2) a text-to-speech program written by Carlson and Granström (1975). The information encoded in the notation is translated into "vowel sounds", which possess, among other characteristics, duration, fundamental frequency and amplitude, which can be manipulated by the rules. Apart from the information normally included in a music score, special signs were used to mark (a) changes in harmony and (b) boundaries between phrases and sub-phrases.

Rules

We will now present the various rules that we have formulated so far (November, 1982). In order to illustrate clearly the significance of each rule, sound examples are provided in which different melodies or themes are played several times. In most of these sound examples one version represents the case that the durations of all notes are nominal, in another version the effect of the rule is exaggerated, and in a third version the rule has been applied in accordance with its formulation in our rule system. The exact content of each sound example is specified in the List of Sound Examples.

THE HIGHER, THE LOUDER

The amplitude is increased as function of fundamental frequency. The amount is 4 dB/octave rise in the fundamental frequency, see Fig. 1.

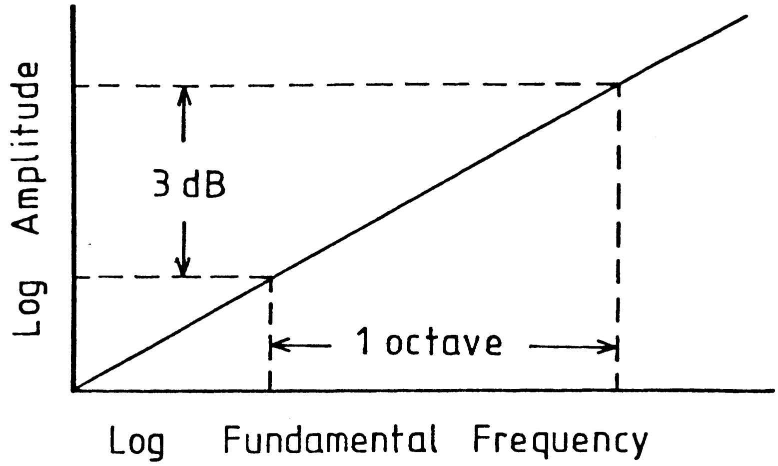


Fig. 1. Schematical illustration of the rule increasing the amplitude of a note as a function of its pitch.

SHARPENING DURATIONAL CONTRASTS

Short note values are shortened according to the values shown in Table I. No compensation is made for the resulting perturbation of the mechanical meter.

Table I. Shortening of the durations for different note values.

Note value	Shortening csec	%
Sixteenth	-0.5	-3.1
Eighth	-1.0	-3.1
Quarter	-1.0	-1.6
Half	0	0
Whole	0	0

SHORTENING LOWER NOTE IN RISING INTERVAL

The duration of a note initiating a rising interval is decreased by 1 csec, see Fig. 2. In sequences of rising intervals the rule has the effect of raising the tempo somewhat. As before, no compensation is made for the resulting perturbations of the meter.

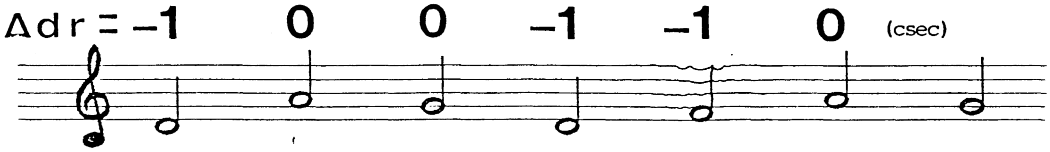


Fig. 2. Illustration of the effect of the rule which shortens the durations of notes initiating a rising melodic leap by 1 csec.

LENGTHENING TARGET NOTE IN LEAPS

The duration of tones terminating a single melodic leap of a given direction is shortened. The amount is $0.6*I^{1/2}$ (csek), where I is the size of the interval in semitones, see Fig. 3.

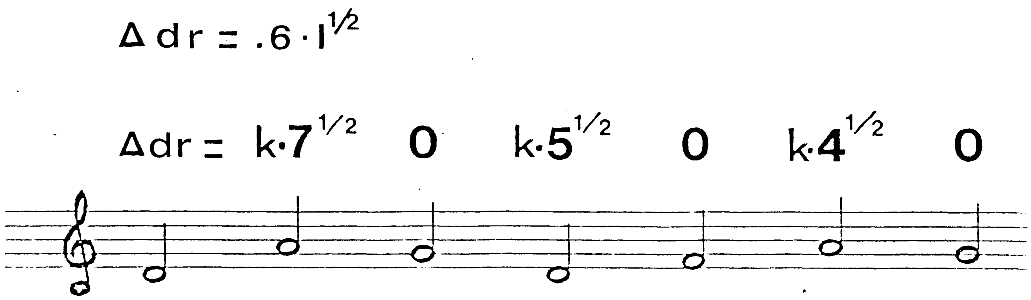


Fig. 3. Illustration of the effect of the rule which lengthens the duration of a note terminating a single melodic leap in a given direction.

PAUSES IN LEAPS

The amplitude of the final portion of the tone is decreased at a constant rate. The start of this amplitude decrease occurs at 0.5*I csek from the end of the note, and the final amplitude value is 3*I dB below the initial amplitude, where I is the interval size in semitones. The effect of this rule is negligeable for narrow intervals but is quite noticeable for wide intervals, see Fig. 4.

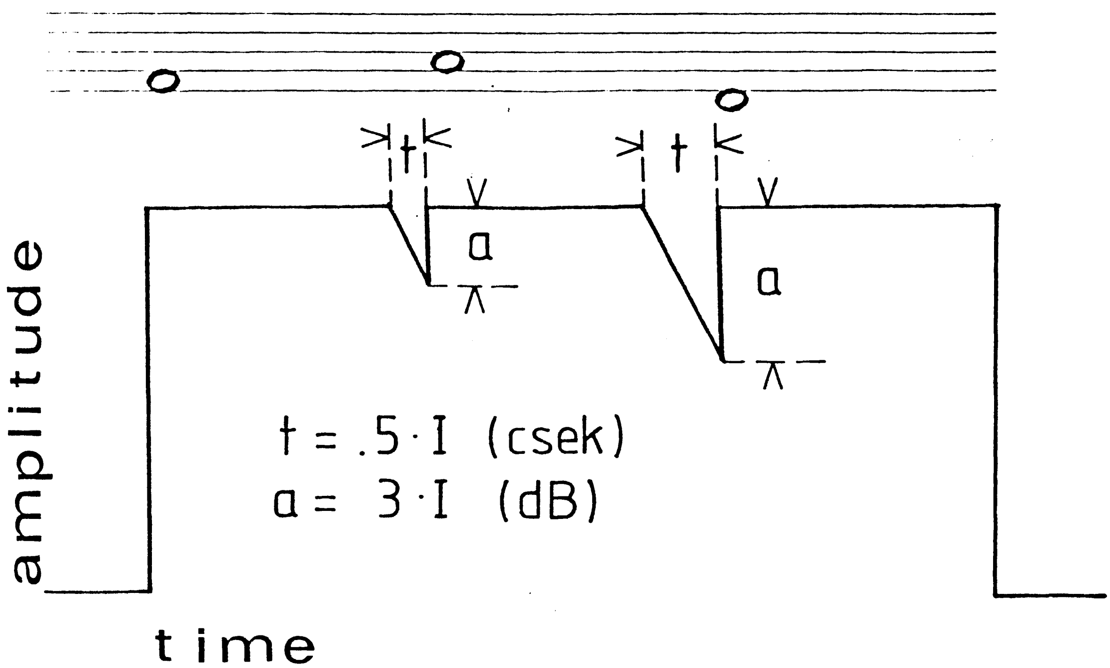
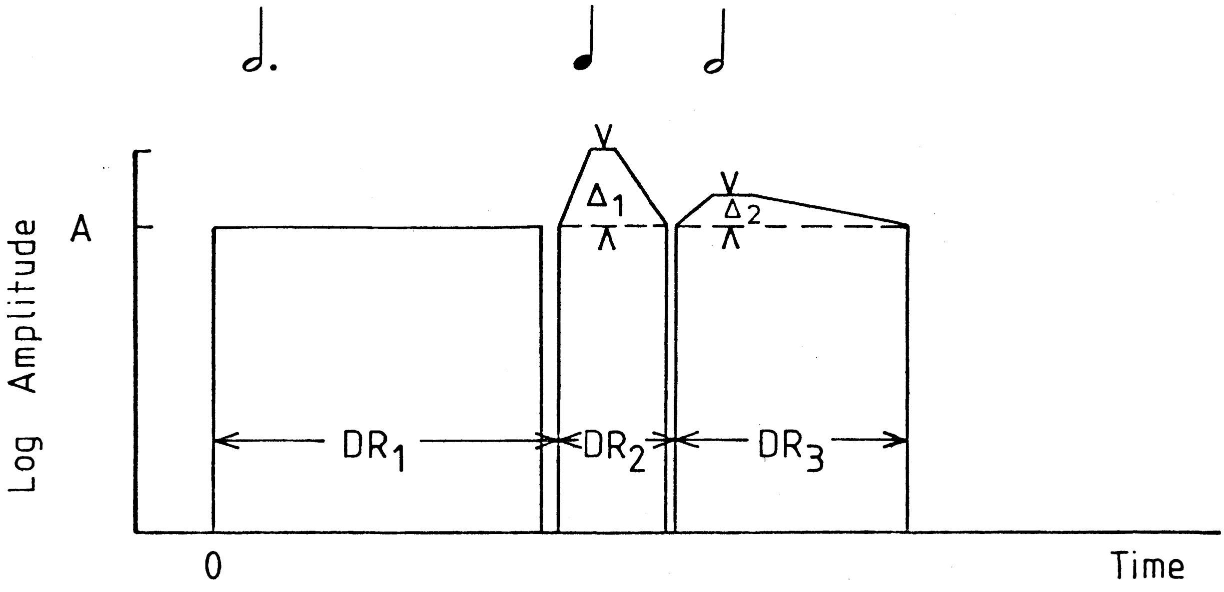


Fig. 4. Schematical illustration of the rule which inserts amplitude decreases towards the end of a note. The decrease has a constant rate. The onset time of the decrease is determined by the interval between the note and the following note.

ACCENTS MARKING CERTAIN DURATIONAL CONTRASTS

Accents are distributed to certain notes which constitute a contrast in duration between adjacent notes. The accent corresponds to an amplitude event with the following characteristics. The amplitude is increased by 6/DR dB, where DR is the duration of the note in csek; this amplitude value is reached after .1*DR + 3 csek and is kept for 7 csecs. Thereafter the amplitude falls off towards the initial value, which is reached at the end of the note, see Fig. 5. The rule adds such an accent to two types of notes. One is a short note surrounded by longer notes. The other case is a note terminating a specific pattern of changes in duration: a



$$\Delta_1 = 40 / DR_2 \text{ (dB)}$$

$$\Delta_2 = 60 / DR_3 \text{ (dB)}$$

Fig. 5. Schematical illustration of the accents marking certain contrasts in note value.

decrease followed by an increase. This rule has a clear effect particularly on the short notes after a dotted note.

AMPLITUDE SMOOTHING

Large stepwise changes of amplitude between adjacent tones are eliminated by adding to or subtracting from the last amplitude value of each tone a constant corresponding to 80% (in log. terms) of the amplitude difference with the following note, see Fig. 6.

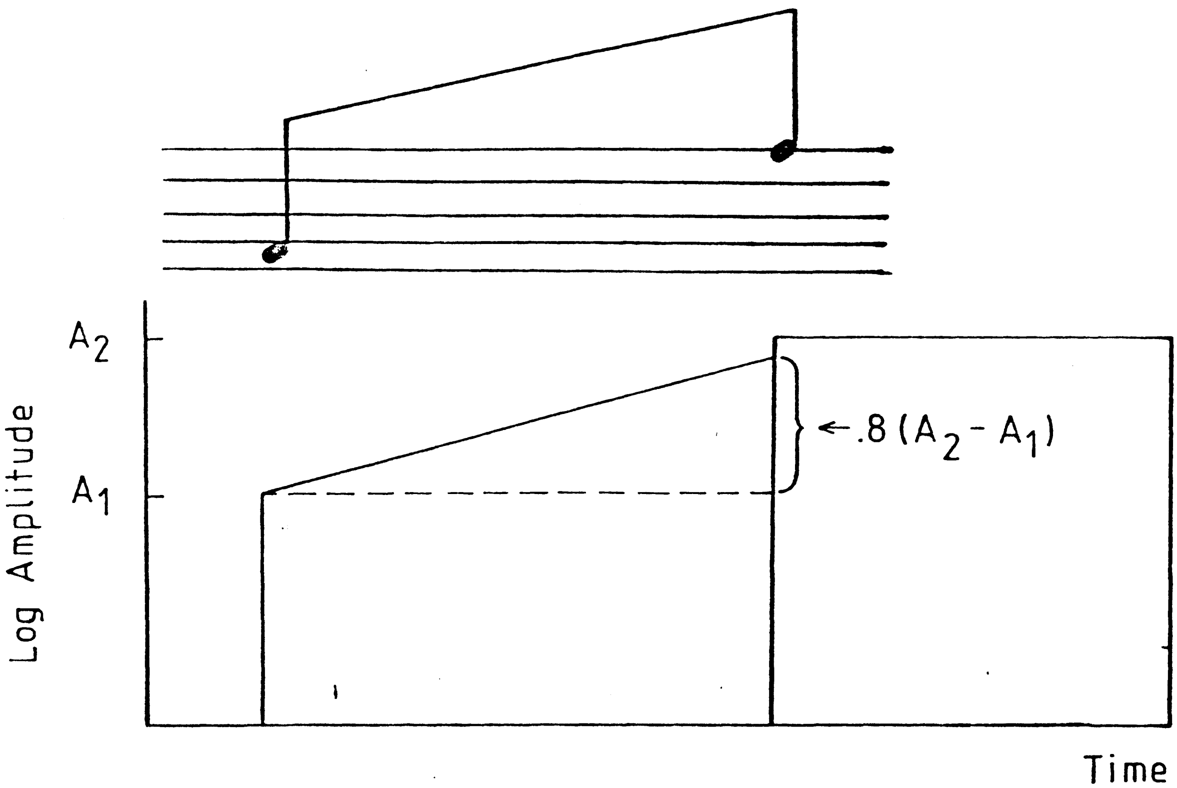


Fig. 6. Schematical illustration of the rule decreasing the amplitude contrasts between adjacent notes. The last amplitude reading of a note is corrected by 80% of the amplitude difference with the following note.

AMPLITUDE MARKING HARMONIC DISTANCE

This rule generates crescendos and decrescendos. The technicalities are as follows. In the input notation the chord changes are marked and each chord is specified. The rule assigns to each chord a value corresponding to its <u>harmonic distance</u> (see Fig. 7). The harmonic distance of a chord equals the number of chord changes required in traditional harmony in order to reach the tonic again (see Sundberg & Lindblom, 1976). By multiplying the square root of this harmonic distance by 18, an amplitude

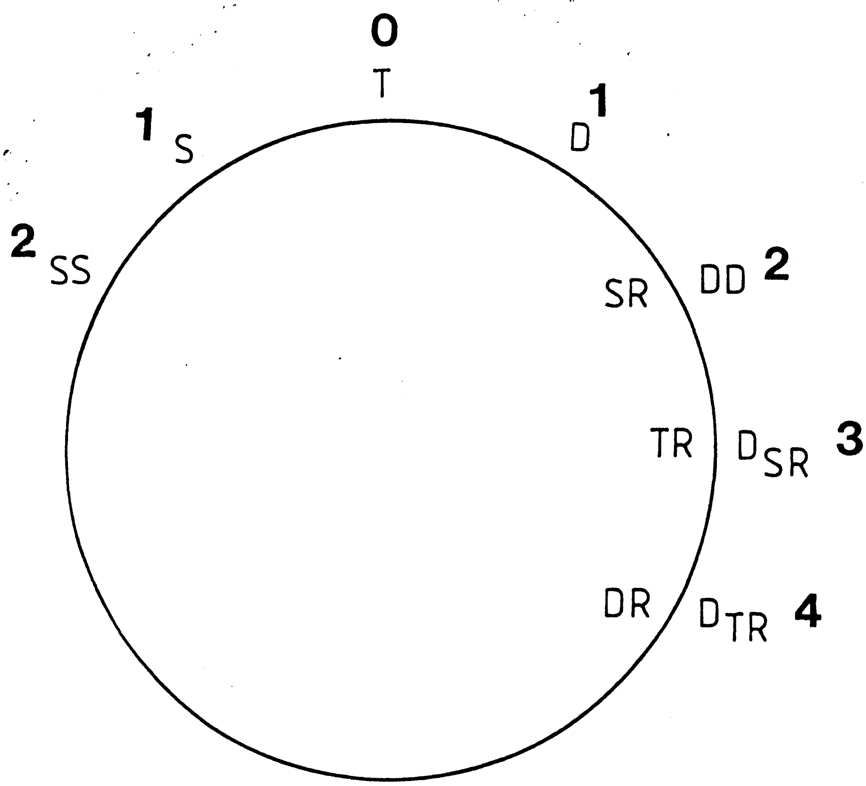


Fig. 7. Definition of harmonic distance by means of the circle of fifths. For a given chord this distance equals the number of chord changes which is required in traditional harmony in order to reach the tonic chord again.

value is obtained, which is added to the first tone appearing over the chord considered. The same procedure is repeated for each chord. Finally, the amplitudes of the remaining tones are linearly interpolated on a dB-scale. Thereby, too slow crescendos are avoided by letting the amplitude remain constant until 1.6 sec before the chord change. The end result is crescendos culminating on harmonic changes introducing a chord which is more remote from the tonic than the preceding chord and decrescendos ending on chords which are less remote from the tonic than the preceding chord. The upper part of Fig. 8 demonstrates how the rule operates on a typical cadence.

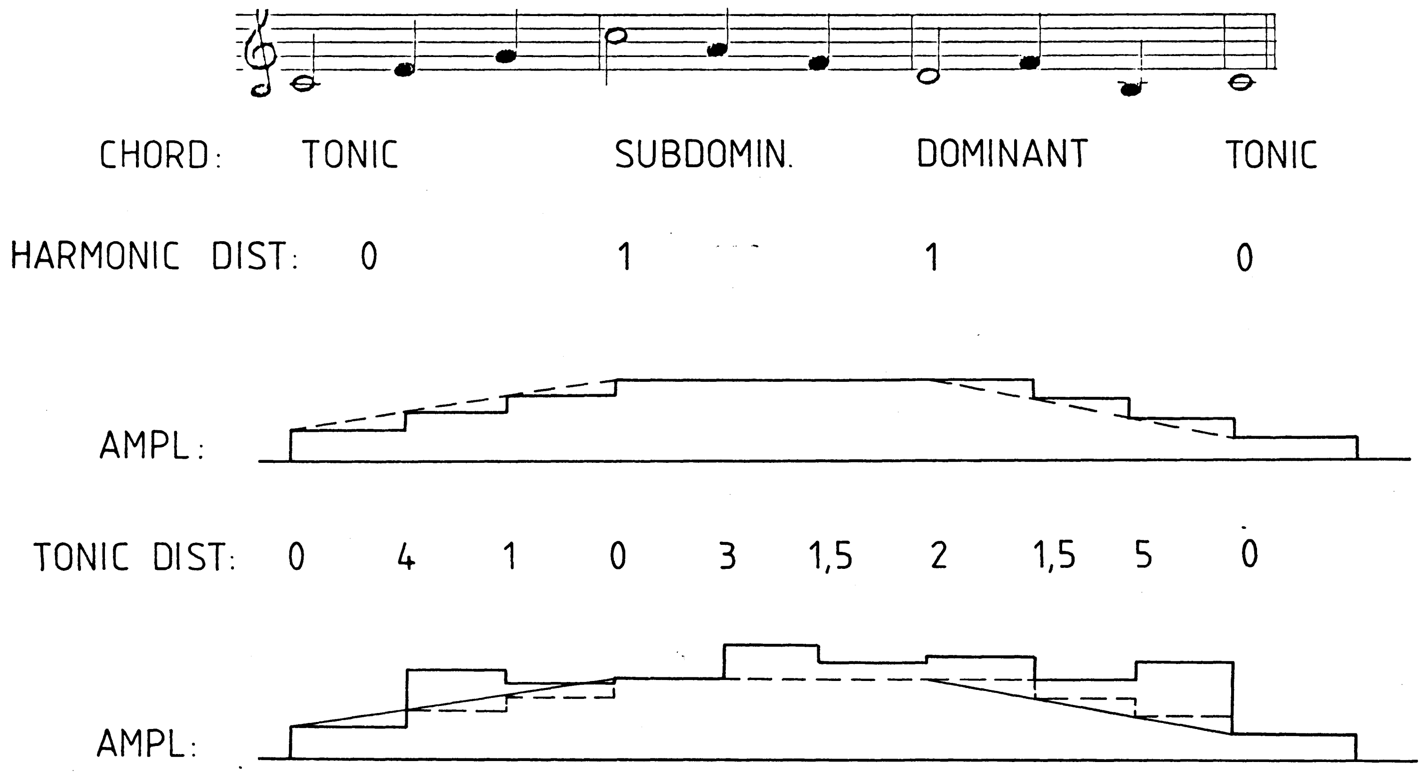


Fig. 8. Schematical illustration of the various steps which generate crescendos and diminuendos. First, the chords are identified, and the chord changes are marked. Second, the harmonic distance is determined for each note in accordance with Fig. 7. Last, the harmonic distance is converted into an amplitude increment which is applied to the first note appearing over a new harmony. Finally, the amplitude of the remaining notes are linearly interpolated on a logarithmic scale.

MARKING TONIC DISTANCE

The distance along the circle of fifths from the root of the tonic is determined for each note. This distance is multiplied by 1.5 for scale tones located on the subdominant side of the circle. We have called the resulting values tonic distances, see Fig. 9. By multiplying this tonic distance by .5, this tonic distance is converted into an amplitude value which is added to each note. For example, in C major tonality the pitch of F sharp receives a rather large amplitude increase, while the pitch of G receives a negligeable increase. The rule is illustrated in the lower half of Fig 8.

LENGTHENING FIRST NOTE AFTER CHORD CHANGE

The first note appearing over a new harmony is lengthened by the number of csec which corresponds to the harmonic distance of the underlying chord.

FINAL LENGTHENING

In the input notation phrases and subphrases are marked by specific signs. The rule adds 4 csec to the note terminating a phrase. For notes terminating subphrases the last 1 csec is used for a pause.

Discussion

Of course, more performance rules than those presented above exist, particularly if we turn to the performance of multiphonic music. Also, we do not pretend that the present formulation of the rules is definite nor that all of them possess generality.

We have not tried to model the multitude of choices which is available to the living musician and which allows him to play the same piece in many different ways, all of which are equally acceptable from a musical point of view. On the other hand, there would be many possibilities to include such a liberty. For instance, different interpretations of where the boundaries are between phrases and subphrases will result in different performances. It also may be that the quantity of the effect of the rules may vary from one performance to the other. We also would like to

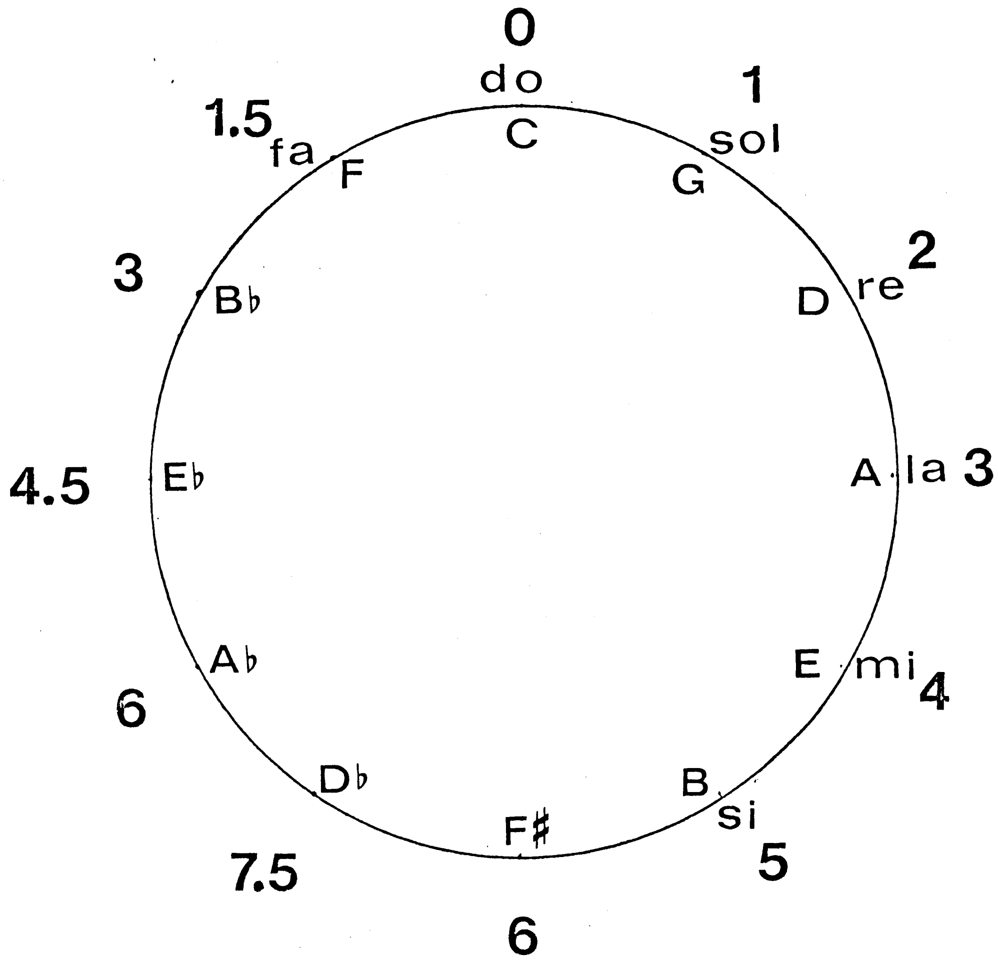


Fig. 9. Definition of tonic distance of the various scale tones. For tones lying on the dominant side of the tonic on the circle of fifths, the tonic distance is the number of fifths separating the note from the root of the tonic. For tones on the subdominant side of the tonic, the tonic distance is the same number multiplied by 1.5.

declare that we do not believe that our performance rules must always be obeyed in a good performance. On the contrary, such a performance may be boring in the long run. We believe that musicians should violate one or more of the performance rules as as soon as they want to communicate something in particular or excite the audience by means of a surprise.

In our work formulating rules we have had the experience that the quantity of amplitude or duration is highly critical by which a rule is affecting a specific note. Even when the effect is only slightly exaggerated, it becomes over-explicit and embarrassing, as the reader might have experienced when listening to the exaggerated versions of the sound examples. The musically useful quantity appears to be one, which is just noticeable but not <u>identifiable</u>. Perhaps this is something which is essential for art in general: we do not want to be disturbed by information about the technical means producing the piece of art, we just want to enjoy it.

The rules presented above share an ad-hoc character. However, several of them seem related to psychoacoustic or other types of already existing evidence. The principle of lengthening the note which terminates a leap might reflect certain effects studied by van Noorden (1975); the disruption of a melodic line, which is often the result of a wide melodic leap, can be eliminated by slowing the tempo. A similar effect might be obtained if the tone terminating the leap is lengthened.

Some rules appear to have other types of origin in that they seem to serve different purposes associated with the psychological process involved in musical communication. One group of rules seem to apply to notes which in some respects are more or less surprising to the listener. It is as if the player wanted to point out to the listener that he/she does no mistake in playing this unexpected note. Examples of such "no-mistake!"-rules may be the lengthening of the target note in leaps, the amplitude increases on notes with high tonic distance, the crescendos towards harmonically remote harmonies, the accents on short notes surrounded by long notes, and the lengthening of the first tone appearing after a change in harmony. Generally, the rule generates crescendos culminating at chords with the function of a dominant and decrescendos to their following "rest chords". As such sequences of dominant chord - rest chord are used to mark - among other things - the termination of phrases and subphrases in simple tunes, this rule often has the effect of marking the melody structure (cf Sundberg & Lindblom, 1976).

A second group of rules appears to serve the purpose of bringing the synthesis in reasonably close agreement with the sound of music as played on a traditional instrument (including the human voice). The rule increasing the amplitude with pitch is a good example, as this is a characteristic which most traditional instruments share. It is also possible that the rule inserting pauses in wide leaps refers to a general characterstic of many instruments; for instance, the fingers have to be moved a large distance on the fingerboard, when wide leaps are being performed, and this would give rise to small pauses.

A third group of rules appears to take into consideration different kinds of associations, which a listener is likely to experience by listening to the music. Even though not included in the present study, the final retard represents a classical example of this (see Sundberg & Verrillo, 1980). Apparently, it would be perfectly possible to end a piece of motor music without a retard. However, if the music remind the listener of physical motion, a retard is needed, because we know from experience with e. g. running that physical motion is preferably slowed down before it stops. It is possible that the accelerando in sequences of rising intervals is another example; if pitch increases tend to cause associations with upward physical motion, and vice versa, then a tempo increase in "uphill" motion might inform the listener that the motion is performed without strain.

Every music listener would be biased from his/her acquaintance with speech. In other words, in trying to decode the sequence of acoustic signals a music listener is likely to make use of his/her skill in doing the same thing in a speech listening situation. The fact that speech and music both represent systematized interhuman communication by means of acoustic signals suggest that they share some of the code. In speech the final lengthening seems to be a principle of great generality (Lindblom, 1978). This means that most listeners are inclined to interpret lengthening as a sign of termination. This might be the background of the rule which lengthens the last tone in phrases.

It is interesting to note that many rules appear to have an extramusical background. This suggests that music communication requires both intra- and extramusical experience from the part of the listener. We believe that further research on this background will be interesting and rewarding.

In summary, then, it seems possible to imagine plausible backgrounds and purposes behind several of our rules, in spite of the ad-hoc-origin of these rules.

Conclusions

From the above we conclude the following

(1) It is possible to improve the musical acceptability of a performance by applying a limited set of "pronunciation" rules.

(2) Such rules can be discovered by means of an analysis-by-synthesis approach.

(3) Such an approach enables us to formulate new hypotheses as to how the rules proposed should be complemented and thus to contribute to knowledge about and scientific understanding of music.

(4) Some of the rules seem to reveal basic requirements for musical communication.

Acknowledgement

This is a status report of a project in progress; after the above text was written the formulation of some rules has been improved, particularly regarding the crescendo/diminuendo.

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EXPRESSIVE MICROSTRUCTURE IN MUSIC, LINKED TO LIVING QUALITIES*

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Table of Contents

SUMMARY

Beyond what is specified in the score, vital musical communication demands the creation of varied, subtle and distinctive forms for each musical tone, forms whose nature and function we attempt to elucidate. Expressive microstructure, essential for living and authentical musical communication, is present in musical thought also as an integral part of musical structure. Principal features of microstructure are distinctive amplitude shapes for individual tones of a melody, and duration deviations from the note values of the score. These were studied with sinusoidal carrier tones that were amplitude modulated by so called Beta Functions to shape the tones of melodies of various composers and using a computer program to sculpt each tone with high resolution. A wide range of expressiveness was found to be possible without the additional factors of timbre and vibrato. The following systematic functions were discovered:

1. Amplitude shapes of individual tones may be largely determined by the slope ot the melodic contour, i. e. by the slope of their essentic form. An equation is given (and illustrated by computer realizations) that predicts appropriate amplitude shapes for the individual tones of any melody from its structure. Musical illustrations are given from various composers from J. S. Bach to P. Tchaikowsky. The forms appear to greatly increase the musicality of phrasing and even of scale passages.

2. Composer's individual pulse forms are seen to produce characteristic microstructure in their music in terms of the relative amplitude size of the component tones within a pulse and of their duration deviations. Pulse matrix values that determine this microstructure are given for Beethoven, Mozart and Schubert.

These two functions, together with micropauses, appear to comprise a major part of microstructure. The role of timbre in expressiveness can now be investigated from a clearer perspective.

The expression of essentic form of a specific quality of feeling through pitch-time relationship is strengthened by its concurrent expression as an amplitude form - linking peaks, in faster music, and as individual tone amplitude shapes in slower music.

Computer performances are presented of melodies of various composers, specified mathematically in verifiable form, with microstructure entered according to musical feeling, and as calculated by the computer based on the relationships given. The computer program appears to be able to play artistically any melodies by Mozart, Beethoven, and Schubert according to authentic, moving sensitivity and subtlety - which appears to confirm the musical validity and understanding of the relationship and principles given.

I INTRODUCTION

This paper is a result of a continuing search - ever more important it seems - for how a phrase of superbly expressed music has the power to change the state of a listener, while less well expressed music does not - how a seemingly small difference in expression can make a big difference in the power of communication. Functions considered in this paper appear to contribute to this power.

That Music is infinitely more subtle than can be notated in a musical score is known to every musician. Many subtleties are required to be read into the score, some of these by accepted convention, but most through the interpretive powers of the performer. Recent studies (Sundberg 1982, 1980, 1977, this volume, Bengtsson and Gabrielsson 1980, 1977, Gabrielsson 1982, 1979 this volume, Clynes and Nettheim 1982, Clynes and Walker 1982) have been concerned with aspects of these functions. Others have studied relevant temporal motor performance characteristics (Michon 1974, 19v7, Povel 1976, Schaffer 1981, 1980, Viviani and Tezuolo 1980, Wing 1977). "Fidelity to the score" is thus seen as a necessary homage to the composer, but not a sufficient one. Clearly, there is an organic hierarchy of structure, from the minute structural details within each tone to the largest relation between component parts of the music. In the best performances this organic hierarchy is revealed, as a higher level fidelity to the composer.

Regarding detailed requirements of performances (and of musical thought) in relation to what is written in the score we may note:

a) The musical score does not specify the relative loudness of individual notes, either in a melody or in a chord, with anywhere near the degree of discrimination that the performer requires.

b) Less well known but often even more important to a satisfactory performance is that the amplitude contour of each tone needs to be individually shaped in accordance with the musical requirements. These shapes are in general completely unspecified, yet every performer who has the freedom to shape each tone, such as a violinist, cellist or singer for example, does in fact create an amplitude shape for every performed tone - some more satisfactorily than others. A great performer uses such varied amplitude shapes as a principal means of expression. In instrumental music where this is not readily possible (e.g. organ, piano, harpsichord), we tend to compensate for their absence by mentally imagining them from our understanding of the form of a theme.*

c) Further, the demands of a living or vital performance include the subtle deviations from the temporal values prescribed in the score (some of which turn out to be quite unsuspected). Arithmetic ratios of simple whole numbers such as 1, 1/2, 1/3, 1/4, 1/8, 1/16, 1/32 need to be emended to values that are in some sense "truer" than these values given in the score (we shall try to clarify that sense in what is to follow).

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* Musicians may attempt to illustrate and approximate these shapes (and other aspects of microstructure) through using appropriate syllables for the tones. This was a favorite method of instruction of Pablo Casals, who used it especially to demonstrated phrasing subtleties to the orchestra he was conducting. Arthur Schnabel used a similar method, but attempted to use meaningful words also, as a linguistic phrase, to illustrate the subtle phrasing and accentuation of a theme (Wolff, 1972). Thus we may note the following characteristic of the syllables used:

1. Consonant at the beginning, e.g. t, d, l, r, p (may be absent)
2. Central vowel, a, e, i, o (rarely u)
3. Auxillary vowel, ai, ei, or ya (in this there is a transition in the same tone from the first vowel to the second)
4. Terminating consonant, l, m, t, p as in lal, tam, tat, pam, rat, yam, yap or absent as in ta, la, pa.
5. Fast notes of the same nominal duration are da ga da ga,or ta ka ta ka in duple rhythm, or da ga da da ga da or ta ka ta ta ka ta in triple rhythm.

For example, a passage may end in a "tam" or a "ta", a "pam" or a "pa", implying a different shape. The consonants and vowels used are not arbitrary but fit the expressive nature of the motif.

See also Schaffer, 1981, Martin 1972, Fonagy 1968, for aspects of the tone group as prosodic unit.

If modern electronic facilities had been available to earlier composers, so that they would have clearly known the various extent of these deviations, a more precise musical notation might perhaps have developed from the needs of musical expression. One may surmise that theorists would have been inclined to study these deviations carefully, certainly the exponents of the Affektenlehre in the eighteenth century, such as Marpurg, Mattheson, Quantz, Leopold Mozart, Carl Phillip Emmanuel Bach, to name a few, all of whom specifically emphasized the importance of subtleties of inflections that need to be read into the score.* These

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* Thus Leopold Mozart writes:
"With half notes that occur among shorter values, the invariable custom is to attack them vigorously and then to diminish the tone again. Indeed, quarters are sometimes played in just this way.

And this is (also) the expression actually called for by the composer when he marks a note with an f p, that is, with a forte piano. But after the player has vigorously attacked the note, he must not let his bow leave the strings, as some clumsy players do; the stroke must be continued and consequently the tone still heard, though it will gently taper off.

- ...The particularly strong notes are the following: in every measure, the note beginning the quarter; in the half measure, the first note, or in 4/4 time, the first note of the third quarter; in 6/4 and 6/8 time, the first notes of the first and fourth quarters... These, then, are the initial notes on which the maximum intensity of the tone will fall, wherever the composer has indicated no other expression.

- ... The other "good" notes are those which are always distinguished from the rest by slightly increased intensity, but to which this increased intensity must be very moderately applied.

- ...When several notes of this sort follow one after another, slurred two and two, the accent will fall on the first of each two, and this first note will not only be attacked somewhat more vigorously but will also be sustained somewhat longer while the second note will be bound to it, quite gently and quietly and somewhat retarded. It often happens, however, that three, four and even more such notes are bound together by a slur of this sort. In such a case, the player must attack the first of them somewhat more vigorously and sustain it longer."

Thus Leopold Mozart. There has been no more precise formulation of these matters until our time!

temporal deviations relate to structure, meter and rhythm, but as we shall see also specifically and systematically to the composer´s own individuality from the second half of the eighteenth century on - in music that has a pulse or beat.

d) A further element of music not precisely specified in the score is the timbre of each tone, and also

e) the variations of timbre within such tones. Composers specify on what instruments to play, and sometimes a particular way of performing on that instrument, but instrumental qualities vary (e.g. Schubert often may sound better on a Boesendorfer, and Chopin on a Steinway; French oboes sound differently from German ones), and further, a good performer is able to produce a considerable range of timbre on each note that is played, for the majority of instruments (a fact that tends to be neglected in creating the sound synthesizer versions of "instruments"). For example, varying the pressure and velocity of the bow, or lip pressure and wind velocity, within a single note the performer can produce not only variations of loudness but also variations in timbre independently of loudness.

All of these variables remain generally unspecified in most music scores. These give the performer additional freedom, but not arbitrary license: they need to be used in fidelity to the composer´s music.

In the present paper we will be concerned with three of these five variables:

1. Loudness differences between different tones of a theme.

2. Distinctive amplitude shapes of the individual tones of a theme.

3. Tone duration deviations (from the values given in the score) for expressive performance of these melodies, and also those induced by the specific pulse of the music.

We will attempt to relate these microstructural requirements to the identity and meaning of the music. We will also show aspects of how they relate to form; and since form and content are indissoluble in music, to shed some light on differences between meaningful and meaningless form, exaggerated and insufficient expression.

We have studied this microstructure by means of a special computer program that allows us to shape individual tones and their durations with high precision. As we are interested in the three factors of amplitude relationship, amplitude shape, and timing, we have deliberately confined ourselves to use what appears to be the most reproducible and simplest timbre, that is a pure sinusoidal carrier. We also use no vibrato (which could be considered a sixth varying function, whose rate and modulation depth are further functions of time, and which is partly frequency and partly amplitude vibrato in various proportions). At times we make use of expressive intonation, i.e. slight alteration of frequency from the well tempered scale, such as raised leading tones or a slightly flattened minor thirds, where appropriate. Such intonation has a negligible effect on amplitude relationships, tone shapes, or durations.

The degree of expressiveness that is possible using only amplitude modulated sinusoids is quite surprising. Our ears appear to be highly sensitive to amplitude shape and our memories effortlessly keen in noting relative amplitudes (and amplitude shapes) sounded in sequence in a musical context - even when the corresponding tones are sounded up to 10 or 15 seconds apart (with many other tones inbetween).

This faculty of short term memory for comparing tone amplitudes and tone shapes allows us to distinguish between identical forms (mostly perceived as monotonous and mechanical) and slightly varying forms. The latter, played even a few seconds apart, perceived in relationship to one another can produce varied meaning and vitality. These relationships of shapes form a <u>microstructure</u> in the music not explicit in the score, but vital to its meaningful understanding. It would seem that the microstructure is in fact more effortlessly experienced than the macrostructure. Appropriately performed in relation to the larger structure, it satisfies the musical requirements of true convincing musical communication.*

This microstructure made evident through our studies is also an essential part of musical logic. It is quite systematic and integrates meaningfully with the larger structures to which the attention of music theory has been chiefly confined (Cooper & Meyer, 1960; Sorantin, 1932; Batel, 1974; Schenker, 1935). We may say that it helps to flesh out the bones of the structure of music as seen by musical theorists, and brings music theory a step closer to the realities of musical performance. The warmth of immediacy, the very product of that microstructure, is no longer eliminated in theory.

Also, our studies are aspects of attempts to use computers to perfect interpretations of great music, much like a sculptor can work on his creations, gradually perfecting the forms over long periods, to a level of communication limited only by the artistic understanding, not by the executive skill of fingers, arms and lips.

We shall first study a number of musical examples made by this method, through a "manual" shaping of amplitude shapes and durations, i.e. by entering the parameter values into the computer program. We shall then proceed to demonstrate with further examples two main systematic aspects of microstructure.

1. Amplitude shapes of individual tones are related to the form of the melody, in particular to the <u>slope of the pitch contour</u> (i.e. the slope of the essentic form). Musical examples will be given for which the computer calculates the amplitude shapes according to this rule, to be described.

2. Amplitude size of tones within a pulse or beat, and their duration deviations are related to a pulse form specific for a composer (to be

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* It seems that neglect of different amplitude shapes of individual tones is often an important contributing factor to the limited expressiveness of certain synthesized instrumental music and computer music.

detailed for a number of composers) which applies to his works. Musical examples calculated by the computer according to these functions will be given.

II PREVIOUS WORK AS BACKGROUND

We shall briefly review our previous work that served as a background for the present studies (for fuller details see Clynes & Nettheim, 1982; Clynes & Walker, 1982; Clynes, 1980, 1977, 1975, 1973, 1969). The studies presented in this paper draw on two lines of research:

A. Studies of essentic form, the dynamic expressive forms of specific emotions, as studied in touch and sound.

B. The inner pulse of composers as measured through rhythmic studies.

We will briefly summarize relevant aspects of each of these.

II A.1. Expressive Sounds Transformed from Touch Expression

In Clynes & Nettheim (1982), and Clynes (1980a) it was shown that touch expressions of specific emotions can be transformed into sound expressions of like emotions, i.e. the nature of the transforms was found so that the sound expresses the same emotional quality as the touch expression from which it is transformed.

The touch expressions are measured by recording the transient forms of finger pressure when these are voluntarily expressed. The instrument enabling this measurement to be made is called the Sentograph; it measures both the vertical and horizontal components of finger pressure independently as vector components varying with time. The sentographic forms obtained are stored in a computer memory and can be reproduced at will.

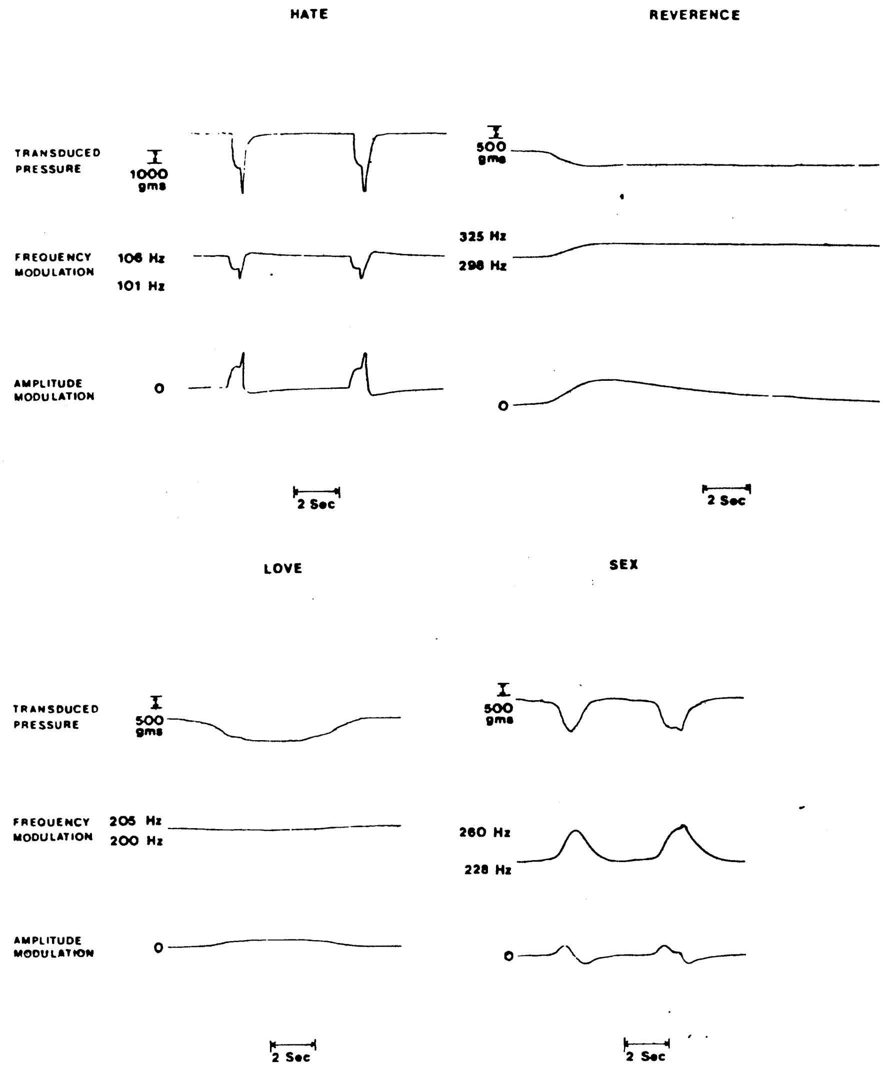

Fig. 1

Fig. 1 and 2. Examples of transformation of expressive forms of touch to sound that expresses the same feeling. The top trace shows expressive finger pressure (vertical component); the middle the frequency modulation envelope; and the lower trace the amplitude modulation envelope. The time scale is doubled for Joy and Anger. The frequency envelope is the same as the pressure apart from a vertical scale factor, except for Joy, where the wide dynamic range requires an approximately logarithmic scaling. Reproduced from Music, Mind, and Brain, ed. Clynes (1982).

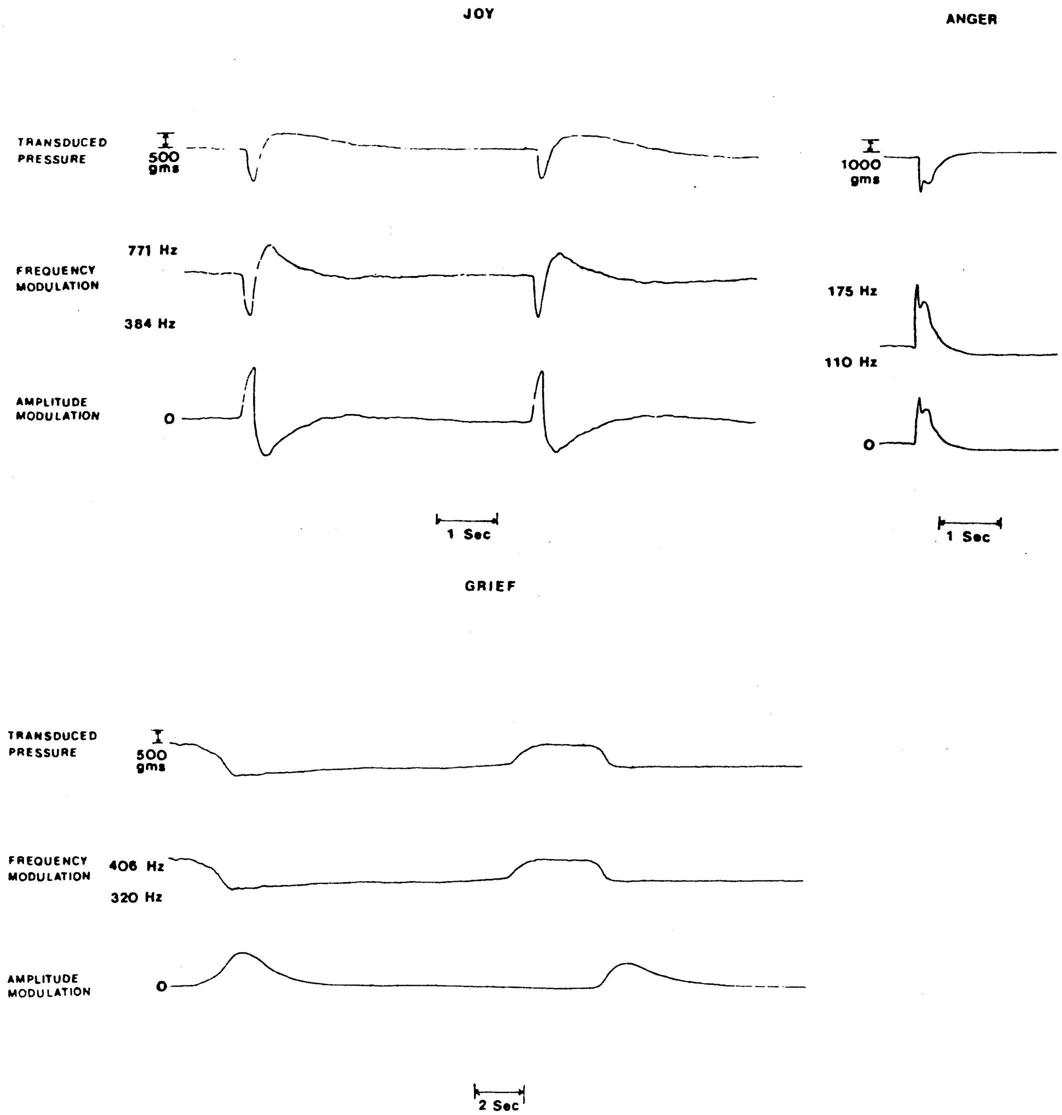

Fig. 2

In transforming the sentograms for touch expression of specific emotions into corresponding sound expression it was found that the dynamic form (essentic form) of the touch was preserved to become the frequency contour of the sound. The sound is a frequency and amplitude modulated sinusoid. The amplitude modulation also was related to the dynamic touch form but needed to be passed through an imperfect differentiation network, i.e. an adaptive time constant. Table 1 and Fig.s 1 and 2 show the nature of the transform (for details of the measurement of the essentic form through touch expression, see Clynes, 1969, 1975, 1977, 1980).

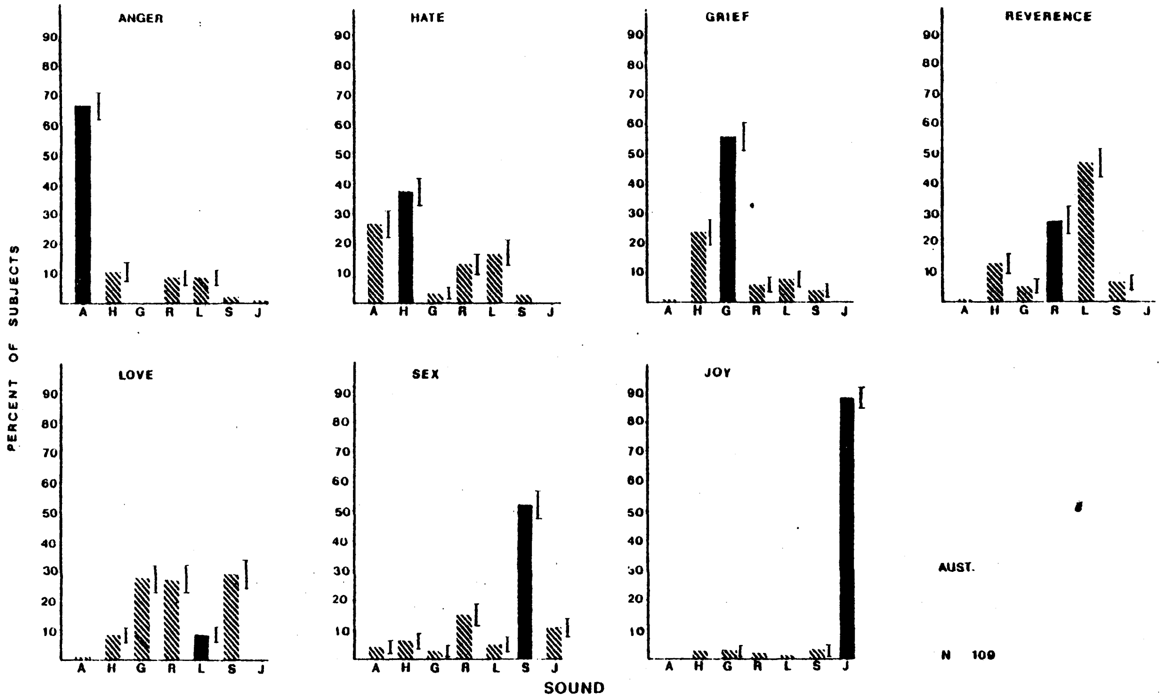

Fig. 3

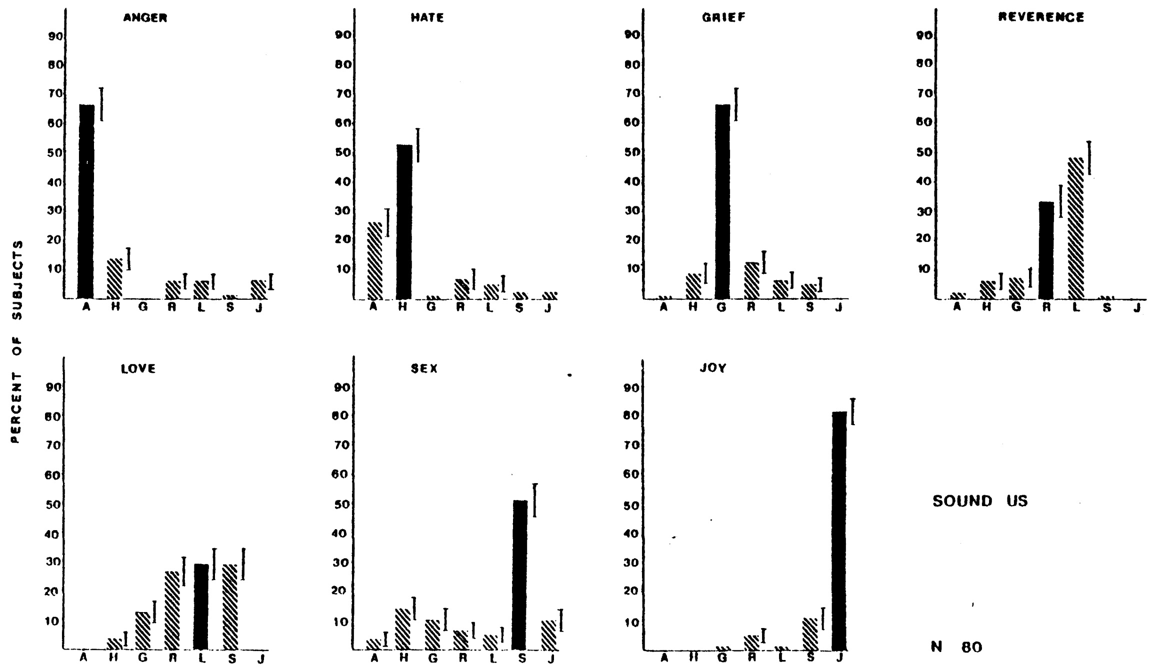

Fig. 4

Fig. 3 and Fig. 4. Recognition of sound expressions transformed from expressive touch. This figure shows that recognition of emotions was (cont. p. 88)

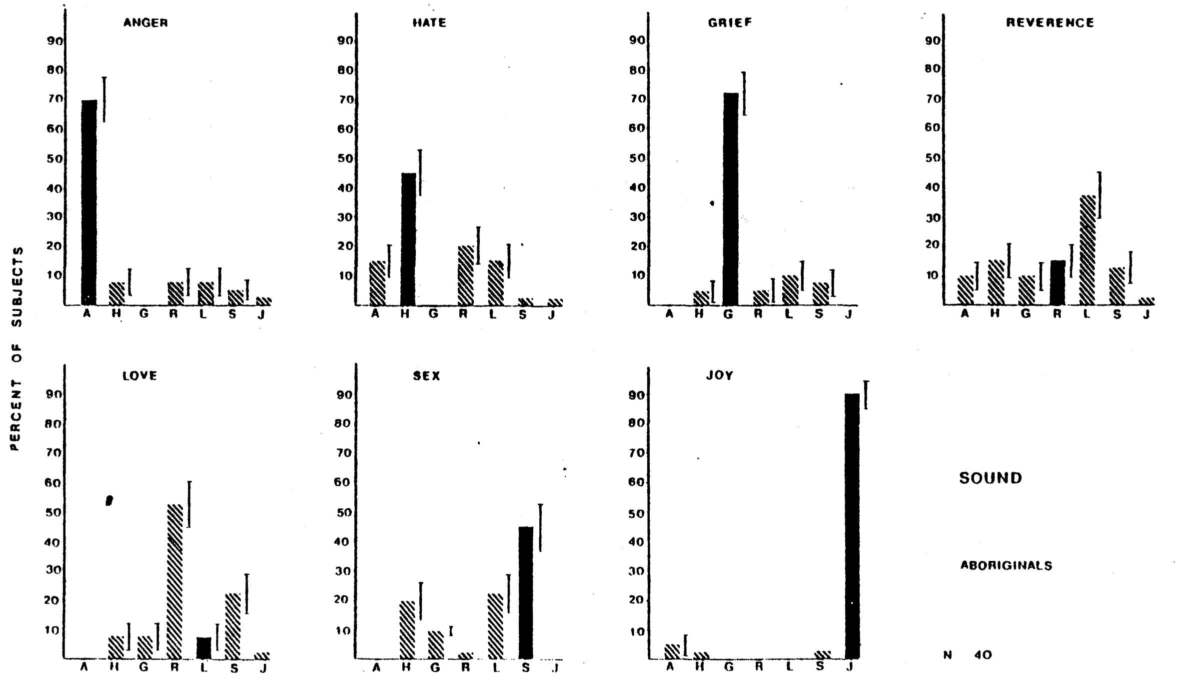

Fig. 5

(cont. from p. 87)
high for all emotions except for Love and Reverence, which were largely confused with each other.
Fig. 3 (top) refers to an experiment where the subjects were students of M. I. T. and University of California, Berkley.
Fig. 4 (bottom) refers to an experiment where the subjects were medical students of the University of New South Wales. The bars show the percentage of correct identification. Shaded bars show errors made. Standard deviations are drawn with each bar (±).

Fig. 5. Recognition of a group of 40 Australian Aborigines of the Warlbiri Tribe in central Australia, of sounds produced from white urban touch expression of finger pressure. Performance is very similar to the high recognition shown by the M. I. T. and Berkley students, and the by the medical students of the University of New South Wales (cf. Fig. 3 and 4). They did somewhat better than those groups in idewntifying Joy, Anger, and Grief, although differences between groups were not statistically significant. Instead of confusing Reverence and Love they chose more clearly, but the choice was opposite o f that intended: Love was chosen for Reverence, and vice versa. This may have been due to subtleties of translation. Differences between male and female scores were not significant in this group. Reprinted from Clynes & Nettheim (1982).

Sounds thus transformed from touch expressions of seven specific emotions were tested on 229 subjects as illustrated in Fig. 3, 4 and 5, in a forced choice test (Clynes & Nettheim, 1982).

The results show that subjects recognized the emotions well, regardless of whether they were a group of Australian medical students, U.S. students at Berkeley and MIT, or Central Australian Aborigines from Yuendumu (Warlbiri tribe) who hardly spoke English. Joy, Anger, Grief, Hate and Sex were generally recognized between 88% and 50% correctly ($p<.0001$). Males and females in all groups did equally well. An exception were the results of Love and Reverence which were mutually confused by the American and Australian groups, and were switched for one another by the Aboriginal group: In the latter group, Love was chosen significantly for Reverence and vice versa. (This could signify a superior ability of the Aboriginal group for differentiating these sounds, if translation produced a switched meaning between these two qualities, as may be possible.) In the main, however, the confusion between Love and Reverence may be taken to indicate that our sounds were not sufficiently characteristic, or that a considerable overlap exists in the minds of the subjects between these two categories, or both. (We have since produced an improved version of the Love sound, which is being tested currently.)

Confidence index scores (Clynes & Nettheim, 1982) showed that subjects were more confident when they made a correct choice - an independent confirmation of the recognition results ($p<.00005$).

These studies on several hundred subjects provided convincing evidence that the sounds derived from touch expressions of the respective emotions did in fact contain these qualities.

II A.2. Melodies and Essentic Form

How are these expressive sound shapes (of "continuous" frequency modulation) related to melodies ("discrete" frequency modulation)?* It was shown (Clynes & Nettheim, 1982) that it was possible to create musical melodies which express a similar emotional quality to the dynamic "continuous" expressive sound forms we had identified, in such a way that:

1. The melodic steps of the created melody outline the frequency contour of the "continuous" form.

2. The amplitude contour of the expressive sound is preserved.

As different melodic steps are chosen, their duration would be such as to conform to the continuous frequency modulation time curve (essentic form). We showed for example that a set of 28 different Grief melodies may be constructed which will contain the essentic form of Grief in this manner (Fig. 6, Table 2). Each of these melodies sounds sad, but has different harmonic implications. The duration of the steps is modified by the requirements of the form, as a trade-off between duration and step size, so as to still fall on the pitch time function for Grief.

Note that in each case the amplitude contour is the same, that of the "continuous" Grief expressive sound.

The mind apparently extrapolates the discrete frequency points, aided by the amplitude contour, to recognize the Grief form. It is as if the

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* Cleonides, around the first century A.D. writes about this distinction: "The things considered under quality of voice are these. The voice has two sorts of movements: one is called continuous and belongs to speech, the other is diastematic and belongs to melody. In continuous movement, tensions and relaxations occur imperceptibly and the voice is never at rest until it becomes silent. In diastematic movement, the opposite takes place, the voice dwells on certain points and passes over the distances between them, proceeding first in the one way, then in the other. The points on which it dwells we call pitches, the passages from pitch to pitch we call intervals."

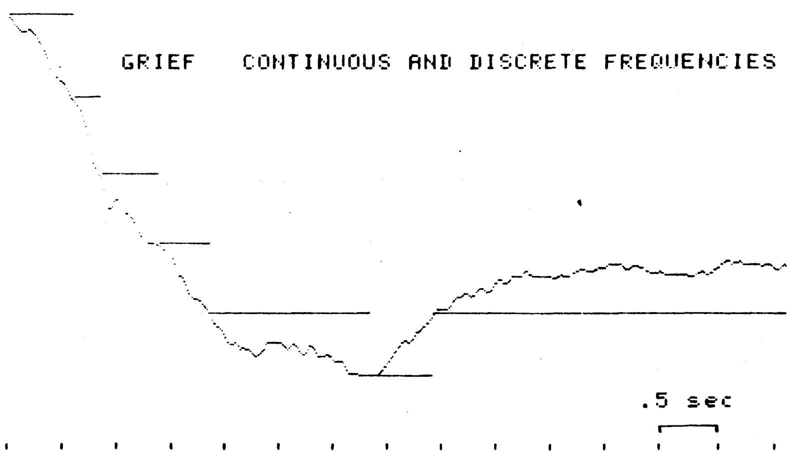

Fig. 6. ´Continuous´ and ´discrete´ frequency contours for a Grief sound expression. The discrete steps are semitones that fit the contour of the continuous form. Other discrete step combinations are derived likewise from the continous form. Durations of the melodic tones in the ´discrete´ versions are governed by the shape of the continuous form. The set of all 28 possible melodic combinations (eliminating 3 combinations using the first two semitone steps or less where these two semitone steps fall very close to the beginning of the form, making them in effect appogiaturas) are shown in Table 2. Reprinted from Clynes & Nettheim (1982).

frequency curve represented a trajectory, representing an inner action, and that the actual frequency points represent "steps" taken inwardly along the "road" of this trajectory. This is more than metaphorical: It is meant that some motor initiation takes place mentally for each tone of the melody (even when thought silently) - for example, a subliminal activation of the muscles active in singing (similar to the well-known, often observed subliminal activation of speech related muscles as one thinks words; or sometimes a desire to tap with the hand or foot). In each case, the amplitude of the motor impulse for that tone would correspond to the amplitude of the tone, i.e. the amplitude contour of the motor impulses would trace the sound amplitude contour of the essentic form; much as the frequency steps do with regard to the frequency contour.

II B. Studies of the Inner Pulse of Composers

The first sentographic studies ever carried out in fact consisted of the measurement of the inner pulse of specific composers (Clynes, 1969). The sentographic forms that were observed for the inner pulse of Beethoven, Mozart and Schubert are shown in Fig. 7, 8, and 9. These forms, obtained by thinking the music and expressing the pulse by "conducting" on the sentograph with finger pressure, suggested that some composers were able to impart individual characteristic pulse forms to their music - pulse forms that characterized their identity; and that this tended to apply to their musical output as a whole (Becking, 1928; Sievers, 1875-1915). As a distant analogy we may see that a painter has characteristic individual brush strokes. Moreover, it seemed clear that this characteristic pulse needs to be present for an authentic performance. How exactly that experienced pulse was manifest in the musical sound, however, remained to be ascertained until now.

Later studies (Clynes & Walker, 1982), stimulated by the properties of Time Form Printing of the nervous system which were being dicovered, attempted to recreate the inner pulse as a sound pulse, such that the same sentographic responses are produced by the sound pulse alone as by the inner pulse of the music.

Current studies of these sound pulse images of the inner pulse - as amplitude modulated sinusoids - show convincingly how the same characteristic sound pulse of a particular composer fits different pieces of that composer, while that of other composers does not (Clynes & Walker, in press).

A number of musical examples of the composer´s sound pulse fitted on a separate channel synchronized with various pieces of his, of ifferent meter and tempo, are presented, for Mozart, Beethoven, Schubert, Brahms and Chopin. Some deliberately false examples are also given in which a Schubert pulse is switched for a Mozart pulse, a Chopin pulse for a Beethoven pulse, and so on, to show the kind of misfit that occurs if the wrong sound pulse is played with the music. As Bengtsson has noted (personal communication, 1982), hearing a composer´s sound pulses played in

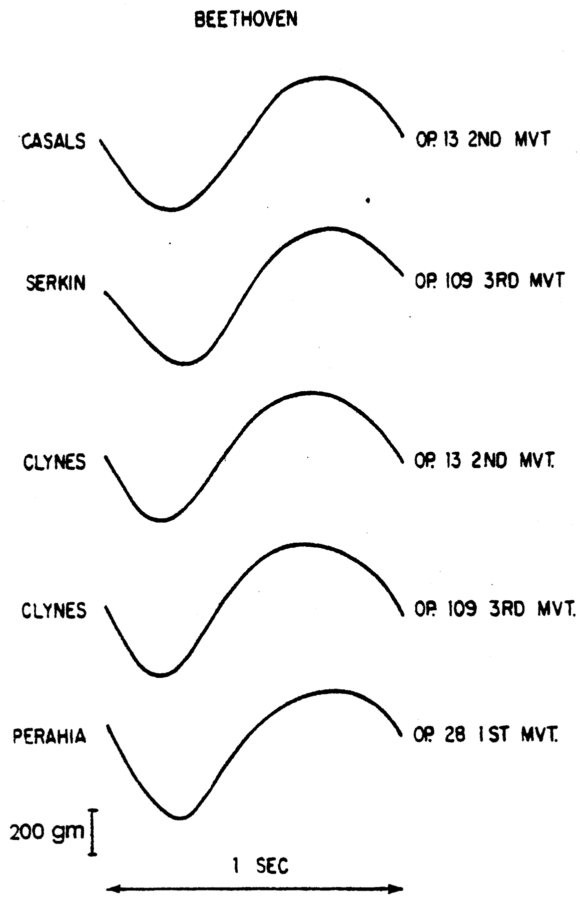

Fig. 7. Essentic form of the inner pulse of slow movements of Beethoven (vertical component). Different movements are compared, as well as the same movement for different interpreters. The lowest trace is of a first movement in triple meter, whose pulse is considered comparable in an appropriate time scale (one pulse per bar in this case). The inner pulse shape continues into periods of rest. Considered as a second order dynamic system, it has a damping factor equivalent to appriximately 0.2, indicating about three afterbeats before cessation, and comparatively high inertia. The high inertia tends to give both an inherent propulsion and a comparatively late down (negative) peak. Sentographic measure of "conducting" the pieces with finger pressure while thinking the music in real time, without sound. The curves represent the average of 50 pulses. Reprinted from Information Processing in the Nervous System, ed. Leibovic & Eccles, 1969.

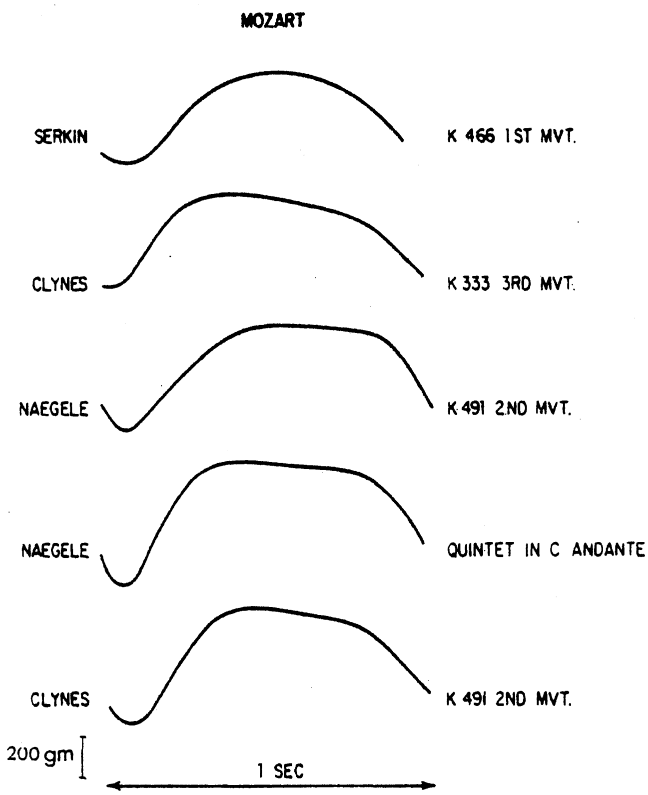

Fig. 8. The essentic form of the inner pulse of Mozart shows considerably lower inertia than that of Beethoven. The down peak occurs much earlier, and there is a small overshoot with damping of about 0.7. The Mozart pulse has no more than one afterbeat compared with several for Beethoven. Its relatively light and bouyant character is related to the low-inertia term coupled with slight underdamping. The curves represent the average of 50 pulses.

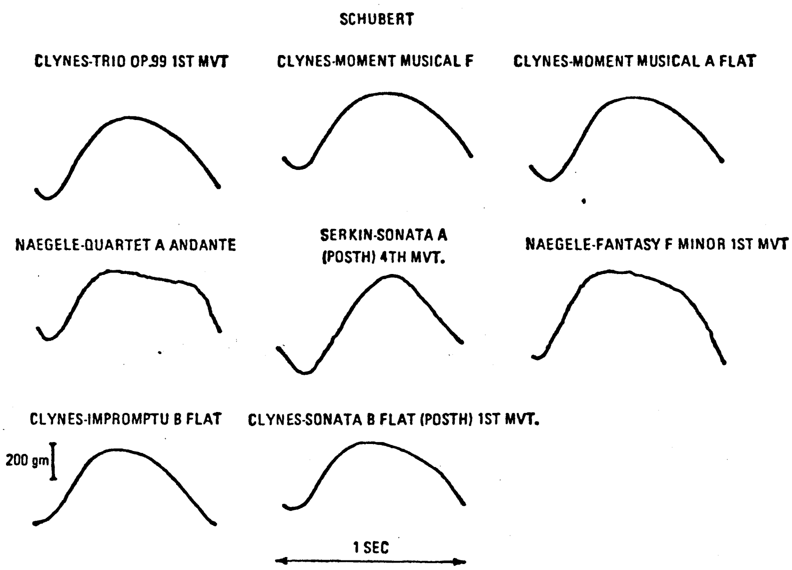

Fig. 9. Essentic form of the Schubert pulse illustrated shows a generally very early down peak, and low inertia, but also a rise leading to a sustained overshoot. There is a characteristic upward deflection related to elements of hope and longing. The initially free beat tends to experience increased resistance and tension in this phase (involving more of the upper arm, in conducting, than at the beginning of the beat).

this way tends to bring to mind a large number of pieces of that composer that fit the pulse; and one can mentally readily switch from one piece to another without a "stumble".

The recognition of these correct pulses for each composer is tested by asking subjects to pick the "correct" pulse from a test tape on which excerpts with correct and with incorrect pulses are randomly presented, for a number of musical examples of each of the five composers being tested. Subjects readily identify the correct pulse regardless of which piece of the composer is being presented (Clynes & Walker, in press).*

These studies may be considered as precursors to the findings shown here regarding the precise nature in which the composer's pulse affects musical performance and thought.

III MICROSTRUCTURE AND EXPRESSIVENESS

In the following main sections we shall describe and investigate, each with musical example (as many as space allows):

1. The extent to which detailed expressiveness is possible without vibrato and variation of timbre, using only sinusoidal tones with individually shaped amplitude envelopes, representing the notes of the music, with duration modification. Such amplitude modulation appears to be the most basic mode of dynamic expression and thus the understanding of this should precede the analysis of the expressive effects of vibrato, timbre and of timbre variation. It turns out that much expressiveness is indeed possible with these very simple means; many of the subtlest nuances can be realized. This mode of expression then, while simple, need not be considered primitive.

2. In doing this, we shall also investigate the relationship between the amplitude shapes of individual tones and the shape of the melody (i.e. essentic form). We shall show that a simple relationship holds between the shapes of individual tones of a melody and the form of its time course. Its shape within a continuum of upright "assertive" ( ) and forward sloping "plaintive" form ( ), to be described precisely is seen to be a function of the slope of the essentic form. This means in practice that the shape of a tone is strongly and predictably influenced

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* It cannot be emphasized too strongly that these sound images of the inner pulse are but shadows of shadows: the inner pulse itself is not a sound, although it is expressed in terms of sound in music; it is a specific command configuration that directs (repeated) inner gesture, which affects the sound in a corresponding manner (cf. the personal gait).

by the pitch of the next tone and by the time when it occurs. The shape of individual tones has a musically predictive function contributing to continuity, and thus, we may say, to musical logic.

3. We shall show in an initial report how the individual pulse characteristics of a number of composers, in particular Mozart, Beethoven and Schubert, systematically modulate the pattern of tones both in amplitude and temporally, in characteristic ways which will be precisely given.

In the course of the above we shall also outline how certain microstructure functions, involving durations, silences and amplitude shapes, relate to various aspects of phrase and larger structure.

III A. Methodology

III A. 1. The Beta Function for Calculating Amplitude Shapes

In order to produce convenient shapes for amplitude modulating individual tones we have used a mathematical means, briefly called the Beta Function. This permits us to create a wide variety of shapes with the aid of only two parameters. It has a considerably wider scope than the use of two exponentials would have, for example.

In electronic generation of musical sounds it has been a convention to specify tones using parameters of rise time, decay time, sustain time, release time and final decay, or some subset of these. These parameters, natural to the electronic engineer, do not really have a musical function of like aptness. Amplitude shapes of musical tones often need to be convex rather than concave (or vice versa) in particular portions of their course (e.g. convex in their termination), and hardly ever have sustained plateaux. Moreover, separation of the termination of a tone into a decay and a release in general is the result of the mechanical properties of keyboard instruments and not a musical requirement.

We found that the varied rounded forms available through the Beta Function (a suggestion of Nigel Nettheim, originally for pulse studies) allow a simple and time-economical realization of the multitude of nuances of musical tone amplitude forms. The Beta Function* is defined as:

$$x^{p_2} (1 - x)^{p_1} \quad \text{for} \quad 0 \leq x \leq 1,$$

and is normalized for a mixmum amplitude of 1 by dividing by a constant N

$$N = \frac{p_1^{p_1} \; p_2^{p_2}}{(p_1 + p_2)^{p_1 + p_2}}$$

for a particular set of values of p_1 and p_2.

p_1, p_2 have values ≥ 0.

The resulting shape is multiplied by a parameter G to give the amplitude size of the particular tone. The shape stretches over a number of points determined by the duration of the tone. Thus, the amplitude envelope as a function of time A(t) of a tone is given by

$$A(t) = \frac{G}{N} \cdot \left(\frac{t}{T}\right)^{p_1} \cdot \left[1 - \frac{t}{T}\right]^{p_2}$$

$$= \frac{G}{N} \cdot \frac{t^{p_1} (T - t)^{p_2}}{T^{p_1 + p_2}}$$

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* The name Beta Function derives from a similar-named function used in mathematical statistics. The Beta Function as used here is the argument of integration of the statistician's Beta Function.

By choosing suitable values of p_1 and p_2 a shape may be selected from families of shapes such as the ones shown in Fig.s 10 and 11. Choosing the value 1 for both parameters results in a symmetrical, rounded form, and 0.89 for both parameters produces a form very close to a half sine wave. Smaller values of p_1 result in steeper rises; zero being a step function. Larger values than 1 for either p_1 or p_2 make the curve concave, at the corresponding regions. A combination of 0 and 1 results in a sawtooth.

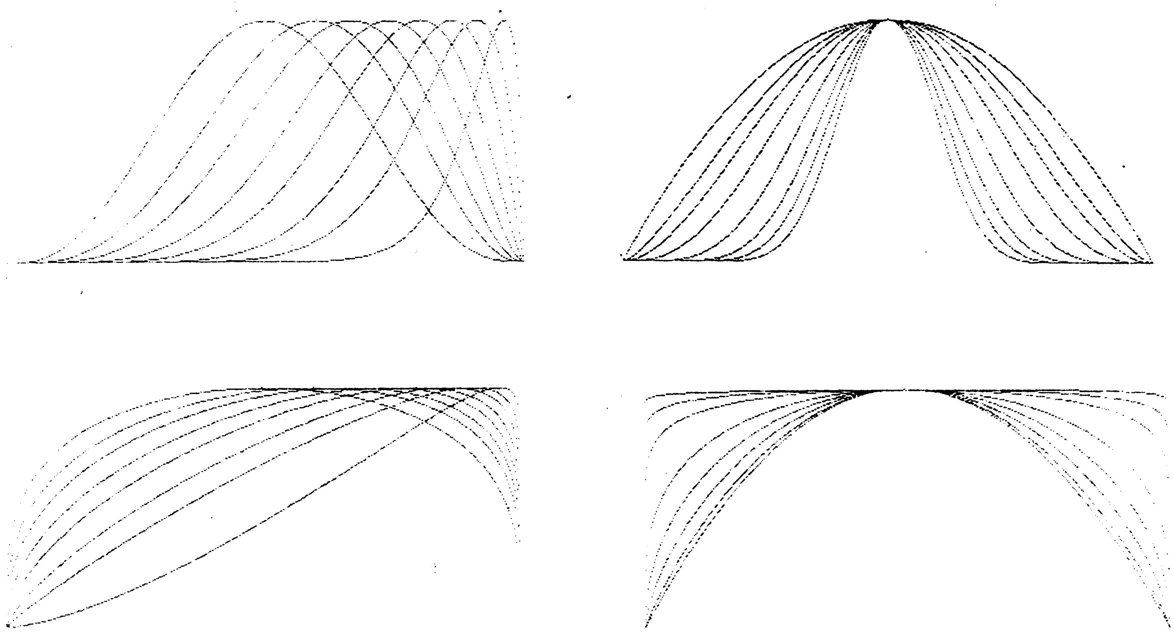

Fig. 10. Families of Beta Function shapes, showing some of the kinds of shapes readily obtained by chosing appropriate p^1 and p^2 values. In the top left graphs the p^1 and p^2 values used are 3,3 (leftmost curve), 3.6,2.4; 4.2,2.1; 5.1,1.8; 6.1,0.5; 7.5,0.2; 9,0.9; and 15,0.6 (rightmost curve). The corresponding values are 1,1; 1.5,1.5; 2,2; 3,3; 5,5; 8,8; 11,11; and 15,15 for the top right graph, 0.3,0.3; 0.24,0.36; 0.21,0.42; 0.18,0.51; 0.15,0.6; 0.12,0.75; 0.09,0.9; and 0.06,1.5 for the bottom left graph, and 0.01,0.01; 0.04,0.04; 0.1,0.1; 0.3,0.3; 0.5,0.5; 0.7,0.7; 0.9,0.9; and 1,1 for the bottom right graph. Maximum amplitude is normalised as 1.

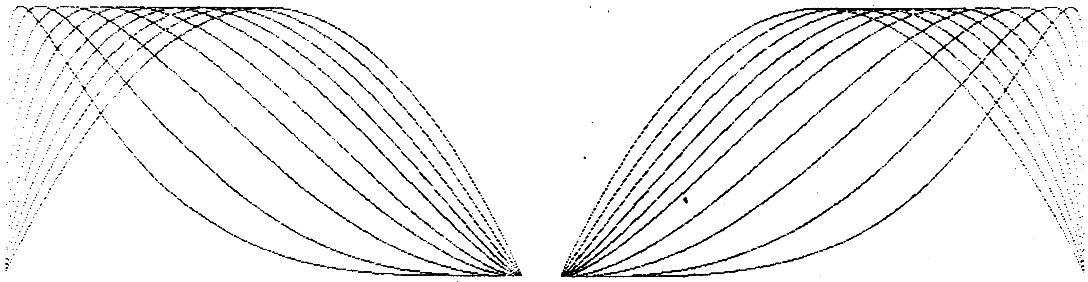

Fig. 11. Beta Function shapes illustrating degrees of skewness, starting from a symmetrical 1,1-form with pairs of p-values forming a series as shown. These are types of shapes used for the amplitude of many musical tones called A and P types (left and right groups, respectively). The p^1 and p^2 values used are 1,1 (symmetrical curve); 0.9,1.1; 0.8,1.2; 0.7,1.3; 0.6,1.4; 0.5,1.6; 0.4,1.8; 0.3,2.2; 0.2,3.0; and 0.1,4.0 in the left graph and in the right graph 1,1 (symmetrical curve); 1.1,0.9; 1.2,0.8; 1.3,0.7; 1.4,0.6; 1.6,0.5; 1.8,0.4; 2.2,0.3; 3.0,0.2; and 4.0,0.1.

Most commonly used p values for musical tones generally lie within the region of 0.5 to 5, as we shall see, and most frequently in the region of 0.7 to 2.

Where required, a second or several more Beta Functions may be added to produce the desired shape - this is seldom necessary, however.

III A. 2. Computer Program for Shaping and Playing Melodies

The Beta Function is used in a computer program that calculates individual tone shapes. In our program the amplitude character of a tone is specified by three numbers, the number denoting the amplitude magnitude G and p_1 and p_2. We use a linear scale for the magnitude with a resolution of 1 part in 4096. This is in accordance with our earlier findings that such transient sound phenomena may often be better understood by changes in amplitude on a linear rather than logarithmic scale, see Clynes & Walker, 1982. It also presents a visually more tractable aspect. (A comparison between linear and logarithmic readouts of the shapes is included in Fig. 13.)

Silences of various durations in the millisecond and centisecond range can also be readily inserted between tones.

The duration of each tone is specified by the number of points it occupies over which the Beta Function is calculated. The calculation for each tone is done without affecting the duration and number of points of other tones. The temporal resolution of tones is usually better than 1 millisecond.

The amplitude contour is constituted by a 12 bit digital-to-analogue (DA) converter and modulates a voltage-controlled amplifier of linearity better than 0.1 % over a dynamic range of 1 to 4096.

The frequency of the tones is set by another channel of a DA conversion which modulates a voltage-controlled oscillation.*

The FORTRAN IV program is run on a PDP 11-23 in our laboratory. The program on our PDP 11-23 can readily play melodies up to 32000 points long using computer memory, i.e. typically up to 100 tones, depending on the number of points per tone (much longer ones using disc storage). The tempo can be varied over a very wide range - there is no lower limit, and the upper limit is around 4000 points per sec, corresponding typically to

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* In this method we have no control over the phase of the sinusoid modulated. Since the melodies we use do not go to very low frequencies and since only single sinusoids are used, one voice at a time, this is not a serious shortcoming. In later studies we are also using a second microprocessor in place of the voltage-controlled oscillator, providing control of phase. There tends to be no noticeable difference aurally between the two realizations.

a metronome mark of 400 per minute for a quarter note; rather beyond most requirements! Parameters of any tone can be readily varied and the changed result listened to in a few seconds (5 - 10 sec. typically).

Further features of the program will become evident as we present the individual musical functions studied.

III B. Microstructure explored through "manually" created examples

III B. 1. Some Observations on the Process of Forming Melodies

Before looking at the details of the examples, some general comments may be appropriate.

(i) It may take a musical person a day or two to perfect such a theme by gradually improving the values of the parameters, and repeatedly listening until it is refined to a degree where he no longer is sure what change would be an improvement.

(ii) As one listens repeatedly and changes parameter values for a time, one eventually experiences satiation or lessening of sensitivity to particular aspects and/or the totality of the expression. It appears that one's sensitivities in this regard are dulled with repeated exposure, and need some time to recover, to regain their spontaneous freshness. A few minutes is sometimes sufficient, but after many hours of work, several hours or overnight may be required to revitalize one's listening.

(iii) Working on a theme in this manner in fact sharpens one's hearing and attention to detail in regard to expressive qualities, and can be considered invaluable for that reason alone.

(iv) A further phenomenon occurs as one continues working with a theme in this manner: the theme teaches one its own nature. As one repeatedly interacts, many new aspects, relationships and meanings become clear (Klages, 1950; Imberty, 1979; Lashley, 1951). One becomes more and more involved with the theme, and it gains more vitality and clarity in one's mind. The goal becomes clearer; yet its form also develops as one works towards it. The process becomes self-refining, a systematic interaction with a stable limit; assymptotic and thus not seemingly finite, but stable. When one finally reaches the point of not being able to improve it any further, one feels this is not because it could not be improved, but rather that the required changes are so subtle, that greater understanding than can be summoned at the time for A-B comparison would be required in order to continue. But still, there is joy and satisfaction in having created something vital, particularly on hearing it freshly at a later time.

This method of sculpturing tones and melodies allows a musical artist, then, to perfect the expression in much the same manner as a painter or a sculptor can, working with a painting for long periods of time, gradually perfecting the forms so that they correspond to his inner vision, a vision which itself is becoming more perfect as the interaction grows. At what stage to say "it is enough" depends on a higher level of integration where another vision and its realization interact in a like manner.

It is also in many ways similar to the process of practicing for a musical performance in course of which the artist, in love with the piece, refines his performance and understanding through repeated reciprocal interaction - feedforward and feedback.

III B. 2. Resolution of Parameter Values

Sensitivity in discriminating different shapes of tones is typically of the order of 0.01 - 0.02 in the p values in the range of 0.5 to 2 (most commonly used). For larger values it is correspondingly greater. The limen of discrimination of the magnitude of amplitude peaks within a melody is of the order of 2%, or about 1/4dB. This means that the ear is more sensitive to the shape than to peak amplitude. For example a difference in shape resulting in 2% deviations of critical portions of the shape (referred to peak amplitude) will be considerably more noticeable than a 2% change in overall amplitude (concerning relatively critical portions of the shape of a tone with respect to sensivity, see Clynes & Walker, 1982).

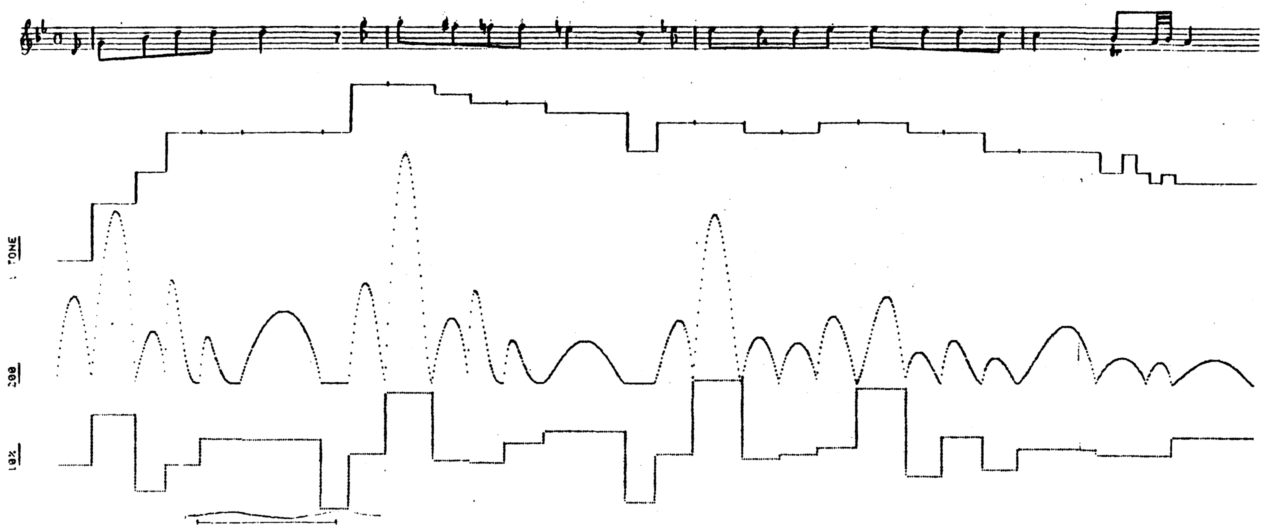

Fig. 12. In this figure and in all following figures the top line shows the notes of the melody. For details of phrasing please see the corresponding score excerpt.

The graph below this represents the pitch of the sinusoidal tones. Small markers on this graph indicate repetition of the same note and micropauses.

The next lower graph is the amplitude contour in linear scale (from 0 to 4096, the value of 200 thus corresponding to -26 dB relative to the loudest level; 1000 being played at about 50 dB above threshold normally).

The lowest trace represents the temporal deviations from the nominal values for each tone, in per cent, upward deflection being slower. (Micropauses are often included in this representation.) The time marker at the bottom of all figures represents 1 second.
Note that the digital printouts prints only every sixth point of the functions - actual resolution is thus six times greater than that shown in the illustrations.

An example of a theme embodied by this method is the first eight bars of the Mozart Quintet in g minor, K516, first movement cf. Fig. 12 and Table 3. The chosen unit of time in the melody, in this case an eighth note, is assigned 100 points duration nominally, so that the quarter note becomes 200 points nominally, the half note 400, and so forth. The actual duration of each tone is modified from these so that a particular eighth tone may have a duration of 96 say, a half tone 220; and so on, depending on its position and expressive requirements.

In this example, all parameters (4 for each tone: duration, peak amplitude, p^1 and p^2) were chosen by trial and error, that is by repeated listening and gradually improving the values as dictated by "the ear".

The program allows us to play any portion or the entire theme, and will repeat as many times as desired (with a short pause between repetitions). The metronome mark entered, e.g. 123, refers to the nominal chosen unit of duration (in the present example, 100 points for an eighth note). If an actual tone has more or fewer number of points than 100, it will have a correspondingly different duration. Minute tempo variations within the theme arise from the differences from nominal values in the number of points for each of the tones.

In this example, we may note the following:

(1) Amplitude Relationship within a Four-tone Group (One Pulse)

The amplitude relationship between the four eighth notes of the first bar shows that the second and fourth tones are much smaller, the fourth one being a little less than the second. The third tone is considerably larger in amplitude than the second and fourth but less than the first. A similar pattern is repeated in the third bar but the accentuation of the first tone is even greater.

Throughout the theme the first tone of each bar is considerably larger in amplitude.

(2) Peak Amplitudes Outline Essentic Form

The peak amplitudes form a descending curve from bar 3 to bar 4. This descending amplitude curve combines with the frequency contour to produce an essentic form related to grief (this form may well be considered to be a mixed emotion: predominantly sad, with aspects of loneliness, anxiety, and perhaps regret). Bars 1 and 2 provide similar forms of diminshing amplitude, but in bar 1 combined with rising frequency. Pain and sadness are implicit in bar 2. Bar 1 suggests a resigned view, accepting fate, without the quality of hope; "this is how it is; there is nothing that can be done about it". The combined effect is a combination of grief with stoical, strong acceptance of what is; without defiance or rebellion (this impression is further aided by the nature of the Mozart pulse which has a spectator point of view - see Clynes, 1977b).

(3) Individual Tone Shapes

The shapes of each individual tone are governed by their place in the melodic context. The shorter tones may seem similar in shape on the graph, but in fact they are varied, as can be seen from the p vaues in Table 3. (Small changes in the p values noticeably affect the quality of the sound.) In the longer tones such as the fifth tone of bars 1 and 2, first and fifth tones of bar 4, the shape of the termination of the tone is as important as its rise, for appropriate expression. For the shorter tones, the termination phase of the tone relates to the degree of legato that is achieved. Smaller p values result in greater legato. (It is not generally necessary to include a DC component to maintain a legato between successive tones. The momentary drop in amplitude between tones shaped by the Beta Function is not perceived by the ear if it is quite short, as is the case for appropriately low p values.) Staccato tones are produced in the first few examples by choosing appropriate Beta functions with high p^2 values.

(4) Duration Deviations

We may note systematic time deviations from the given note values. First notes in each bar are lengthened, the second shortened. Hardly any tones correspond in duration to the actual note value. Some tones are lengthened by as much as 39% (first tone in bar 3). Specially lengthened are first notes of beats 5, 9, that correspond to accentuated dissonant tones, which like suspensions are resolved in the following, second tone of the bar. Such prolongations induce a lamenting quality in the expression.

Sound example I:1

In Sound example I:1 the theme as shown in Fig. 12 is repeated twice. It is then heard performed by the Pro Arte Quintet (COLH 42 Angel, Great Recordings of the Century). After this, four stages are illustrated which show the effect of incorporating the above elements of expression.

Stage 1. The theme is played with no elements of expression "read into" the score, with note values exactly as indicated in the score, all tones of equal amplitude, and of the same amplitude shape (p values are 1, 1 for all tones). This of course results in a flat, monotonous, dull performance devoid of significance.

Stage 2. This version introduces varying tone amplitudes as shown in Fig. 10, but not varying amplitude shapes, and retains the durations as required by the score.

Stage 3. Introduces the variety of shapes of amplitude tones as illustrated in the figure, using the p values given in Table 3.

Stage 4. Introduces subtle deviations from the note durations according to the values in Table 3, thereby giving it increased vitality.

Further Observations

a) When working with such a theme one notices fairly quickly that when one changes the amplitude, or duration, of one note, it affects the balance of all notes: that is, the theme is an organic entity. Increasing the loudness of the fifth tone of bar 3 for example even by only say 5%, or one dB, will affect its relationship with first tones of bars 3 and 4. Also it affects its prominence compared to its adjacent tones, the sixth and fourth tones of bar 3. But further, the altered amplitude contour now constituted by the peaks of the first and fifth tones of bar 3, and the first tone of bar 4 affects how bars 1 to 2 balance with bars 3 to 4.

Similar organic behavior is evident in changing the duration of a tone. Additionally, changing the duration of a tone also affects its relative emphasis. For example, lengthening the upbeat duration will tend to give greater prominence and energy to the following main beat, which then in turn will affect its relation to the other main beats.

b) The appropriate way to realize the trill, in bar 4, seemed to be to group the trill in terms of 3 and 2 notes (the latter being its termination), each group under a single amplitude contour.

c) When a phrase is repeated such as in bar 3, the amplitude relationships may be similar, but never the same. Whether they tend to be augmented or diminished in successive repetitions depends on the specific piece, the structural design, and the nature of the composer. In the present theme the second presentation is less emphatic than the first.

General Character

The thematic material for Ex. III B:2, taken from Schubert's Symphony No. 5 in Bb, cf. Fig. 13 and Table 4, begins rather similarly to the previous example by Mozart, with a broken triad followed by three repeated tones on the dominant. But what a vast difference in mood! The Schubert theme is sprigthly, full of wonder, of exploration: the expression of the feeling of spring, or renewal, of hope and gratitude are the images that spring to mind as one thinks of the Schubert theme. In bar 10, elements of desire and longing, of being drawn to something of ineffable quality, are added to the previous joyful movement and impulse, to the simple wonder at the beauty of the world.

Now, how is all this communicated in the microstructure and the structure?

A precise answer requires detailed examination of the shapes, duration and relationships of the tones in Fig. 13. This examination occurs in fact as the melody is shaped by iteration of parameter changes: a nonrandom walk. We can describe some features of this process.

Looking at Fig. 13, we immediately note a greater variety of shapes than in the previous example. The opening triad of the theme is in a dotted rhythm, in major rather than minor. To obtain the appropriate,

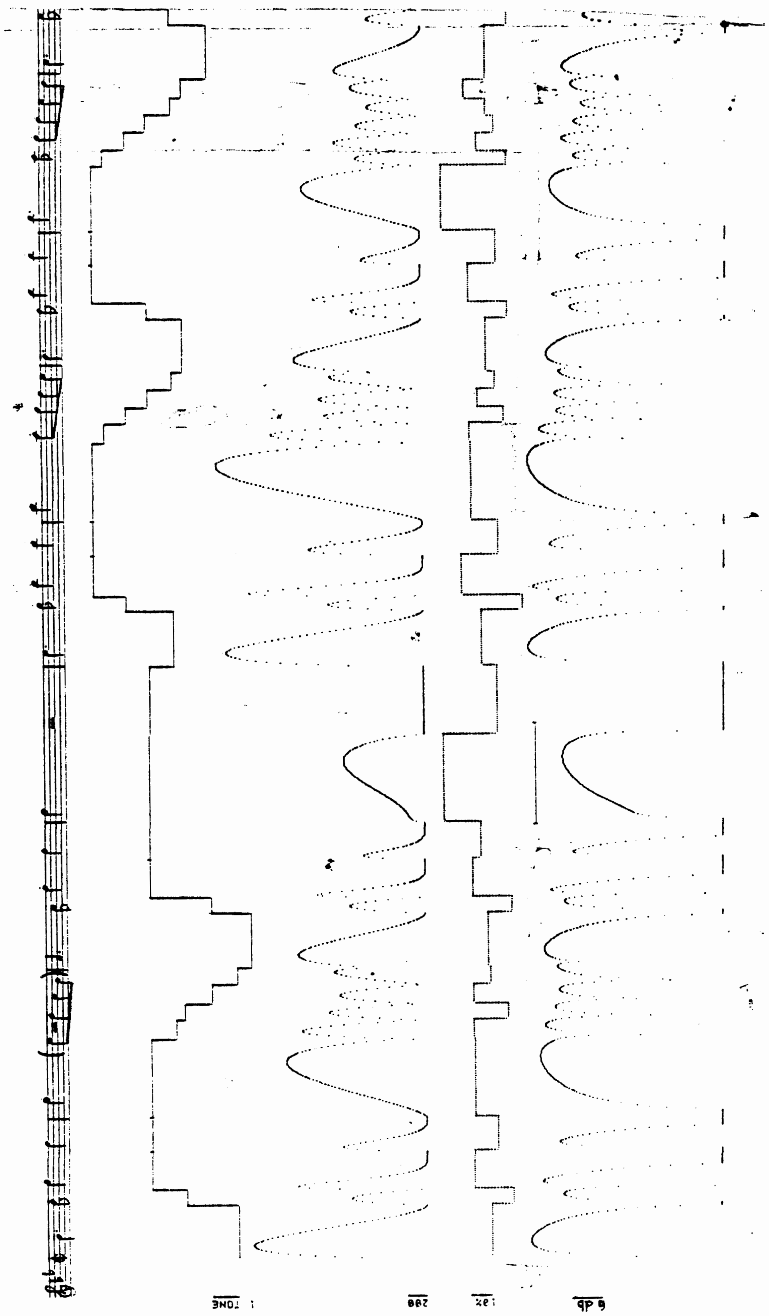

Fig. 13a

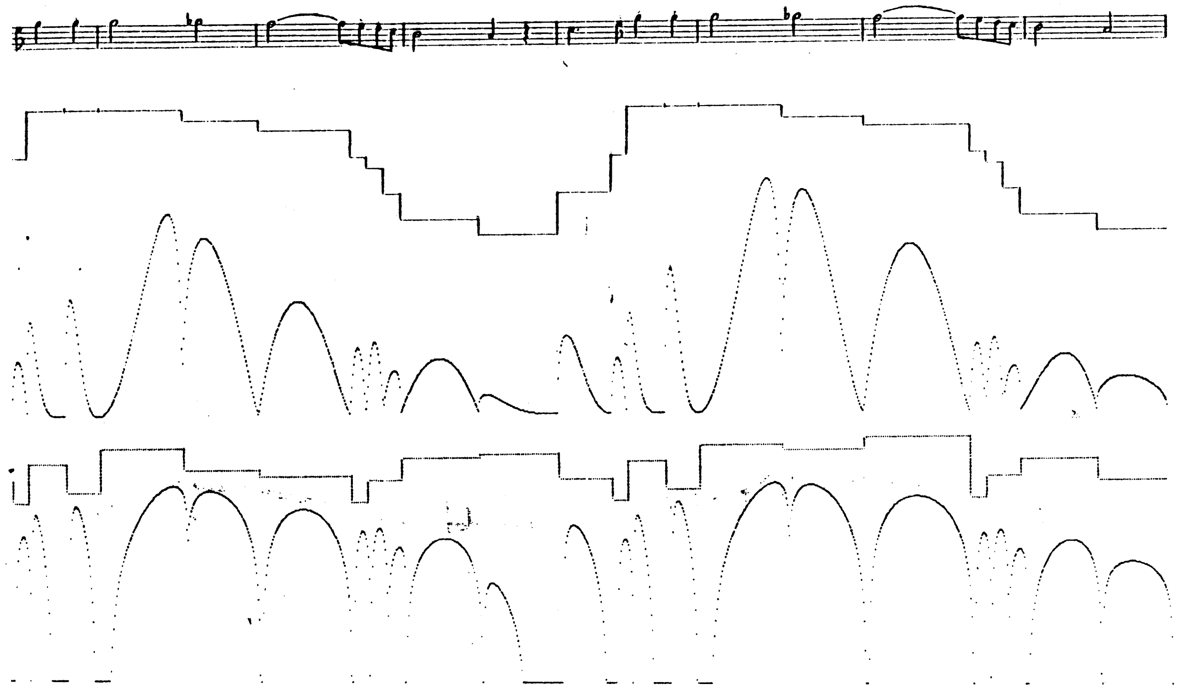

Fig. 13b

Fig. 13, Example III B:2. This figure also shows a comparison between linearly and logarithmically plotted amplitude shapes. The logarithmically scaled shapes are given in the lowest trace. It may be seen that they show visually less distinctive forms than the linear version. Listening to and viewing these forms simultaneously, the auditory experience notwithstanding, its nonlinear aspects seems on the whole to be parallel better by the linear forms than by the logarthmic. A wholly appropriate visual representation of the auditory experience in visual form still remains elusive, as both static and dynamic aspects would need to be incorporated in the scaling. The computer plays this example an octave lower than written.

elastic bounce, the short note has to be shorter than the written value, and also somewhat softer than the following main note.

Of the two F:s, the second F is less staccato. This allows a joyous floating quality to be embodied in the theme: the second F does not have a driven quality and is a rebound rather than a bound. (The relationship between the two Fs is very precisely circumscribed by the quality to be expressed.)

The following long note (also F) has a comparatively gradual rise compatible with a sense of wonder, with being drawn towards something encompassingly life giving - e.g. the woods in springtime. The syllable "ah!" said with the above expression gives an idea of the type of shape we are concerned with here. This is not a curve of sexual longing, however - that would have a different shape. The following four notes, all of uneven loudness, serve as a link or elaboration (actually performed by a different instrument, the flute in the symphony). The reiteration has the same general character as the first statement but of subtly different proportions, slightly more reticent. The long final F here has an amplitude shape very much like the sound of the Schubert pulse itself. The following linking flute passage has been omitted here because it starts on a different tone than the last tone of the opening motif and so would require two voices for its realization.

The pair of iterations of the motif starting on E flat is more intense. The statement of the motif in the minor triad continues with a chromatic sequence, a gesture bringing a change in feeling tone, becoming more inward; while the following six note cadential passage suggests* gratitude and thankfulness. The entire section starting from the minor triad is then repeated, more intensely and with subtly different inflection, implying knowledge of the first enunciation, and says also, as it

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* The word "suggest" has the same root as "gesture".

were, "Yes, it is so, very much so!", and then with a micropause* , repeats the last group of 6 tones.

The micropause, only 25 milliseconds, is essential to the integral experience of the 8 bar phrase. It gives the sense that the last 6 notes are the final expression of the 8 bar statement. In harmonic terms, the micropause gives greater emphasis to the following F, the Dominant, and prepares us for a perfect cadence to the Tonic of the next bar, (6), instead of the V-II (fifth to second) sequence heard the first time. If the same pause occurred also in the corresponding place the first time the chromatic phrase is presented, it would destroy the significance of the second pause, and make the entire phrase more banal. Here we encounter the first example of the significance of the appropriate placing and duration of a micropause.

The reflective, chromatic part of the theme uses different type of shapes than we have encountered so far; and the G has a concave rather than convex rising curve, with a relatively higher P^1 value.

The melodic outline of the first two bars of the Schubert example can be superimposed on a joy essentic form curve without too much constraint, as an example of a discrete realization of the continuous curve. The dotted rhythm and the prolonged first note admit a "jumping for joy" effect to be embodied. This gives an earthy character to the first tone (B flat), a solidity which contrasts with the airiness of the first two repeated F:s. The distinction here is far more subtle than a mere accentuation of the first beat of the bar - which would apply as well to the first G of the Mozart example. They each require a very different form of stress and amplitude shape. We can also illustrate the difference in shape and stress of the first notes of bar 1 in the Schubert and Mozart examples by thinking syllables for them: in the Schubert, we may think

$\overline{\text{lai}}$-a-lal-la-$\overline{\text{la}}$

or, $\overline{\text{dai}}$-a-$\overline{\text{lal}}$-lal-$\overline{\text{la}}$

----

* Not as long as a "breathing pause" or "Luftpause" is generally taken.

In the Mozart, we have

$$(\text{ta})\text{-}\bar{\text{ta}}\text{-da-}\bar{\text{ta}}\text{-ta-}\bar{\text{ta}}.$$

Note that the ai syllable, pronounced ah ee, carries with it a shape giving upward momentum, the i having a higher second formant, so that we tend to feel, on that first single tone, a turn of direction, a swing from down to up. If accompanied by a single beat of the arm, la is on the down swing*, i on the up bound. Consider how deadly it is to use the syllables for the Mozart example on the Schubert theme.

We shall see later in Section D how many microstructural characteristics observed so far turn out to be the consequence of the specific pulse of the composer, and that by seeing how the pulse modifies both the amplitude patterns and the durations we find an important key to generating the appropriate nuances demanded by the music.

Sound Example I:2

As for the Mozart example, the computer version is played first, and repeated in Sound Example I:2. The two performances of the same passage is played, first by Herbert von Karajan and the Berlin Philharmonic, and secondly by Karl Böhm and the Vienna Philharmonic.

Then, to show the relative contributions of the various factors to the expressiveness we present four different stages of developing the microstructure of the theme, as for the Mozart example. First, showing the theme without reading any loudness relationships into the score; secondly, including relative amplitude sizes, but of the same shape; thirdly, including varying amplitude shapes; fourthly, including duration

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* This means also that the consonant in such a syllable comes well before the down beat in sound, in fact begins together with the beginning of the downward motion (cf. Clynes & Walker, 1982).

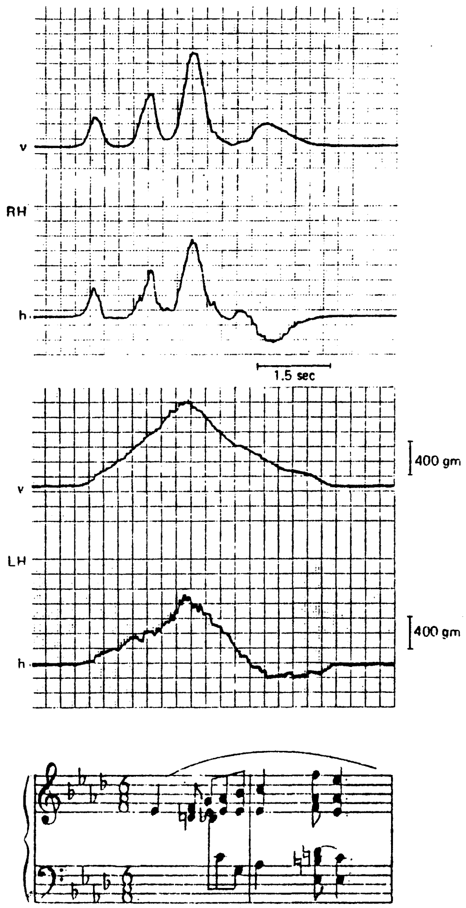

Fig. 14a

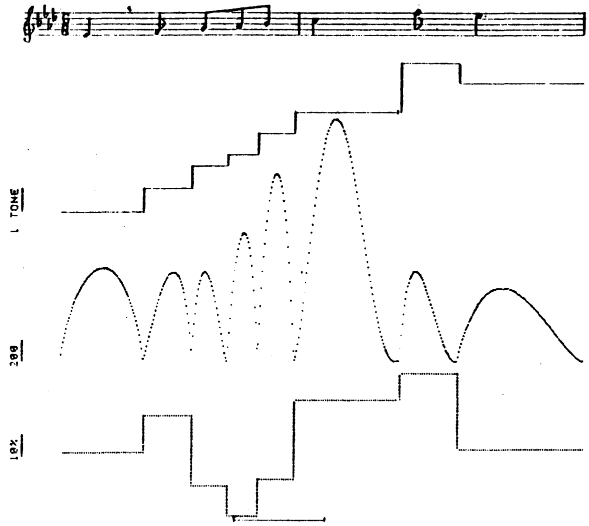

Fig. 14b

Fig. 14a. Sentograms for pulse (top traces) and essentic form (bottom traces) simultaneously expressed by right hand (pulse, RH) and left hand (essentic form, LH) on two sentographs. The subject is asked to "conduct" the music in this manner, touching and pressing on each sentograph with the middle finger of each hand, in a sitting position. The sentograms express the music, illustrated at the bottom of the figure that is being thought by the subject (no sound is used). For each hand, vertical and horizontal components are shown (v and h). Reprinted from M. Clynes: Sentics, the Touch of Emotions (1977b).

Fig. 14b, Example III B:3, F. Chopin, Ballade No. 3, Op. 47. For explanations, see legend of Fig. 12.

deviations. The hearer will be able to judge for himself the relative contribution of each factor. In creating these expressive qualities on the computer as described in a previous section, these stages are not carried out consecutively; the "stages" are presented for illustration purposes only.

The opening theme of Chopin's Ballade Number 3 in A flat, cf. Fig. 14 and Table 5, illustrates how a melody written for piano, an instrument of limited ability to vary amplitude shapes, can be expressed by varying amplitude shapes according to its character and not in violation of it. In this example amplitude tone shapes are realized that are implicit in the melody, and are heard inwardly even when they are not actually produced. One thinks this melody with these shapes.

It is interesting to compare the realization of this theme with the sentic analysis given in Clynes (1977b), see Fig. 14a, showing similar features in terms of touch expression - an observation that has relevance to the touch-to-sound transform.

Sound Example I:3

In this example the computer version, is first played twice. Then comes the theme as performed by Arthur Rubinstein, followed once more by the computer version. Notable in this example is the strong rubato in the second part of the first bar. This quickening reaches its maximum extent on the fourth eighth note and is counterweighed by a slowing down in much of the second bar.

Comments

The lengthened first tone of the second bar, after the urgency of the previous bar, with its shape suggests a continuing sensation of being carried upwards, almost weightless, followed by a gentle return to earth in the final two notes. The upward sweep is not the result of physical exertion, as the example of joyous activity in the previous example from Schubert, but rather of being carried by an ambience, almost a swoon: as if a magic event has occurred. All that is implied by this short theme of a few notes played with appropriate nuance and inflection.

We may also sense a freeing of fantasy from ordinary sensory experience towards magical transformation: a longing, fascination, bewitchment with loveliness, a seeking of another person, an apparition. How well does this theme in fact portray the atmosphere of the poem - Chopin's background for this composition - of Ondine and the beguiled fisherman!

Ex. III B:4, Beethoven Violin Concerto, 3rd Movement, cf. Fig. 15 and Table 6, shows a number of aspects not previously encountered. First is the need to use more than one Beta Function for certain tones in order to create the proper amplitude form. In the second note of the theme a later peak provides an added emphasis, a winged pulsation needed for the special qualities of energy required by this tone. The activity of the tone continues after the first attack, a secondary action approximately 230 msec after the first attack adding swing to the movement implied by the motif. In the absence of the secondary activity the tone would sound quite flat and uninteresting. (The effect should be clearly distinguished from vibrato.)

Secondly, we encounter the use of alterations of durations of notes that have a larger structural meaning and serve to group tones together as separate gestures. This occurs for example at the 5th note from the end. The previous note is appreciably shortened, and the new note enters before its due time, signifying with its five note group that it is terminating the theme, saying as it were, "no more" with Beethovenian determination. If the 6th note before the end is not shortened the theme becomes more relaxed, un-Beethovenian.

A similar shortening must not occur of course in the corresponding place in bar 3 and 4. There, however, musical logic requires a different microstructural intervention, a subtle, slight acceleration within three eighths notes of bar 4, grouping them so that the second is heard as a rebound from the first.

(In the musical illustration the Fritz Kreisler presents a rather extreme version of this nuance, adding a measure of charm and humour.)

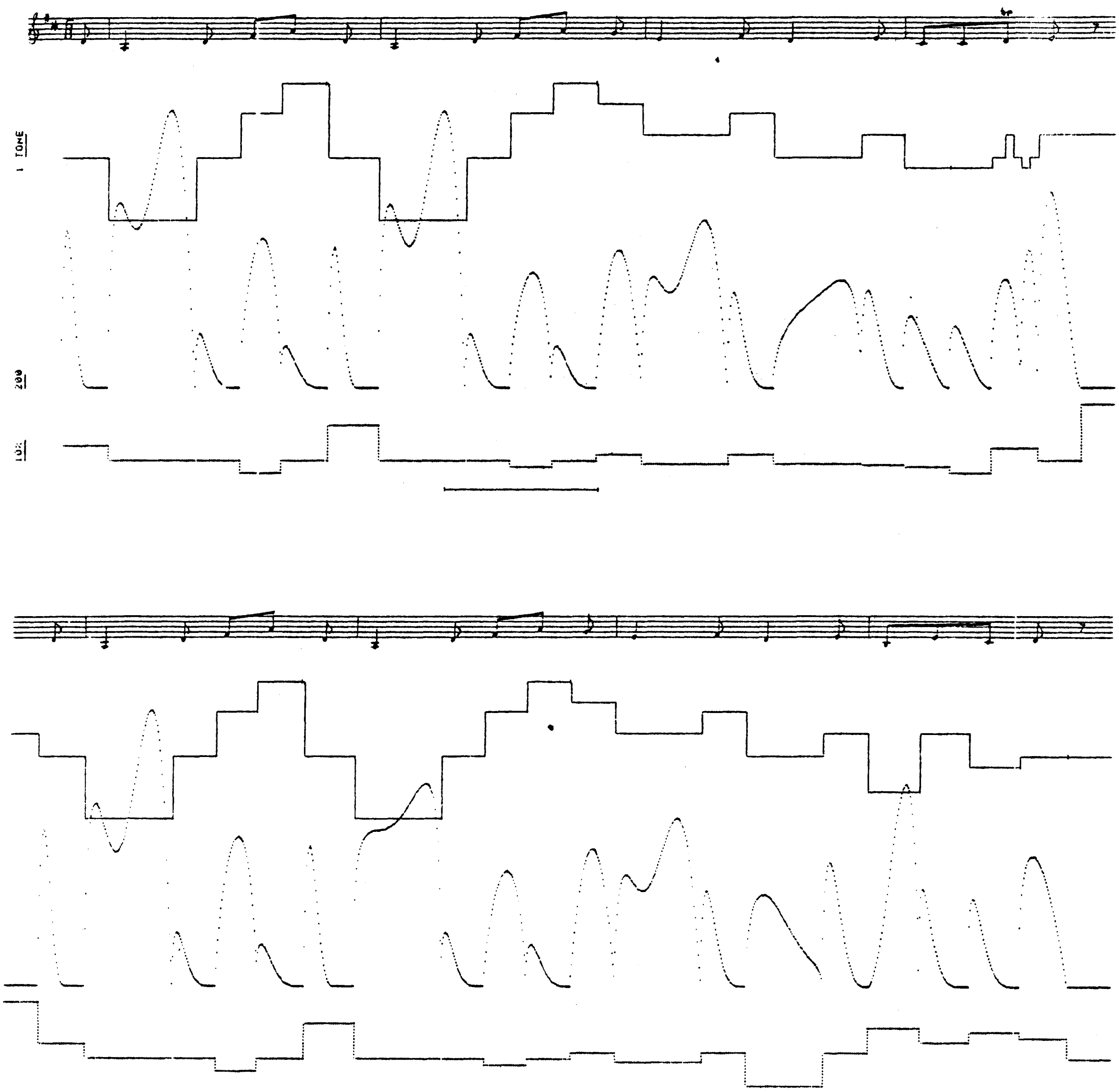

Fig. 15, Example III B:4, L. van Beethoven, Violin Concerto, Op. 61, third movement. For explanations, see legend of Fig. 12.

Without such grouping, these notes are structurally isolated, and the theme loses continuity and humor, becomes stodgy.

An interesting feature is also the way in which the repetition of the first five notes needs to be different in subtle ways each time it occurs. If that motif is played in the same way each time, even though it is wholly satisfying the first time it is played, it loses interest on repetition. Here we see how the brain remembers the specific relationships and amplitude shapes so that even slight changes on repetition are perceived, and affect the significance of what is played.

The Beethovenian way in this example appears to play the second time somewhat more emphatically. For the third and fourth repetetions this pattern cannot be repeated, however. It would lead to wrong expectations (and appear dull witted). Instead, the order is now reversed, the fourth repetition is less emphatic than the third. We thus have an ABBA structure of intensity where B is more intense than A, an unwritten structure which we may find is often applicable to Beethoven.* (In Mozart we often find ABAB where B may be less intense than A.)

The relationship is not one of intensity alone, however. In the fourth repetition, the tone A needs to have less of the "swing", less secondary activation, i.e. the shape of tone needs to be different as well as its volume. Only in that way is musical logic satisfied.

The need for the different microstructure for the Ds in bars 3 and 7, respectively, arises out of the specific melodic and harmonic structure of the theme; in one case the impetus being continuingly forward, ending in a semicadence, in the second case preparing for the ending of the phrase, putting a slight brake on the impetus before arrival of the cadence.

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* A symmetry that contributes to the feeling of strength inherent in Beethoven´s music.

The point is in the balanced treatment of the great accumulation of energy. A sense of directed energy, dignity and even a touch of nobility is achieved in this way which we recognize as particularly Beethovenian.*

The slight shortening of tones 4 and 10 (a little less) and similar places is required for the joyful and playful character of the theme; here, there is an upward bound followed by a rest, a micropause - if we think of an analogy as an eagle might float for an instant before exerting his wings again, this analogy points to patterns of motoric command sequence as underlying microstructure.

The trill, as in the Mozart example, appears to be best executed by grouping three and two notes together under one amplitude shape each (violinists often execute less than 5 notes for the trill).

The various degrees of staccato with which each of the eight notes in bar 3 (and bar 7) are played (as well as the last eighth note in bar 2, and in bar 6) has an important bearing on how the music is mentally grouped (cf. the Heifetz and the Menuhin performances for entirely different views).

Sound Example I:4

The theme is played twice by the computer. Then we hear versions by

1. David Oistrakh and Orchestra Nationale, conducted by Andre Cluytens.
2. Jascha Heifetz, and N.B.C. Symphony, conducted by Arturo Toscanini.
3. Yehudi Menuhin, and Berlin Philharmonic, conducted by Wilhelm Furtwängler
4. Fritz Kreisler, and Berlin Staatsoper Orchestra conducted by Leo Blech
5. Wolfgang Schneiderhan, and the Berlin Philharmonic, conducted by Paul von Kemper

Finally, the computer is heard again.

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* A similar treatment is often found in Händel, a composer for whom Beethoven had the greatest admiration.

Note that for all the examples given in this paper, the computer versions were made independently from and before any of the recorded examples were listened to. There was no attempt to match any characteristics from the recorded performances, or to match the timbres of a violin eventhough they contribute significantly to the energy.

The example shown in Fig. 16, cf. also Table 7, allows us to observe the expressive forms of love and reverence in terms of the behaviour of amplitude forms. In the first bar the expression of love is comprised in the pitch contour: the tones F sharp E (and its reiteration) can be considered to be discrete realizations fitting the shape of the love frequency contour. The amplitude forms clarify and reinforce the essentic form. One can obtain different shades of the expression of love by choosing different amplitude shapes of these two tones, especially the E:s; depending on the amplitude forms chosen we can obtain a more agape-like or a more passionate expression. The 16th notes that follow are a wonderful link, with its own exalted expression, preparing us for the next love expression with a somewhat greater intensity, one step higher in the scale, G and F sharp. Similarly, for the next repetition, with more intensity. The love expression reaches its greatest intensity at the high point of the phrase, with the ED. Here again the way the amplitude forms are shaped on the E and D is critical to the type of expression. Thus, if we shape the E with a relatively early peak followed by a decaying phase this produces a poignant inwardness, (cf. an inspiration). A more rounded shape of that tone produces a more outflowing love expression, (cf. expiration) - in each case the gesture and meaning have a different form. Towards the end of the theme we encounter the expression of reverence, which is enhanced by the proper choice of amplitude sizes and forms for each tone.

It is a matter of perfecting the sizes and shapes of these tones to obtain a more and more appropriately meaningful expression in this theme which serves as a repository of man's most exalted feelings.

In this example, essentic form plays a greater role in comparison with the effects of the pulse than we found in the earlier examples. The

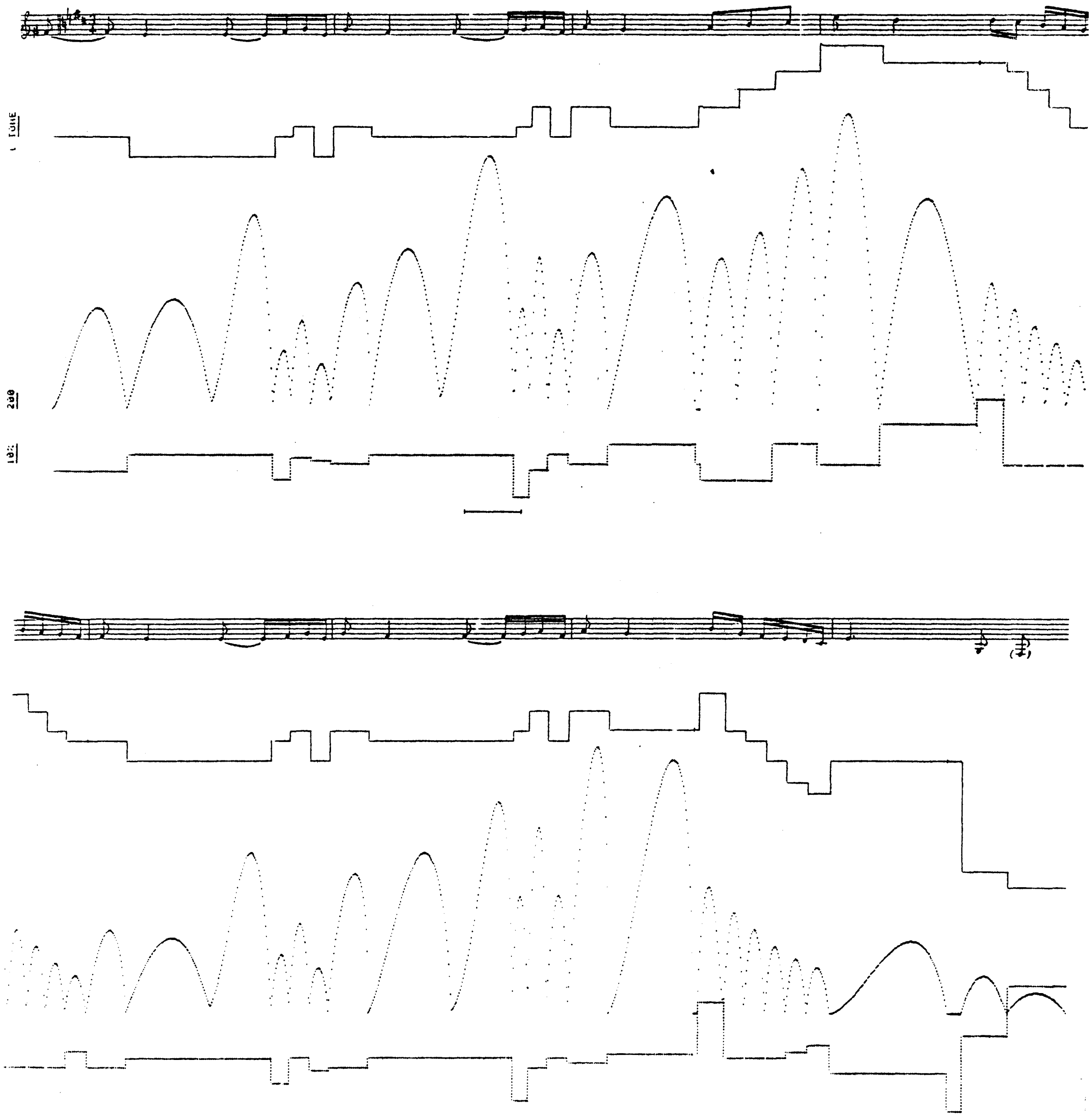

Fig. 16, Example III B:5, L. van Beethoven, Symphony No. 9, Op. 125, third movement. For explanations, see legend of Fig. 12.

slower the music, the more prominent the features of the essentic form are compared with those of the pulse; both in terms of amplitude relationship and in duration deviations.

Sound Example I:5

In addition to the computer version, performances by Arturo Toscanini and the NBC Symphony, and by Wilhelm Furtwängler and the Berlin Philharmonic are heard.

III C. Relation linking amplitude shapes of individual tones to melodic form

Having observed and worked with a large number of examples in the manner illustrated in the previous section, and considered the interaction between amplitude shapes of individual tones and the music, we were enabled to posit the following relationship between the amplitude shapes and the melodic course of the music.

A and P Classes of Amplitude Shapes

1. Let us consider these shapes to belong to a continum between two classes,  and  with intermediate shapes between the two extremes. We may conveniently call these classes (A) assertive and (P) plaintive or pleading, respectively, without wishing at all thereby to tie the musical expression to such categories of course, cf Fig 11.

We can then consider an actual tone shape as placed somewhere along this continuum - and consider the nature of the influence that displaces it from a neutral position, i. e. the base shape, to the place on this continuum where it needs to be.

We can describe forms along this continuum by pairs of p values, starting from a base shape, say 1, 1, such that as the values of p_1 increase those of p_2 decrease in proportion, and vice versa. Thus say for example 0.9, 1.11; 0.8, 1.25; 0.7, 1.42 etc. will give a series of shapes shifting gradually towards class A, which has a relatively sharp rise time. The inverse series 1.11, .9; 1.25, 0.8; 1.42, 0.7 etc. will tend more and more towards class P, of gradual rise time.

2. We then can consider the influence which causes the shift to be the slope of the essentic form, as measured by the slope of the pitch contour.

More particularly, the deviation from a base shape for a particular tone is seen to be a function of the slope of the pitch contour (essentic form) at that tone: both pitch and duration determine the deviation in such a way that:

a) Downward steps in pitch deviate the shape towards A, upward steps towards P, in proportion to the number of semitones between tone and the next tone.

b) Deviations are affected by the duration of the tone so that the longer the tone, the smaller the deviation (since the slope is correspondingly smaller).

Further, in practice, the slope is measured from the beginning of the tone considered to the <u>following tone</u>. In measuring the slope between the tone and the next tone, rather than the previous tone, the amplitude shape acquires a predictive function.* This appears to match well with its actual function in music, relating the present tone to what is to follow, and may be considered to be in accordance with musical logic. It gives a sense of continuity both musically and in terms of feeling.

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* The first derivative of a function has a predictive property (lead in phase). The amplitude shape associated with a particular slope leads us to expect a melodic step in accordance with it. The movement of the melodic line is thus prepared.

Experience shows that the proportionality constant needs to be an approximately 10% change in the p-values per semitone, for tones of 250 msec duration. The shift is of course to be expected to be linear only over a limited range; the degree of nonlinearity for both the duration and pitch factors needs to be determined more precisely.

In order to see how the duration factor and the pitch factor may obey different power laws, the equation is put into the form:

$$p_1 = p_{1(i)} e^{bs\exp(-aT)}$$

$$p_2 = p_{2(i)} e^{-bs\exp(-aT)}$$

where s = number of semitones upwards to <u>next</u> tone
b = modulation constant of $p_{1,2}$ by <u>frequency</u>
a = modulation constant of $p_{1,2}$ by <u>duration</u>
T = duration of tone in milliseconds
$p_1(i)$, $p_2(i)$ = initial base values of p_1 and p_2

Experience has shown that for much music preferred values are

$$a = 0.00236 \pm .00006 \qquad b = 0.20 \pm .005$$

Table 8 gives the deviations of p values for various durations and steps. The formulation, of course, is an initial one and is subject to refinement.*

----

*To the extent that equivalent amplitude shapes at different pitches may be somewhat different, a small correction factor for transposition would apply to the values of a and b in the equation; the amount of such correction needs to be determined.

Choice of Base Values

There remains to consider the choice of the base form, which we have nominally put at 1, 1.

In music of different composers, and of different types, it would seem that certain preferred base values apply. Values in the vicinity of 1.2, 0.8 appear an appropriate choice for much of Beethoven - giving a greater legato and more gradual attack. For Mozart, base values around 0.9, 1.1 give a more rapidly decaying sound, and a somewhat sharper attack. For Schubert base values in the vicinity of 1.15, 0.9 seem to be appropriate.

These values are influenced by the type of instrumental sound that the style of the composer appears to require, and may also be linked to historical considerations of the instruments in use at the time. They may also be related to how the inner pulse affects the microstructure, which we will consider in the next section.

Other Implications

(1) Silence before downward leaps

The rule implies that, within a legato-type melody, for a tone of given duration, the larger the upward leap in pitch to the tone that follows, the more should the tone have a P-form, and the larger the downward leap, the more marked the A-form. In the case of a downward leap in moderate and fast tempo, this can, depending on the size of the leap and the duration of the tone starting the leap, result in a momentary silence i. e. a microsilence, due to the tail of the A-form, before the low tone. This is felt as appropriate in larger downward leaps. In upward leaps, silence will tend to occur before the tone starting the leap*.

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* Note, however, that for staccato or strongly non-legato upward leaps, a micropause is often required after the tone <u>starting</u> the leap. This micropause is greater, the larger the leap. The Beta function shape cannot in these cases predict the leap as effectively, so that the micropause often stands in as a predictive device - in accordance also with the sensed "distance" and implicit muscular effort and time taken to get "up there".

(2) Expressiveness of scales

Also implied is that tones of scales have somewhat more P-shape going up, and going down more A, the exact deviation depending on the tempo as given by equation (3). In fact, scales become considerably more musical when this rule is appropriately observed.

We may also relate the amplitude shape deviations to the type of gestures with which one would conduct the music; often a downward gesture goes with greater A (assertive), an upward gesture with more P (plaintive, pleading).

(3) Limitations of the equation

By the nature of the rule, it cannot predict the amplitude shape of the last tone of a melody, since it measures slope to the next note. Thus, it must be entered manually. It is possible, however, that a rule referring to last notes of phrases only could be formulated which would also take into account aspects of larger structures. Further, it does not apply to tones which require more than one Beta function.

* * *

The basic thought behind this formulation is: if we can consider the available shapes to lie along a continuum between A- and P-forms, then the slope of the essentic form at that tone determines where in that continuum a particular tone lies.

Musical Illustrations

The three examples shown in Fig:s 17, 18, and 19 (cf also Table 9, 10, and 11) for which the p-values determining the amplitude shapes were calculated according to equation (3), show that the relationship of this equation is applicable to various styles. Amplitude shapes are produced

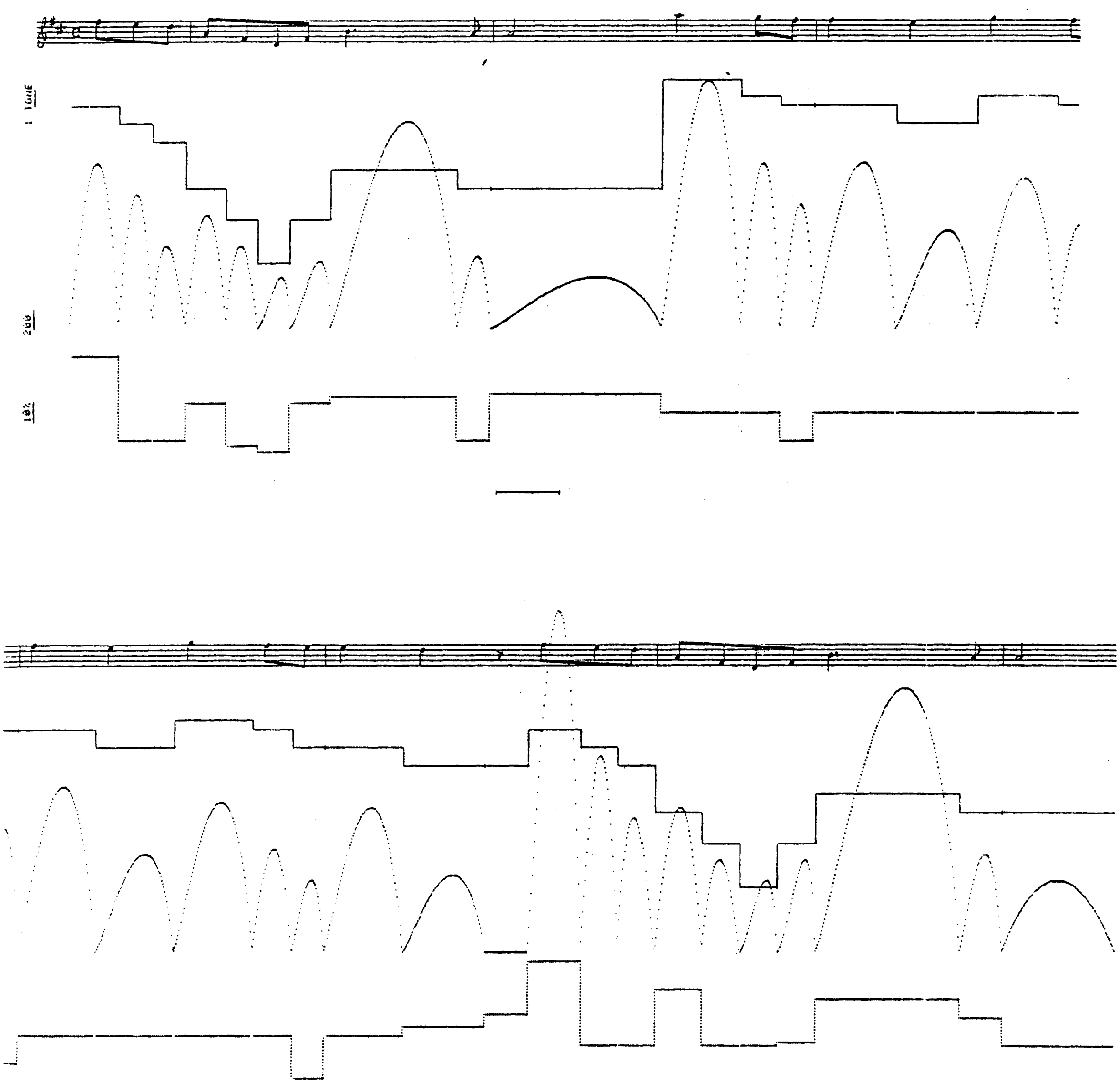

Fig. 17, Example III C:1, P. Tchaikowski, Symphony No. 6, Op. 74, first movement. For explanations, see legend of Fig. 12.

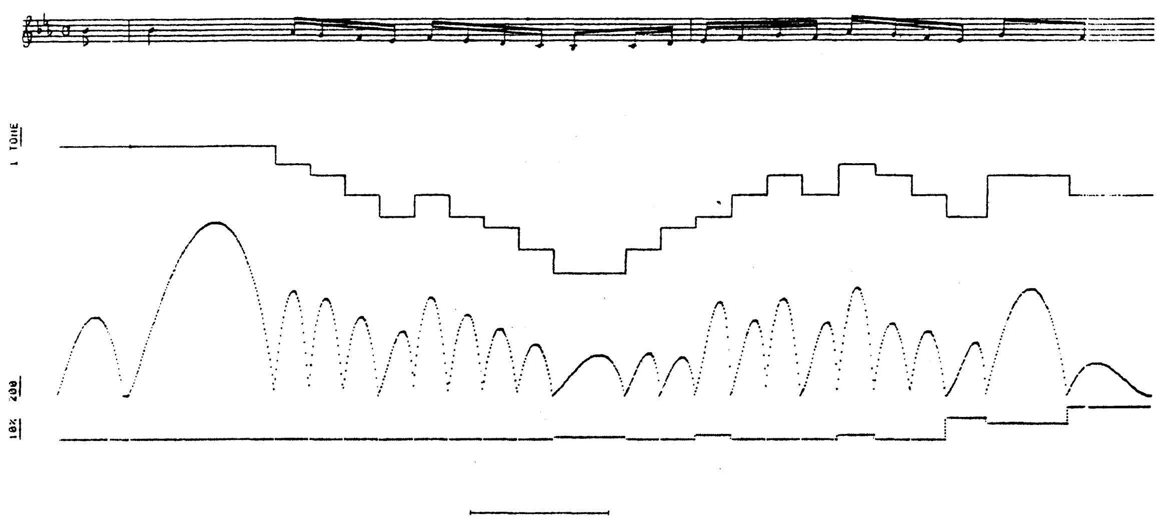

Fig. 18, Example III C:2, J. S. Bach, Choral from Cantata No. 140 "Wachet auf". The computer plays this example in the key of G. For explanations, see legend of Fig. 12.

that fit the melodic character, and augment its eloquence in a way that suits its particular expressive nature. We can also note how they contribute to the feeling of continuity - and the continuity of feeling: the expectancies generated from tone to tone.

We may hear from these examples that the p-values are determined well by the relationship given equation (3). It is interesting to note that for Sound Example 3, two days had been spent trying to find the proper shapes by the "manual" method. But the result was still unsatisfactory, and was rejected. Later, applying the rule of equation (3) to the same example the resulting version sounded much better in less than five minutes than two days´ effort of using one´s musical judgment!

Perhaps the listener may judge that some of the nobility of this theme has been captured by this realization.

The appropriateness of the relationship as given is also demonstrated by the need for observing the right choice of proportionality for the

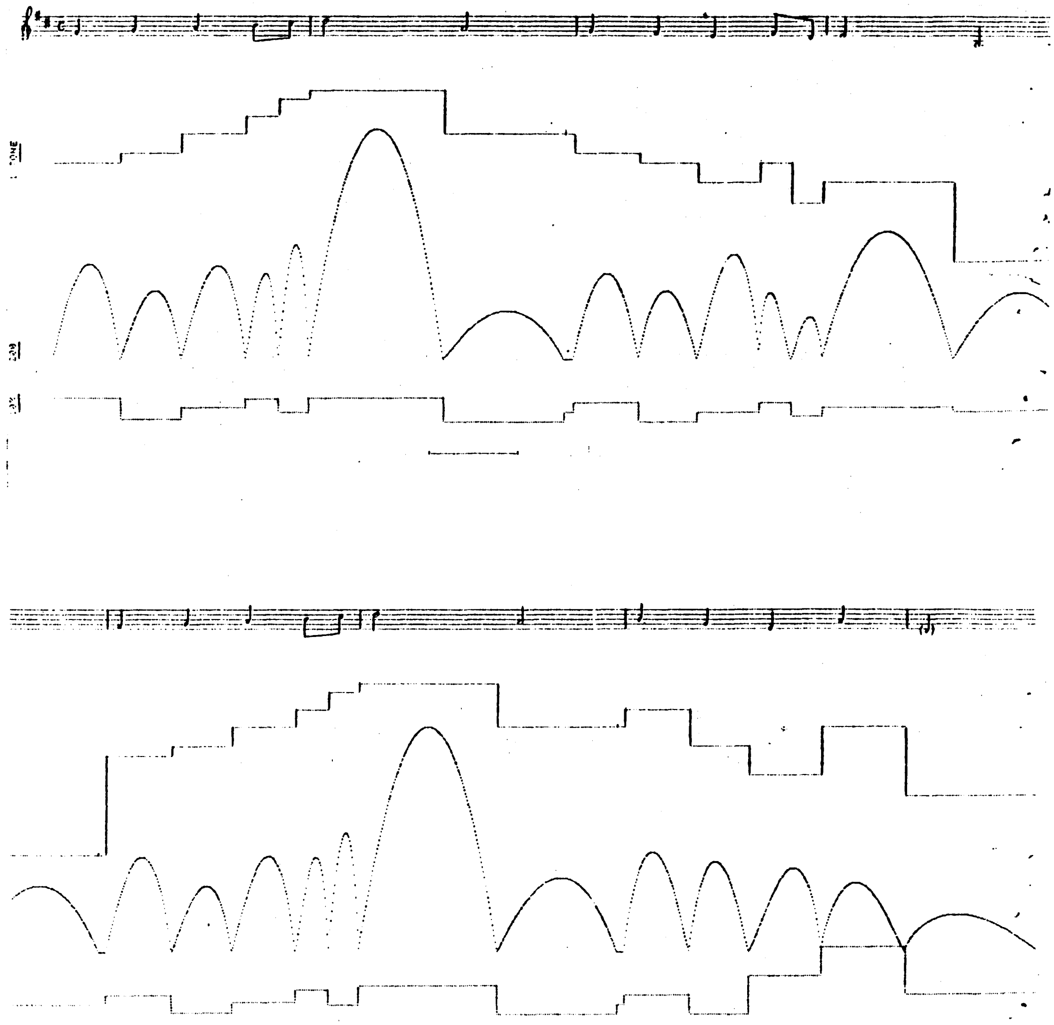

Fig. 19, Example III C:3, L. van Beethoven, Violin Concerto, Op. 61, first movement. For explanations, see legend of Fig. 12.

interaction between pitch change and shape deviations. A deviation of the p-values by 20% per semitone for tones of 250 msec duration, for example, would tend to be felt as greatly exaggerated. Further examples are given in the next section.

The particular merit of this formulation may be seen in that it harmoniously integrates the behaviour of single tones to that of the larger whole, for different kinds of music. In this it seems to show a surprising elegance and power - and musicality.

III D. The composer´s specific pulse expressed in microstructure

In the previous section we have seen how the amplitude shape of individual tones can be derived from the form of the melody. We can now proceed and ask how much of the remaining unaccounted microstructure can be attributed to the function of the inner pulse? It seems an unexpectedly large amount.

The notion of the inner pulse has been described elsewhere in detail e.g. Clynes, 1977b. The inner pulse is not the same as the rhythm or meter of a piece; it is found in slow movements, in fast movements; in duple time, in triple time, or compound time. The tempo of the pulse has generally been considered to be in the range of 50 - 80 per minute. In slow movements one pulse may correspond to an eighth note, even a sixteenth in a very slow movement, in a fast movement a half note, and in a moderate movement a quarter note.

The inner pulse as a specific signature of a composer became established in Western music around the middle of the eighteenth century and continued until the advent of music in whose rhythmic motion there no longer was interfused an intimate revelation of the personality of the composer. In the music of Mozart, Haydn, Beethoven, Schubert, Schumann, Chopin, Brahms for example we find a clear and unique personal pulse which the composer has impregnated successfully into his music (the knowledge of which we ultimately acquire from the score). We cannot discuss here how the pulse is implicit in the score, except in a few particulars to be mentioned. Indeed, because of the time course of the inner pulse, which is generally between 0.7 and 1.2 sec/cycle, the matrix of its wave form is most prominently expressed in microstructure.

In considering the nature of the beat, and of the inner pulse, the property of the nervous system called "time form printing" (Clynes, 1977a, Clynes & Walker, 1982) is very relevant. This function enables the human organism to decide on a particular form of movement to be repeated, and the rate, and then to repeat the movement at that rate without further attention - until a separate decision is made to stop or to alter the form or the rate of the movement. Once conceived as a repetitive movement and initiated the movement will continue in "automatic" fashion until stopped. This process takes place mentally when thinking the beat, and the inner pulse.

In practice this means that once initiated, the inner pulse can carry through the musical piece without need for further specific initiation of form, although the rate will be caused to vary to a degree. Small pauses can momentarily suspend the pulse, and act, as it were, as punctuation in the musical phrasing.

In any composition certain parts of the score embody the pulse more clearly and obviously than others. However, through time form printing, the pulse will tend to carry through all parts, if it has been well initiated at the beginning of the piece. Scale passages for example can become characteristic of the composer through the pulse: the same scale passage can be played with a Mozartian pulse or with a Beethovenian pulse, for example, and will sound appropriate correspondingly. This does in fact happen in satisfying performances. Thus "neutral" passages acquire from the pulse the characteristic "flavor" of the composer. This of course is precisely the province of microstructure, and we shall show how this occurs.

By experimenting with such neutral structures, and combining the results with knowledge of the inner pulse forms as expressed through touch (cf. Figs. 7, 8, and 9) we can arrive empirically at an answer to the question: What does the inner pulse do to the specific tones in a piece of music?

Concerning the Derivation of the Values

The following considerations have aided the derivation of these values.

Characteristics of the pulse matrix may be in part connected to the kinesthetic "feel" of the pulse, observed in recording it sentographically. We have seen that different degrees of inertia, damping, can be experienced for pulse of various composers (Clynes, 1977b); and for some pulses different kinds of tensions occuring at specific phases.

These show up indirectly in the recorded sentographic form; but appear to be significant clues to the deviations in amplitude and duration that constitute the matrix. Different degrees of inertia, or sluggishness, are brought about by different modes of tensions by agonist and antagonist muscle groups (as a result of which greater or lesser massiveness is displayed by the arm - e.g. more of the upperarm mass is involved). This massiveness, a mental program, translates to the degree of flexibility of modulation within a pulse (cf. Section II.A.2). The Beethovenian pulse has high inertia, the Mozart pulse low inertia, cf Fig:s 7-9. Accordingly, we would expect to see much greater differences between the amplitude of component tones for Mozart than for Beethoven. Indeed there is a relative effortlessness in changing the loudness level in Mozart within a pulse, that is not present in Beethoven.

The massiveness has an influence also on the duration deviations, since each pulse cycle contains an initiating point at a particular phase near the time of the upbeat (Clynes & Walker, 1982).

The deviation values can also be looked at in the light of rhythm studies that relate the energy of a beat to the duration and amplitude of upbeat, in relation to a given downbeat (Clynes & Walker, 1982). High inertia would accordingly tend to be accompanied by a longer duration upbeat.

To obtain the final numerical values given, the values were adjusted aurally, and are of course to be considered as a first approximation only.

Pulse Matrix of Mozart, Beethoven and Schubert*

A two-fold effect may be observed. The inner pulse affects

1. Relative amplitude sizes of its component tones, and
2. Duration deviations of its component tones.

Both 1 and 2 must occur. Either alone is insufficient. Accordingly, the influence of a composer's pulse is stated for a particular meter by a matrix that specifies (1) amplitude ratio and (2) duration deviations.

The following matrices specify the influence of the inner pulse for Mozart, Beethoven and Schubert respectively, for the 4/4 meter. For each tone, two numbers are given. One specifies the amplitude size ratio, referred to the first tone as 1. The other gives the duration referred to as 100 as a mean duration for the 4 components. All these values are of course subject to further refinement.

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*These pulse matrices are given here as the first to have been studied, that of other composers are in preparation and will be given in future publications.

	Tone number 1	2	3	4	
Amplitude ratio	1.00	.39	.83	.81	
	0 dB	-7.8 dB	-1.8 dB	-2.0 dB	Beethoven
Duration (msec)	106	89	96	111	
Amplitude ratio	1.00	.21	.53	.23	
	0 dB	-14.4 dB	-6.6 dB	-13.5 dB	Mozart
Duration (msec)	105	95	105	95	
Amplitude ratio	1.00	.65	.40	.75	
	0 dB	-3.1 dB	-7.7 dB	-1.9 dB	Schubert
Duration (msec)	98	115	99	91	

Salient Features of the Pulse Matrices:

The Mozart Pulse

Large amplitude difference between first tone and the others - archness in articulation, second tone very slightly softer than the fourth tone, the third tone having a subsidiary accent, subdividing the four tones. Duration deviations are rather symmetrical, first and third tones moderately longer.

The Beethoven Pulse

Amplitude ratios generally more even, fourth hardly softer than the third. Second considerably softer than first. Durations: first tone considerably extended, fourth tone most extended.

The extended duration of the fourth tone combined with its relatively high amplitude is a cardinal feature of the Beethoven pulse. The third tone is not extended in duration, and is more nearly equal to the first tone in amplitude than for Mozart. In terms of amplitude the Beethoven pulse has a more even, less arched articulation than the Mozart pulse, and has a special emphatic aspect to the fourth tone. A resistance is displayed against "excessive" amplitude modulation - experienced often as a kind of "ethical restraint". First and second tone taken together are contracted compared with the third and fourth tone together.

The Schubert Pulse

Low amplitude of the third tone - no subdivision; higher amplitude and short duration of the fourth tone. No duration extension of the first (or third) tone but a considerably <u>extended duration of the second</u> tone. Third and fourth tones, taken together, are contracted compared with first and second tones together, the reverse of the Beethoven pulse case.

The unusually extended duration, without accent, of the second tone of the Schubert pulse can be linked to the following:

1. The special tension that occurs in the corresponding part of the Schubert pulse, a <u>pulling</u> upward, uniquely characteristic of the Schubert pulse (Clynes, 1977). Its initial downward phase acts on low inertia. During the course of a rebound, however, a tension is added, increasing the resistance and slowing down what otherwise would be a carefree bounce into an entirely different character, an impression of being pulled upwards.

2. It can be seen in the scores of Schubert´s music that there is a predilection for special treatment melodically, or in other ways, of the weak tone following the first tone of the bar.

In performance and in thought these deviations, produced by the pulses of the composers within their own music, are not experienced as unevenness, but appear as an appropriate flow. However, introducing the wrong composer´s pulse to a melody as can be deliberately done may seem disturbing to the flow and somewhat uneven.

Other meters

Matrices for other meters can be appropriately extrapolated or intrapolated from that of the quadruple meter, as discussed in the Appendix where matrices for duple, triple and compound meters are given. The compound meter microstructure 6/8 for example is derived by combining the 2 and 3 microstructure.

Applying the Pulse to a Melody having Various Note Values

When a melody has a combination of notes of different values, as is generally the case, some larger and some smaller than the component values, the following appears to apply:

1. Duration deviations are proportioned according to the component tones of the pulse, e.g. a dotted quarter has the duration deviation of one tone plus half that of the next.

2. The amplitude is taken as that prevalent at the beginning of the tone - i.e. is not averaged, e.g. the dotted quarter has the same amplitude as the quarter would have had without the dot.

Further refinements are being studied, in particular the hierarchical consideration of pulses within pulses, and will be detailed in future publications: thus, for example, the question of how to apply the proportions of a two component pulse to two eighth notes within a triple meter of 3/4, while considering the 3/4 as a single pulse of triple meter, or how to proportion four sixteenth notes within a quarter of a 3/4 pulse.

While it appears that the range of 50 - 80 per minute is an approximately useful guideline in applying the pulse, some pieces may present alternate possibilities of a larger or smaller frame for the pulse.

In general, it should be emphasized that the pulse and its effects in microstructure as described here is in no way to be considered a binding Procrustes bed, but rather as a level from where fine artistic realization of the music can be more readily attempted, taking into account the individual concept of the piece, and particular personal interpretative preference. But a well realized pulse brings with it its own gift of beauty and love, which we receive anew with recurring amazement and wonder as we work with it.

Additional Expressive Functions and Properties Considered

Further properties of melodic relationships relevant to manual and computer realizations are:

(1) Microstructural

In working with the various examples manually, we may readily note that:

a) A tone of smaller amplitude following a larger amplitude tone will sound more legato than in the reverse order, for given amplitude shapes (p-values)

b) A tone will sound softer after a tone of greater amplitude than before it. This may be considered a masking effect, the degree depending on the tempo.

c) Micropauses often need to be inserted between phrases, and longer "Luft"pauses between major sections. They are appropriate for all composers. The placement of these is important, and not automatic. These pauses tend to occur at the end of pulses; before the next upbeat tone, where there is one. They also occur immediately before a subito piano.

At times the required pauses are actually provided for by the p-values, as calculated by the rule given, by means of the tail of the amplitude shape. This means that in such a place the composer's indication of phrasing indicates the amplitude shape required by the music. Also, micropauses may be appropriate between separate bowing marks (as distinguished from phrasing signs - an often difficult distinction) but not always: sometimes the computer can include more notes in a "bow" than is possible for a string player! At other times the effects of the change in bow needs to be minimized, rather than reproduced. Last notes of phrases are entered manually. In the examples given here they are generally considerably softer than the preceding tone.

(2) Structural

a) Pitch Crescendo As many musicians have noted, in particular Casals in his teaching, and Sundberg and Fryden (this book) there is a general tendency within a melody to increased loudness with pitch. This tendency is not found to the same degree, however, for different music and different composers. For Beethoven, it is appropriate to keep the amplitudes similar. This insures a small degree of crescendo, since a given amplitude is perceived as louder when pitch is increased. For Mozart, however, the crescendo tends to be greater - approximately an additional 4 dB/octave. For Schubert it can be even more than 6 dB/octave.

If the same melodic crescendo is applied to Beethoven the effect tends to sound exaggerated. There is a resistance to such crescendo in Beethoven, a restraint that also appears (like in the moderate modulation of tone amplitude heights by the Beethoven pulse) to translate into the strength of an ethical constraint.

In the musical illustrations to follow the pitch-crescendo effect for Mozart, and to a higher degree for Schubert, are included.

b) Alternation of "heavy" and "light" bars. This is a general structural property, not explicit in the score, which can be produced on the computer by scaling the amplitude down in the "light" bars. For Mozart, a amplitude suitable proportion may be 0.72, and bars often, though not always, alternate as heavy-light, heavy-light. This adds considerably to the sense of musical balance and logic, where appropriate; it presents larger units to the mind, allowing a greater overview.

In Beethoven other patterns tend to dominate, as commented on previously in Ex. III B:4, Fig. 15, and often special dramatic devices, such as crescendo and subito piano - as illustrated in Ex. III E:11 (Op. 31, No.3).

Crescendi and diminuendi specially noted by the composer in the score have of course to be included in the computer realizations.

c) Crescendo from Pulse to Pulse or Within each Pulse? We can now ask whether a crescendo or diminuendo should apply from pulse to pulse, or also within a pulse. It is easy to make both kinds of crescendo on the computer and different results of the two methods may be compared. It is likely that each type of crescendo or diminuendo is appropriate for different musical requirements.

III E. Musical Illustrations Incorporating Pulse and Amplitude Shapes According to the Mathematical Functions given in Sections III D and III C

The following examples were calculated by the computer using the inner pulse modulation values given in Section III D, as well as the prediction of p-values from the melodic pitch-time contour as in Section III C.

Only a few examples for each composer can be given here. They are selected for the particular features they illustrate. But the method can be applied to any themes.

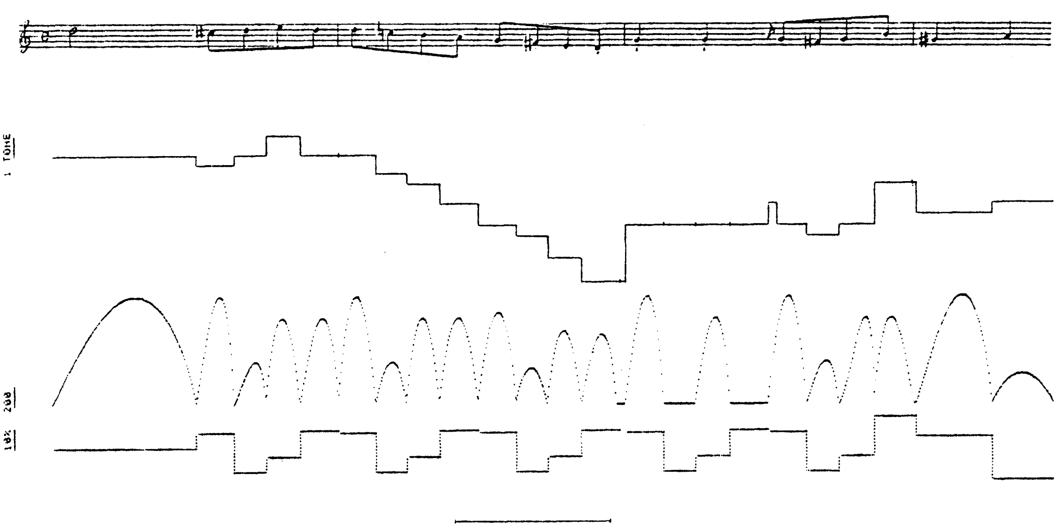

Fig. 20, Example III E:1, L. van Beethoven, Piano Concerto No. 1, Op. 15, first movement. The pulse pattern may be clearly seen in Fig:s 20 - 23. In general, however, with varied note values the pattern will not be seen to have a visual regularity and will appear more like those in earlier sections. See Table 12, for explanations, see legend of Fig. 12.

Ex. III E:1, Beethoven Piano Concerto No 1, 1st Movement, 2nd Subject, cf. Fig. 20, Table 12, and Sound Example III:1, is chosen for two special features:

1. It incorporates a scale passage which displays the Beethoven pulse clearly. The D in the descending scale, the fourth tone of the pulse, is made just sufficiently prolonged and emphatic by the pulse, for the appropriate Beethovenian sense of grouping of the tones. This of course occurs quite unnoticeably, in the conventional sense of "evenness". It can be distinctly noted, however, if special attention is focused on it.

2. It includes a characteristic pattern of two repeated staccato tones* which is useful for comparing microstructures. The second of the two Cs, each occupying half a pulse, has a somewhat greater duration than the first - is thus less staccato, and only slightly softer than the first (-2dB). Such Beethovenian articulation requires considerable subtlety and insight on the part of the performer - here it is produced appropriately, an encouraging result.

A Mozart pulse in this instance, for example, would cause the second tone to be considerably softer than the first (-6.6 dB), and the durations would be even.

Even though this is early Beethoven, and perhaps particularly so, the Beethoven pulse already applies. Note that no other modification of the tones is made; no essentic form is entered. The two functions here supply the entire microstructure, except for a micropause after the scale passage.

Ex. III E:2, Beethoven Op 37 Piano Concerto No 3, 1st Movement, 2nd Subject, cf. Fig. 21, Table 13, and Sound Example III:2, is somewhat

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* Repeated staccato notes are entered with even durations in all such examples before the pulse effects are introduced - the pulse then provides the appropriate microstructural proportions.

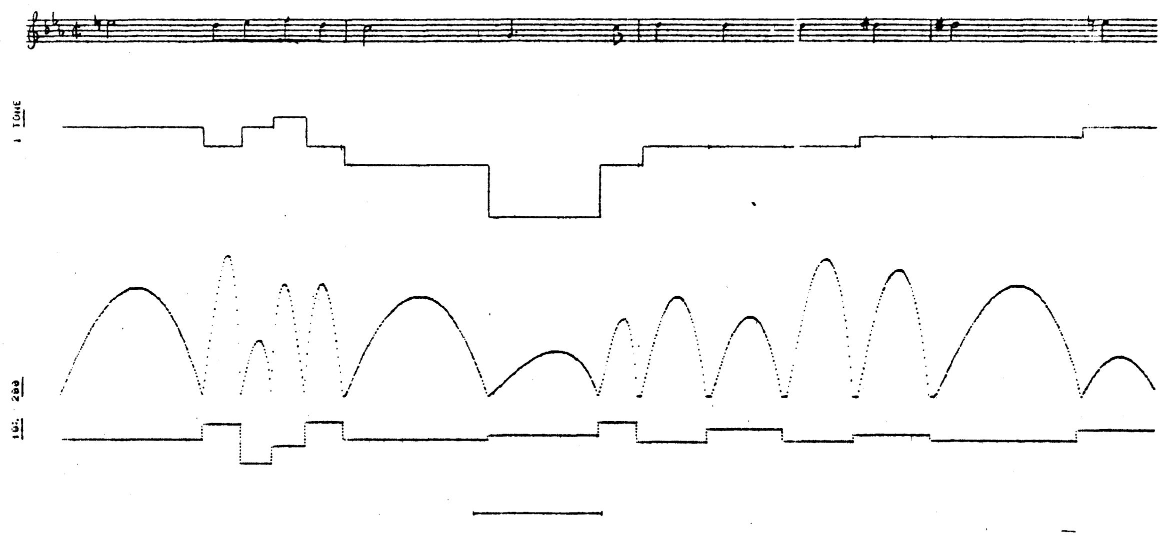


Fig. 21, Example III E:2, L. van Beethoven, Piano Concerto No. 3, Op. 37, first movement. For explanations, see legend of Fig. 12.

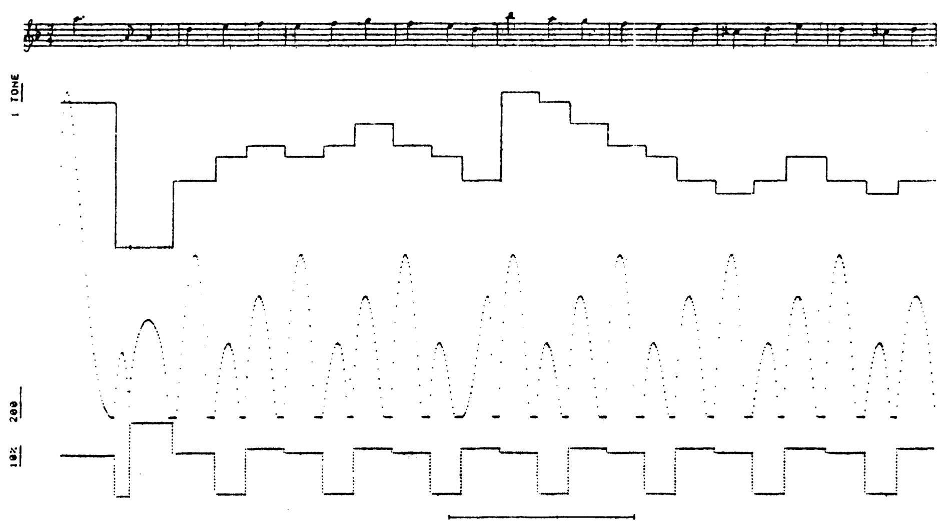


Fig. 22, Example III E:3, L. van Beethoven, Symphony No. 9, Op. 125, Scherzo. For explanations, see legend of Fig. 12.

like the previous example but has four detached tones whose relative weight is determined by the pulse.

The noble and pure quality of the first phrase (which one perhaps could liken to the character of Egmont) is given much of its due merely through the two functions: pulse and amplitude shapes according to the relations given. No further expressive means are added, nor probably required, at least as a first approximation.

This is also an example in which an added melodic pitch related crescendo diminuendo can ruin the expression, causing it to lose its strength.

Ex. III E:3, Beethoven 9th Symphony, Scherzo, cf. Fig. 22, Table 14, and Sound Example III:3 is an 8 bar fragment, which illustrates how the energy of this theme relates to the Beethoven pulse. The accentuation of the first tone is strong or less so, depending on from where within the movement we consider the excerpt to be taken. After the three As, there is a micropause. It seems that wherever an upward skip occurs from a staccato or detached tone to the first tone of a bar, a micropause may be indicated (see also example from Mozart's Jupiter Symphony, Minuet).

In Ex. III E:4, Mozart Haffner Symphony, 2nd Movement, cf. Fig. 23, Table 15, and Sound Example III:4, we can see the effects of the Mozart pulse clearly, with notes of even value. As the melody rises, the pitch - crescendo effect is essential. The heavy-light alternation on like repetitions of the phrase is also appropriate (ratio 0.72) (superimposed on the pitch - crescendo effect). The Mozartean charm and poise of this music would be impossible without realization of the pulse.

If this musical illustration is played in a slower tempo, one can distinctly clearly hear the microstructure of the pulse - the large differences in the loudness of component tones as well as duration deviations. When played at the proper tempo, the large differences in amplitude of the component tones and duration deviations become integrated into an overall perception of shape. The pulse becomes an entity.

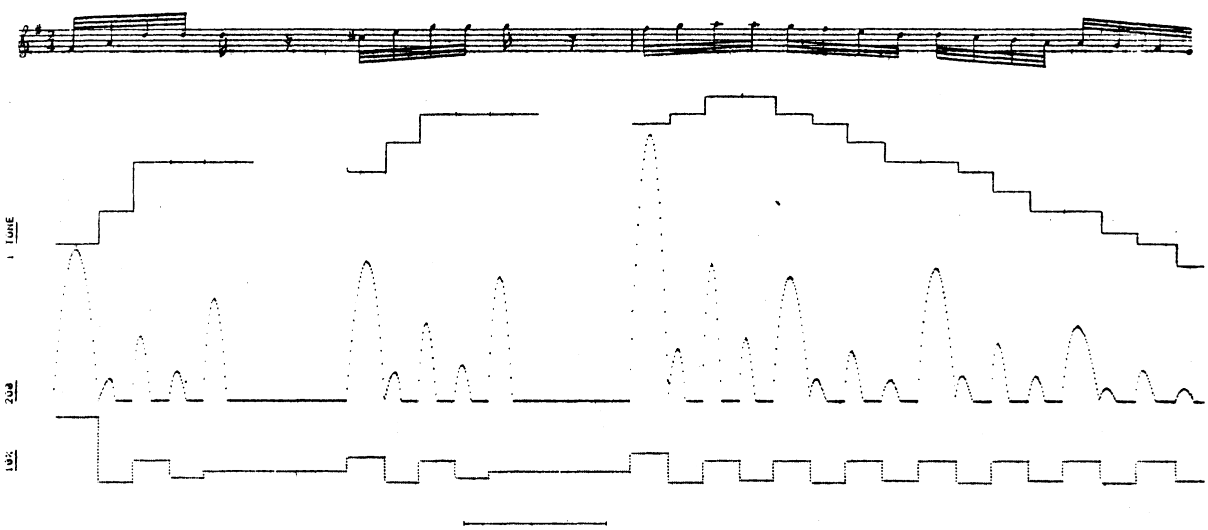


Fig. 23, Example III E:4, W. A. Mozart, "Haffner" Symphony, K385, second movement. For explanations, see legend of Fig. 12.

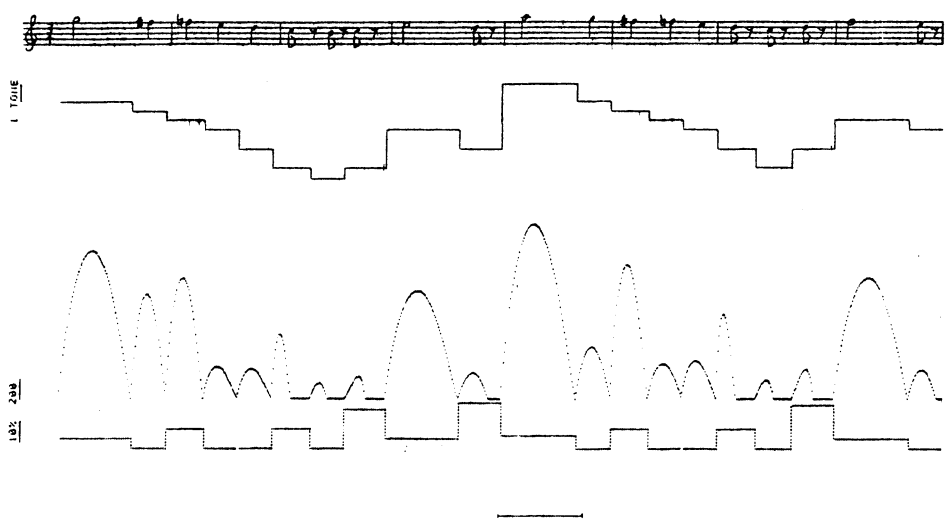


Fig. 24, Example III E:5, W. A. Mozart, "Jupiter" Symphony, K551, third movement. For explanations, see legend of Fig. 12.

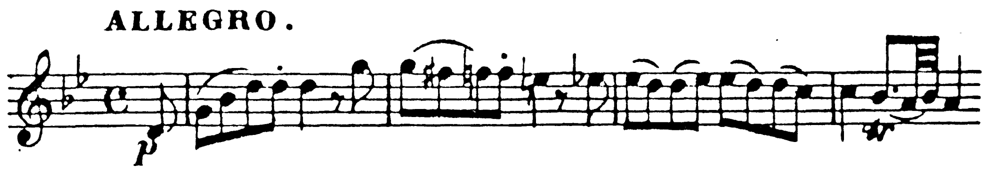
Ex. III E:5, Mozart Jupiter Symphony, Third Movement, cf. Fig. 24, Table 16, and Sound Example III:5 illustrates a Mozart pulse in triple time. Note the implementation of the micropause with the appropriate choice of the p^1, p^2 base values. A great deal of the loveliness and charm of this theme is realised. A subtly different pulse form would make this example sound like Haydn. One can almost see a Mozartean smile in the performance. A special accent is added on the first F sharp for harmonic reasons - F sharp is a chromatic tone and thus deserves a special accent. That constitutes the only modification required by the theme in addition to the functions of III C and III D and the pitch - crescendo function.

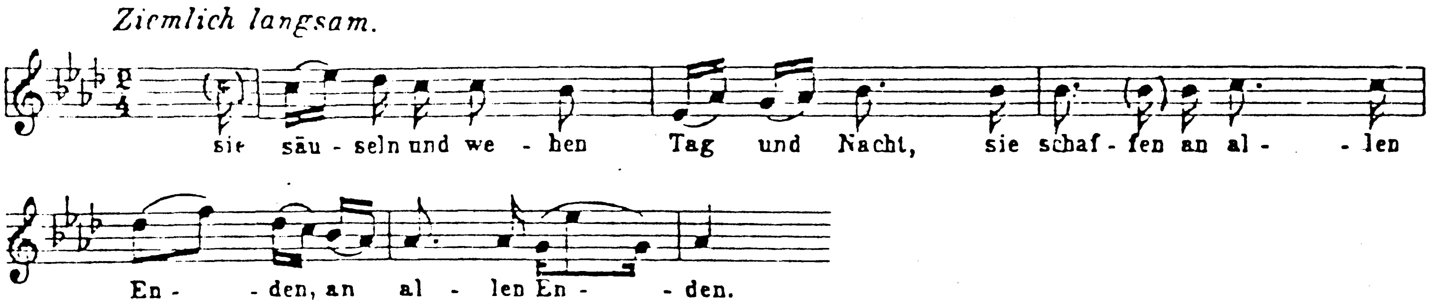
Ex. III E:6, Mozart Quintet in G minor K516, 1st Movement, cf. Table 17, and Sound Example III:6 illustrates the performance of the same excerpt as Ex. III B:1, but this time as calculated by the functions given in Sections III C and III D, and the pitch - crescendo function. As for many themes we need to lengthen the first tone slightly, and here we also need to lengthen the high point of the phrase, the first E flat of bar 3. This version does not sound sufficiently sad, however, although it has a Mozartean character. To achieve a greater expression of sadness the amplitude peaks in bars 3 and 4 are adjusted in accordance with the essentic form of grief.

In Ex. III E:7, Schubert, Song Fruhlingsglaube, cf. Table 18, and Sound Example III:7, the words of the song tend to strongly influence the form of amplitude shapes - being syllables, with consonants and vowels. Small (upward only) portamento slides to E flat in bar 1, in bar 3 and to the E flat in the last bar are also appropriate - but they need to be almost unnoticeable. Our singing sinusoid is severely handicapped compared with the richest of all instruments - the human voice - but the Schubertian character is clear nevertheless, as well as the mood.

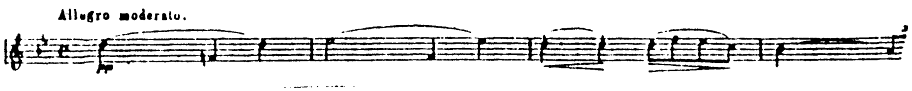
Having applied the Schubert pulse, amplitude shape prediction and strong pitch-crescendo-diminuendo function, the portamenti and micropauses are added, as well as the diminuendo in the last bar. The amplitude shapes of the dotted tones in bar 2 and 3 are subtly adjusted to reflect the essentic form of hope. Sound example III:11 also illustrates

Mozart   Quintet in G minor, K516, 1st Movement.   Example 6, Section III E.

(Table 17)

Schubert   Song "Frühlingsglaube", D686.   Example 7, Section III E.

(Table 18)

Schubert   Trio in B Flat, D898, 1st Movement, 2nd Subject.   Example 8, Section III E.

(Table 19)



how the expression of the theme evolves with these stages, and also how it would sound with a Beethoven pulse and with a Mozart pulse.

Ex. III E:8, Schubert Trio in B Flat, 1st Movement, Second Subject, cf Table 19 and Sound Example III:8, is first heard as calculated by applying the relationships for distinct amplitude shapes and for the Schubert pulse, and including the pitch - crescendo function. The result, while perhaps adequate, cannot be called inspired. It does produce the repeated notes well in a Schubertian way. We may compare this realization with an actual performance by Pablo Casals taken from his recording with Schneider and Istomin (first entrance of the theme). We note that Casals makes a unique and simple contribution to the phrasing here of a suddenly reduced amplitude (of breathing in) on the first eighth note. This produces an immediate gesture of inwardness at that moment adding immeasurably to the power of the music. By this simple device the entire perspective of the phrase of weighth notes is changed from an outward to an inward one. The theme thus achieves balance between an outward flow at the beginning and inward flow towards the close. This simple device of changing the loudness of that crucial tone helps Casals to produce an ineffable quality to the phrasing that none of the other performers in this, or other recordings known to the author appear to achieve. By imitating this process on the computer (reducing the loudness of only one note, the first eighth note A) we can impart at least some of the quality this produces to the computer performance.

This process also exemplifies that starting from a realization based on the functions of III A and III B, only small further changes may be called for to bring the expression to higher levels, and that such changes can be shown to have clear functions.

Ex. III E:10, Schubert Sonata in A Major, 4th Movement, cf. Fig. 25, Table 20, and Sound Example III:9 consists of an eight bar theme. It is illustrated in a version with two pulses per bar, and also with one pulse per bar. The latter version has a "longer line", but the former appears to be more lively and Schubertian. Thus, depending on how we think the pulse, the same piece at the same tempo will sound architecturally differently.

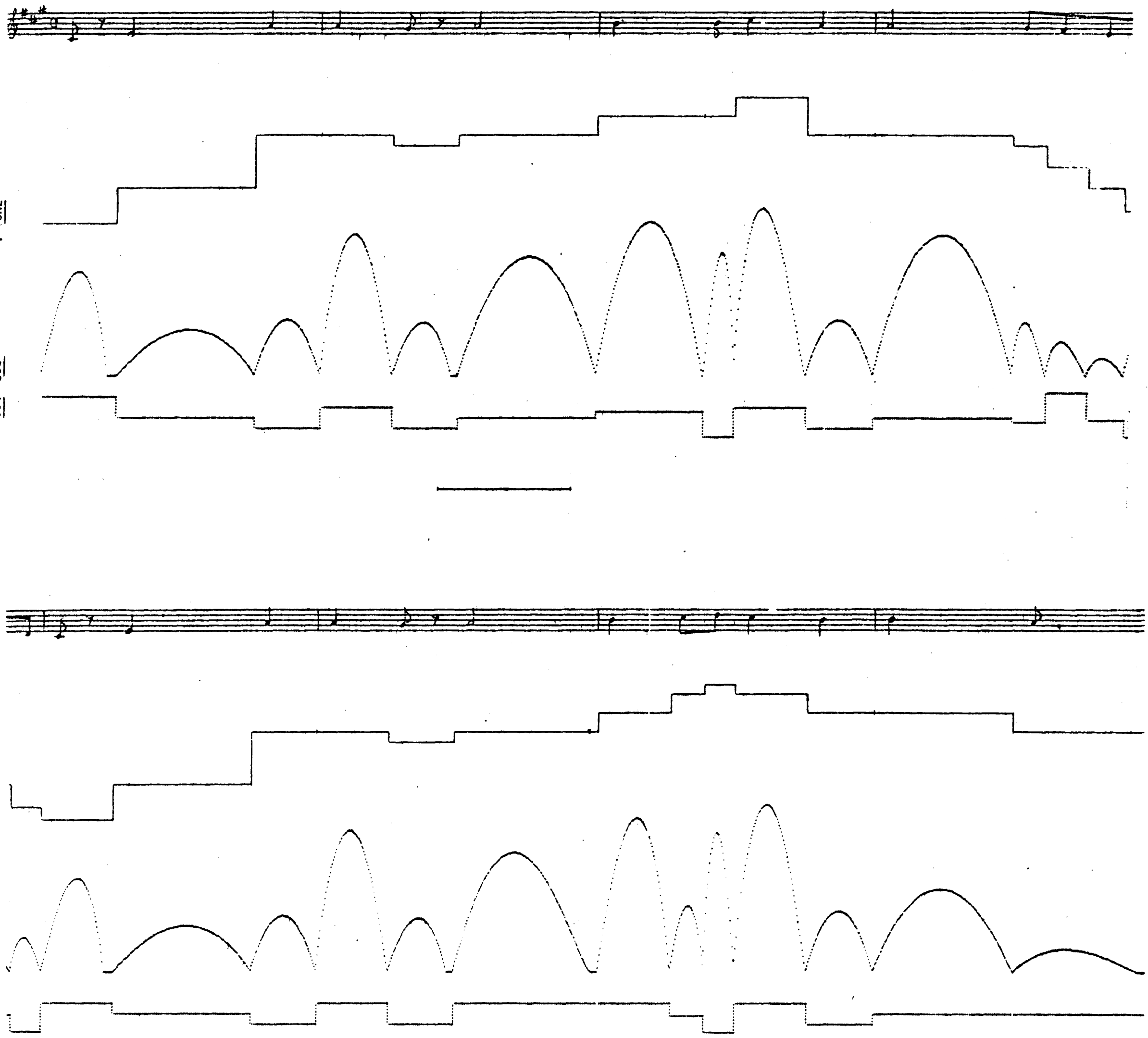


Fig. 25, Example III E:9, F. Schubert, Sonata in A major, Op. Posth, D959, fourth movement. For explanations, see legend of Fig. 12.

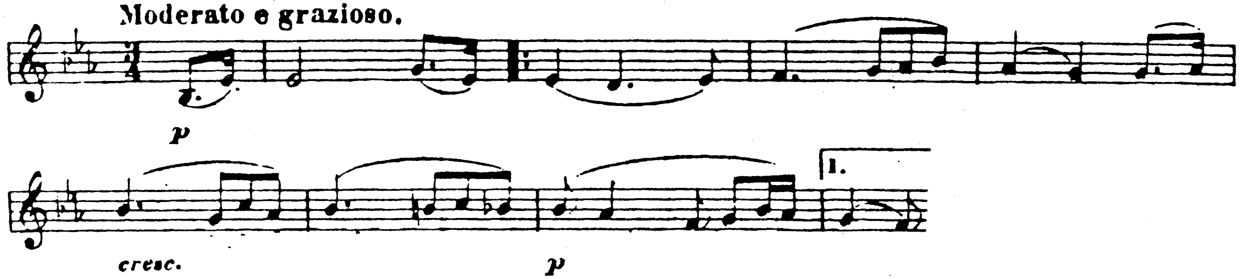
A micropause is required at the end of bar 6, but not at the end of bar 2 where the theme needs to go forward.

A modest crescendo and diminuendo not marked in the score is appropriate, so that bars 1, 2 have cresc., 3, 4 dim., 5, 6 cresc. and 7, 8 dim. to give a songlike character to the theme. Note that the four descending eighths notes in bar four illustrate the four components of the Schubert pulse, in version 1. We can also note the syncopation effect of the second tone of the theme. This is treated giving it the amplitude size it would have had, had it been on the first beat (a phase shift effect, essentially).

Influence of the Inner Pulse on the Composition of a Melodic Line

Ex. III E:10, Beethoven Op 31, No. 3, Minuet, cf. Table 22 and Sound Example III:10, using calculated amplitude shapes and the Beethoven pulse and appropriate micropauses, seems to require little else to be appropriately expressive. The first tone, as in many themes, is slightly lengthened. The crescendo and subito piano with its micropause makes the following B flat eighth note lose the inappropriate character its duration clearly would have without the crescendo subito piano. Note especially the placement and duration of the micropauses.

This example can serve as an illustration of how the pulse may constrain the composer to think along certain melodic ways. It we replace the Beethoven pulse by a Mozart pulse in this example, we find a considerable clash in the second part of the theme. The Mozart pulse requires a different realization of the melodic line (since it has a less prominent third component and the difference in amplitude between the first component and the others is much greater than for the Beethoven pulse). In providing accented passing tones in the melodic line we avoid the awkwardness that the Mozartean microstructure with its large differences in component amplitudes creates in the Beethoven melodic line, and provide a way for these differences to sound natural. Thus a possible more Mozartean realization of the melodic line which would not do as much violence to the Mozart pulse is given in the following example. Of course it is dangerous and overly daring to try to guess how Mozart might have written anything, and we offer this illustration merely as an indication of the direction in which the theme could be shaped following the dictates of this pulse, as it is represented here.

MENUETTO.
Moderato e grazioso.

Melodic modification of last two bars
more consonant with Mozart pulse

This process illustrates that the inner pulse of a composer would tend to influence his choice in shaping a melody, and that certain choices can in fact clash with the composer's inner pulse. Knowing more about this process could be of help to composer to cultivate a flow of melodic invention that reflects his integrity.

IV SUMMING UP AND CONCLUSION

IV A. Overall Procedure for Shaping a Melody

We may concisely summarize the steps involved in using the functions of III C and III D for the artistic shaping of a melody. Steps 7 to 9 are not always required.

1. Enter tones and nominal durations according to the score.
2. Choose tempo.
3. Apply pulse matrix for the particular composer, and particular meter, B, M, or S for Beethoven, Mozart and Schubert respectively, choose length of pulse.
4. Insert micropauses of appropriate duration at appropriate places, e. g. end of phrases and other special points.
5. Choose base p^1- and p^2-values and calculate p-values according to Section III C for amplitude shapes of individual tones.
6. Adjust last tones of phrases by "ear", both amplitude and p-values.
7. Enter pitch crescendo-diminuendo function as appropriate, and any crescendi or diminuendi or special accents directed by the score.
8. As required, modify amplitude and/or duration of one or several key tones to shape a particular essentic form.
9. If phrases repeat, subtly change the repetition as desired.

The first tone only of the theme is generally to be lengthened in duration by about 5 %, at the beginning of a piece, but not on subsequent reintroductions of the theme.

A few minutes are generally sufficient to carry out these steps. It is of course useful to listen to the result after each step is taken.

Micropauses, p^1-, p^2-base values or other parameters can be adjusted at any time to improve the result, as desired.

IV B. Stability of the Pulse Matrices

Some words of caution are in order. As has been said, the pulse matrix values given here are subject to further refinement. While the salient features of the specific pulse matrices hold over a wide range; their degree of prominence however is likely to be influenced to an extent by

1) tempo (within the range given, 50 - 80 per minute)
2) pitch height of the entire theme, i.e. transposition

Thus, how these factors may modify the values of the elements within the pulse matrices needs to be studied further, as a second order effect. Further, to what extent other second order changes in the pulse forms may occur with variables such as the composer´s age, and other variables related to specific pieces, remain to be systematically investigated.

IV C. Relation of Timbre to Microstructure

Having temporarily banished timbre*, we shall need to redeem our sin concerning its importance in music! First of all, timbre is essential for melodic expressiveness when there is more than one melodic line. Several sinusoids tend to coalesce and fuse - for distinctness of voice leading and contrast sounds with different dynamic proportions of harmonics are required. Secondly, we can now, in the light of the present studies with sinusoids, investigate how timbre variations are of help in improving expressiveness of a single melodic line. Within each tone it is possible

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* Small changes in timbre do occur even in our method, since amplitude shaping produces side bands; since the amplitude modulating frequencies are mainly 0.5 - 5 Hz, i. e. in the subaudio range, however, the sideband effects are relatively slight.

to add timbre, and also vibrato, in various dynamic ways to the expressive forms already determined, and to see how such individually shaped time varying functions of timbre for each tone (time-shaped harmonic content - not only in relation to the attack) may augment or interfere with expressiveness. Such a study will have to take into account the complication that adding timbre and/or vibrato can modify the perception of amplitude shapes, in part because the overtones require their own amplitude shaping (not according to the aamplitude shapes of the fundamental), as well as for psychophysiologic reasons related to persistence of hearing, and dynamic masking (Grey 1977, Risset & Wessel 1982).

Of course, timbre has a strong attraction of its own: the sheer loveliness of a sound, its arresting, fascinating, or unique character. The difficulty of the timbre problem lies in reconciling these qualities sui generis with the qualities of expression studied in this paper, especially since the former are also mainly dynamic entities rather than steady state ones. Modern electronic music often favours timbre over pulse and microstructure, impressionism over expressionism, the ego-less over the intimately personal*. A creative balance between the two, as a long term attribute of the art of music, will need understanding of both their detailed dynamic aspects - a worthy if distant goal!

IV D. Comments on the Significance of the Findings

We have found that:

1. Expressiveness and microstructure can be fruitfully studied with amplitude modulated sinusoidal sounds. Musical meaning in its subtlety can be largely expressed by this means for single melodic lines.

2. A systematic relation appears to exist between individual amplitude shapes of tones of a melody and its course, so that the shape can be

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* ignoring that that the most intimate is also the most universal

predicted from the slope; and thus is heard to presage the next tone of a melody - forging an organic link, and making it possible for the living qualities inherent in the melodic shape to cast a presence within each tone.

3. In music which incorporates a personal pulse, this is shown to systematically affect both amplitude and durations of component tones in a way characteristic to that personal pulse, as also an individual's signature bears the continuing stamp of his person. The realization of the pulse and its effects is seen to be necessary for the life, power and beauty of such music.

The third aspect has been illustrated only with music of Mozart, Beethoven and Schubert.* For ethnic music in which the pulse is not an individual personal signature of the composer, it should be possible to apply the method if pulse matrices could be identified.**

Aspects of the findings may also share a common ground in part with some of the microstructure rules proposed by Sundberg & al (this volume), and with characteristics of microstructure derived from consideration of musical syntax by Longuet-Higgins (this volume). We cannot in the space available discuss adequately the extensive implications of the results reported here. We may say in brief that the methods and results obtained:

(1) can improve one's artistic understanding and output,

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* Pulse matrices for Brahms, Chopin as well as computer realizations of themes from the 32 Beethoven piano Sonatas are in preparation.

** For other earlier music, however, a pulse does not seem to modify durations of component tones in a "printed out" manner; for Bach for example, the durations do not seem to be systematically modulated in this way - Bach has retained freedom from its yoke; in his music durations of tones are altered mainly for melodic (essentic form) and stylistic constraints (Schweitzer, 1911) rather than those of a personal pulse.

(2) far from being "mechanical", infuse life and livingness ("Lebendigkeit") into music,

(3) tend to give us a degree of understanding of the very nature of that livingness, as bound to iconic and unique form,

(4) allow us to use imagination and creative insight from a higher hierarchic point of view, using as units of thought entities that before needed to be specially constructed every time from constituent parts,

(5) should be considered as first approximations, from which the next stage can be more readily attempted - "a camp on the way to Mount Everest".

Applications to music education are obvious and need not be detailed here. In an age of personal computers, the programs developed can give access to creative interpretation to all so inclined without the need for physical musical skills.

Our previously developed computer composing program (Clynes and Nettheim, 1982) can now be modified to include amplitude shaping of tones according to the melodies being composed by the program, and it should also be possible to study the effects of including pulse matrices.

Finally, we emphasize that the last word in any realization is always the human shaper´s imagination and discernment; the human feeling, imgination and creativity tells the computer what to do: the computer is only a tool that helps man to think musically, somewhat as an electronic calculator is to a mathematical concept.

Thus also the work presented here is to be gauged by what it may contribute to our understanding of music.

Boethius wrote in the 5th century A.D.:
"Is it not evident that the spirit of warriors is roused by the sound of

the trumpets? If it is true that a peaceful state of mind can be converted into wrath and fury, then beyond doubt a gentler mode can temper the wrath and passionate desire of a perturbed mind. What does it signify that when anyone's ears and mind are pleased by a melody, he involuntarily keeps time by some bodily motion and his memory garners some strain of it? From all this appears the clear and certain proof that music is so much part of our nature that we cannot do without it even if we wish to do so.

The power of the mind should therefore be directed to the purpose of comprehending by science what is inherent by nature. Just as in the study of vision, the learned are not content to behold colors and forms without investigating their properties, so they are not content to be delighted by melodies without knowing by what proportion of sounds these are interrelated."

Today it is not only those interested in nature and in theories who need to comprehend this, but all those who use computers to make music; and especially those for whom the new means of our time hold promise of hitherto undreamed music, in which man's mind and heart may find a more meaningful evolutionary integration.

Acknowledgment

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APPENDIX

Tentative pulse matrix values for triple meters are as follows:

DURATION	AMPLITUDE RATIO
BEETHOVEN	
108	1
88	.46
107	.75
MOZART	
106	1
97	.33
97	.41
SCHUBERT	
97	1
106	.55
98.5	.72

Values for duple meter are derived simply from the quadruple values by adding the duration of tones 1 and 2, and of tones 3 and 4, respectively, to obtain the duration proportions and keeping the amplitude values for tones 1 and 3, which now become 1 and 2.

Thus the matrix values for duple meter are:

DURATION	AMPLITUDE RATIO
BEETHOVEN	
97.5	1
100.3	.83
MOZART	
100	1
100	.51
SCHUBERT	
106	1
94.5	.40

Pulse matrices for compound meters can be derived from the above as follows:

The two matrices are combined so that

amplitude ratio $A_c(i,j) = A_1(i)A_2(j)$

duration factors $D_c(i,j) = \dfrac{D_1(i)D_2(j)}{100}$

where $A_c(i,j)$ is the compound pulse amplitude,

$D_c(i,j)$ is the compound pulse duration,

$A_1(i)$, $A_2(j)$ are the simple pulse amplitudes, and

$D_1(i)$, $D_2(j)$ are the simple pulse durations respectively for the i^{th} and j^{th} tone of the simple pulses.

To allow for different degrees of hierarchical dependence attenuation factors are introduced that allow the effectiveness of the subordinate pulse structure to be de-emphasised or emphasised, with the parameters n and m, so that when n=1 and m=1, a full hierarchical effect is obtained, and for smaller values the duration and/or amplitude effects of the subordinate pulse structure are relatively more attenuated. Thus

amplitude ratio $A_c(i,j) = A_1(i)A_2(j)^n$

duration factors $D_c(i,j) = \frac{D_1(i)D_2(j)}{100} - (1-m)\left[\frac{D_1(i)D_2(j)}{100}\right] - D_1(i)$

Values of n and m in the range of .7 to .8 are found to be often appropriate.

For example, the 6/8 pulse for Beethoven is

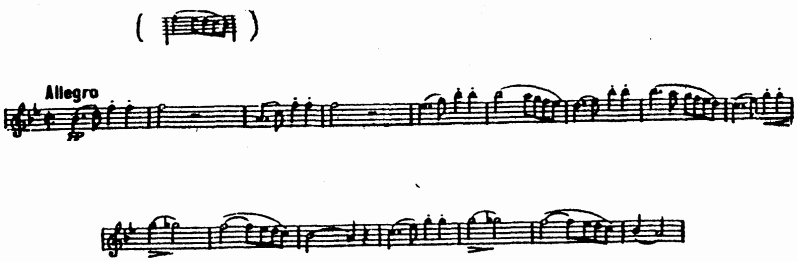
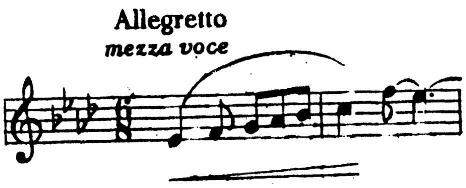
for n = 1, m = 1

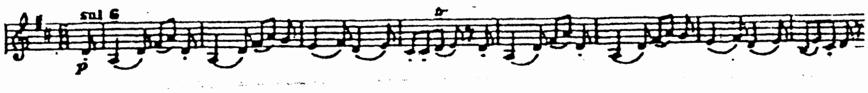
102	1
86	.46
104	.75
109	.83
91	.38
111	.62

for n = .8, m = .7

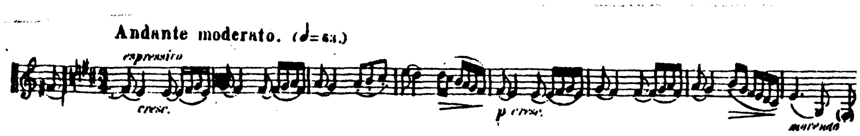
101	1
88	.58
103	.82
108	.83
94	.48
109	.68

The effect is that each group of 3 tones constitutes a small 3-pulse, and the two groups of 3 tones form a 2-pulse.

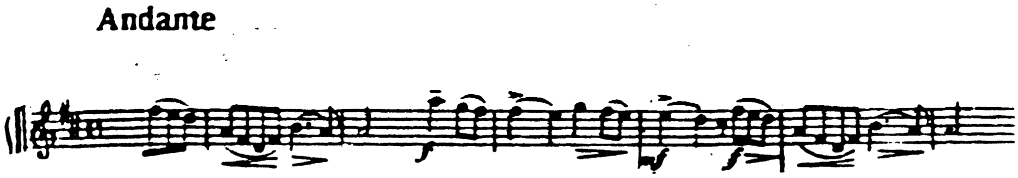
MUSIC EXAMPLES

Example III B:1. F. Schubert, Symphony No. 5 in Bb, see Fig. 13.

Example III B:3. F. Chopin, Ballade No. 3, Op. 47, see Fig. 14.



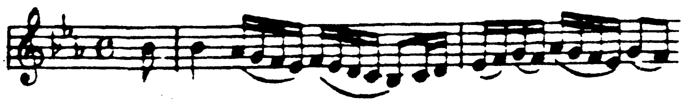
Example III B:4 L. van Beethoven, Violin Concerto, Op. 61, third movement, see Fig. 15.



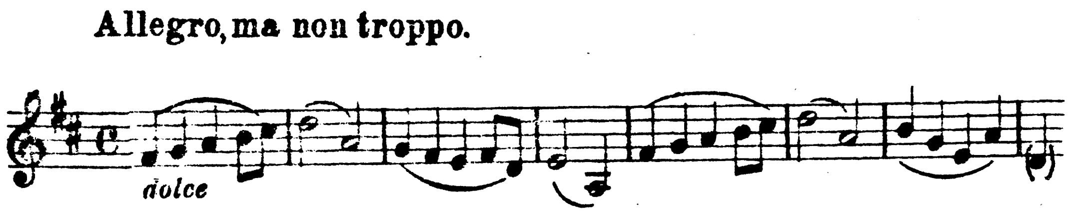
Example III B:5. L. van Beethoven, Symphony No. 9, Op. 125, third movement, see Fig. 16.



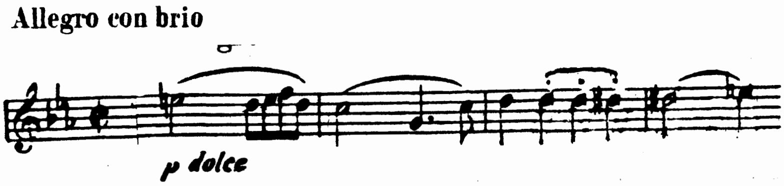
Example III C:1. P. Tchaikowski, Symphony No. 6, Op. 74, first movement, see Fig. 17.

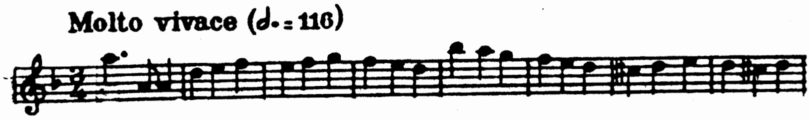


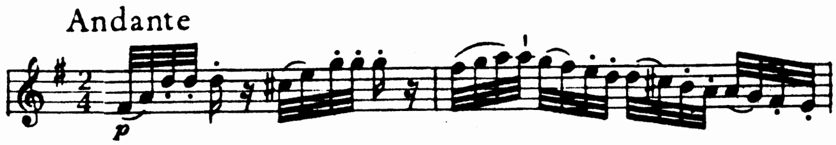
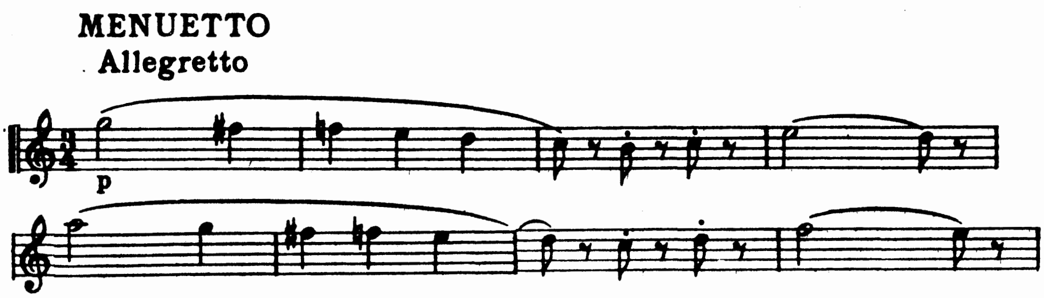
Example III C:2. J. S. Bach, Choral from Cantata No. 140 "Wachet auf", see legend of Fig. 18.

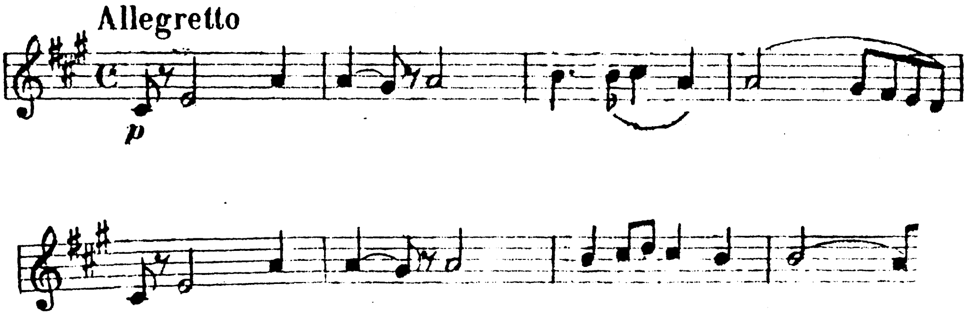


Example III C:3. L. van Beethoven, Violin Concerto, Op. 61, first movement, see Fig. 19.

Example III E:1. L. van Beethoven, Piano Concerto No. 1, Op. 15, first movement, see Fig. 20.

Example III E:2. L. van Beethoven, Piano Concerto No. 3, Op. 37, first movement, see Fig. 21.



Example III E:3. L. van Beethoven, Symphony No. 9, Op. 125, Scherzo, see Fig. 22.

Example III E:4. W. A. Mozart, "Haffner" Symphony, K385, second movement, see Fig. 23.

Example III E:5. W. A. Mozart, "Jupiter" Symphony, K551, third movement, see Fig. 24.



Example III E:9. F. Schubert, Sonata in A major, Op. Posth, D959, fourth movement, see Fig. 25.

T A B L E 5

EMOTION	Sinusoidal base frequency Hz	FREQUENCY MODULATION Depth and Sign	AMPLITUDE MODULATION Propor-tional	Diff. time constant τ (seconds)	A
ANGER	110	+ 59%	Prop.		
HATE	106	- 5%	Prop.	1.2	0.05
GRIEF	406	- 21%		3.1	1
LOVE	205	- 2.4%	Prop.		
SEX	228	+ 14%		1.0	
JOY	480	-, one octave: biphasic 20% down then 61% up	Prop.	0.32	0.20
REVERENCE	298	+ 9%		4.0	1

+ means : frequency ↑ as pressure ↑

- means : frequency ↑ as pressure ↓

Differentiation time constant refers to transfer function $\frac{A\tau s}{1+\tau s}$ for ampl. mod. where s is the Laplace Transform.

PARAMETERS FOR TRANSFORMING
TOUCH FORMS TO SOUND FORMS OF LIKE EXPRESSION

Table 1. Transforms of dynamic forms to sound forms of like expression, as amplitude and frequency modulated sinusoids (see Fig:s 1 and 2): specific scaling parameters.

c^1	b	b flat	a	a flat	g	a flat
0.81	0.23	0.53	0.48	1.49	0.58	3.88
0.81	0.23	0.53	0.48	5.94		
0.81	0.23	0.53	1.97		4.45	
0.81	0.23	1.02		1.49	0.58	3.88
0.81	0.77		0.48	1.49	0.58	3.88
1.05		0.53	0.48	1.49	0.58	3.88
0.81	0.23	0.53	6.42			
0.81	0.23	1.02		5.94		
0.81	0.23	2.50			4.45	
0.81	0.77		0.48	5.94		
0.81	0.77		1.97		4.45	
0.81	1.25			1.49	0.58	3.88
1.05		0.53	0.48	5.94		
1.05		0.53	1.97		4.45	
1.05		1.02		1.49	0.58	3.88
1.58			0.48	1.49	0.58	3.88
0.81	0.77		6.42			
0.81	1.25			5.94		
0.81	2.73				4.45	
1.05		0.53	6.42			
1.05		1.02		5.94		
1.05		2.50			4.45	
1.58			0.48	5.94		
1.58			1.97		4.45	
2.06				1.49	0.58	3.88
1.58			6.42			
2.06				5.94		
3.55					4.45	

Table 2. Set of 28 alternative melodies expressing Grief (shown in the range from C to G). Each melody is one horizontal row. The numbers give the timings of the tones listed at the head of the column. These melodies constitute all the possible combinations of scale steps derived from the essentic form of Grief, as given in Fig. 6. The amplitude envelope contour needs to be that of Grief for all these melodies, as shown in Fig. 2. They can be transposed over a range of about an octave without marked loss of expressive quality.

MOZART: QUINTET IN G MINOR, 1ST MOVEMENT

Duration (sec) : 8.73
MM (100 of tones/min): 220.00

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	D4	100	800	1.00	1.00
2	G4	123	1500	1.10	0.80
3	B4b	88	400	1.20	0.80
4	D5	100	350	0.85	3.40
5	D5	112	430	1.20	4.50
6	D5	223	660	0.96	0.83
7	R	80	0	0.00	0.00
8	G5	195	920	1.10	1.35
9	G5	133	2100	1.15	1.70
10	F5#	102	600	0.97	2.00
11	F5	101	850	0.80	3.20
12	F5	110	400	1.00	2.60
13	E5	231	300	1.15	1.40
14	R	83	0	0.00	0.00
15	E5b	105	580	1.20	0.65
16	E5b	139	1550	1.28	1.65
17	D5	103	430	0.85	1.00
18	D5	105	380	0.85	0.90
19	E5b	108	620	0.80	1.10
20	E5b	135	800	1.80	1.20
21	D5	95	290	0.80	1.30
22	D5	113	400	0.85	1.90
23	C5	98	240	0.80	1.30
24	C5	215	530	1.55	0.90
25	B4b,C,Bb	62,40,38	245	0.83	0.80
26	A4,B4b	31,39	210	0.80	0.70
27	A4	227	235	1.30	1.20

Table 3. This table and similar ones gives a list of all the tones and rests of the computer realisation, specifying for each
1) the duration of the tone, or rest, in points
2) the amplitude size
3) the amplitude shapes in terms of p^1-, p^2-values

In some Tables, where Beta Functions are used to span only part of the duration of the tone, as may occur for staccato tones, the sound duration of staccato tones is given in parenthesis next to the total tone duration. Micropauses are indicated as "P", and rests as "R". When more than one Beta Function is used for a tone amplitude, they are listed in vertical sequence for that tone. Metronome mark for the normal unit used (often a subdivision of a quarter note) is also given.

SCHUBERT: SYMPHONY NO 5 IN B FLAT 1ST MOVT

Duration (sec) : 23.90
MM (100 pt [illegible]/min): 168.00

T#	NOTE	DUR	AMPL	P1	P2
1	B3b	150	1500	0.72	2.00
			230	0.10	0.00
2	D4	45	700	0.90	1.00
3	F4	109	1200	0.60	5.00
4	F4	97	790	0.65	4.50
5	F4	215	1300	1.45	0.50
6	E4b	54	1150	0.80	1.00
7	D4	46	900	0.90	1.00
8	C4	54	800	0.90	1.00
9	B3b	50	950	1.00	0.35
10	A3	152	1150	0.72	2.00
			220	0.10	0.00
11	C4	45	700	0.90	1.00
12	F4	109	1000	0.50	7.20
13	F4	104	570	0.56	5.50
14	F4	242	750	1.60	0.67
			115	0.40	0.00
15	R	192	0	0.00	0.00
16	E4b	155	1800	0.72	2.00
			264	0.10	0.00
17	G4	42	900	0.80	1.00
18	B4b	112	1620	0.60	6.00
19	B4b	95	1056	0.70	3.30
20	B4b	215	1920	1.40	0.50
21	A4	54	1400	0.80	1.00
22	G4	46	900	0.90	1.00
23	F4	52	950	0.90	1.00
24	E4b	48	950	1.00	0.34
25	D4	150	220	0.10	0.00
			1150	0.72	2.00
26	F4	45	650	0.90	1.00
27	B4b	108	1000	0.65	6.00
28	B4b	95	550	0.70	4.00
29	B4b	190	1100	1.40	0.75
30	A4	45	600	0.90	1.00
31	G4	52	900	0.80	1.00
32	F4	48	600	0.80	1.00
33	E4b	50	500	1.00	1.00
34	D4	55	650	0.70	0.50
35	C4	150	300	0.53	2.55
36	E4b	45	500	0.80	1.00
37	G4	108	950	0.60	6.00
38	G4	95	1050	0.70	3.30
39	G4	230	1820	2.00	0.40
40	G4b	210	1600	0.50	1.15
41	F4	295	1020	1.00	1.30
42	E4b	45	600	1.00	1.00
43	D4	50	650	1.00	1.00
44	C4	50	400	0.70	0.40
45	B3b	220	500	1.00	1.00
46	A3	223	150	0.35	3.25
47	C4	150	700	0.53	2.55
48	E4b	45	500	0.80	1.00
49	G4	108	900	0.60	6.00
50	G4	95	1300	0.70	3.30
51	G4	230	2100	2.00	0.40
52	G4b	225	2000	0.55	1.50
53	F4	295	1500	1.00	1.25
54	E4b	45	600	1.00	1.00
55	D4	50	650	1.00	1.00
56	C4	50	400	0.70	0.40
57	B3b	215	500	1.30	0.90
58	A3	135	300	0.35	0.50

Table 4. For explanations see legend of Table 3.

CHOPIN: BALLADE NO 3 IN A FLAT, OP 47

Duration (sec) : 5.81
MM (100 pt tones/min): 145.00

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	E4b	224	840	0.80	0.73
2	F4	130	300	1.20	0.67
3	G4	95	800	1.00	1.50
4	A4b	80	1150	1.00	0.80
5	B4b	98	1680	1.00	0.30
6	C5	276	2170	1.70	2.53
P	-	[illegible]	0	0.00	0.00
7	F5	151	810	0.95	2.36
8	E5b	340	660	0.85	1.55

Table 5. For explanations see legend of Table 3.

BEETHOVEN: VIOLIN CONCERTO OP 61, 3RD MOVT

Duration (sec) : 14.01
MM (100 pt tones/min): 210.00

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	D4	107(68)	2160	1.00	3.80
2	A3	200	2500	0.70	5.00
			3800	3.20	1.20
3	D4	100	747	0.60	4.50
4	F4#	94	2060	0.80	0.65
5	A4	100	585	0.50	3.50
P	-	8	0	0.00	0.00
6	D4	117(75)	1935	1.00	3.80
7	A3	200	2500	0.70	5.00
			3800	3.50	1.15
8	D4	100	747	0.60	4.50
9	F4#	97	1590	0.80	0.65
10	A4	100	585	0.50	3.50
P	-	4	0	0.00	0.00
11	G4	103	1900	1.00	1.00
12	E4	197	2300	3.20	1.20
			1500	0.70	5.00
13	F4#	103	1323	0.65	4.20
14	D4	197	1170	3.00	0.45
			945	0.60	1.20
15	E4	98	1350	0.70	3.00
16	C4#	97	990	0.40	2.00
17	C4#	94	855	0.40	2.20
18	D4,E,D	30,19,19	1500	0.60	0.63
19	C4#,D4	19,19	1900	0.60	0.60
20	E4	100	2700	0.70	1.77
21	R	127	0	0.00	0.00
22	D4	107	2160	1.00	3.80
23	A3	200	2500	0.70	5.00
			3800	3.60	1.10
24	D4	100	747	0.60	4.50
25	F4#	94	2060	0.80	0.65
26	A4	100	585	0.50	3.50
P	-	8	0	0.00	0.00
27	D4	117(75)	1935	1.00	3.80
28	A3	200	495	0.20	2.00
			130	0.13	3.00
			198	0.18	6.00
			630	0.45	2.00
			1800	3.00	0.45
			1060	0.45	0.30
29	D4	100	747	0.60	4.50
30	F4#	97	1590	0.80	0.65
31	A4	100	585	0.50	3.50
	-	4	0	0.00	0.00
32	G4	103	1900	1.00	1.00
33	E4	197	1500	0.70	5.00
			2300	3.20	1.20
34	F4#	103	1323	0.65	4.20
35	D4	174	1260	0.60	2.00
			270	3.00	0.45
36	E4	103	1710	0.70	3.40
37	B3	115	2730	2.20	0.70
38	E4	108	1350	0.47	5.50
39	C4#	113	1215	0.42	4.15
40	D4	110	1300	0.40	1.00
41	R	100	0	0.00	0.00

Table 6. For explanations see legend of Table 3.

BEETHOVEN: NINTH SYMPHONY, OP 125, 3RD MOV

Duration (sec) : 35.93
MM (100 pt tones/min): 103.00

T#	NOTE	DUR (PTS)	AMPL	F1	P2
1	F4#	230	1200	1.67	1.07
2	E4	(1-256)	1300	1.13	0.95
		(237-440)	2300	2.15	0.90
3	F4#	55	700	1.00	0.70
4	G4	62	1050	0.92	0.80
5	E4	61	540	0.80	0.80
6	G4	120	1500	0.80	0.40
7	F4#	(1-218)	1900	1.12	0.95
		(199-440)	3000	1.90	0.92
8	G4	50	1200	1.00	1.00
9	A4	50	1800	1.00	1.00
10	F4#	63	950	0.95	0.80
11	A4	120	1850	0.80	0.60
12	G4	265	2520	1.32	0.70
P	-	15	0	0.00	0.00
13	A4	110	1800	0.80	0.65
14	B4	110	2100	1.00	0.60
15	C5#	133	2850	1.20	0.65
P	-	7	0	0.00	0.00
16	E5	180	3500	0.91	1.20
17	D5	290	2500	1.05	1.20
18	D5	80	1500	1.10	1.00
19	C5#	60	1200	1.00	1.00
20	B4	60	1000	1.00	1.00
21	A4	60	800	1.00	1.00
22	G4	60	600	1.00	1.00
23	F4#	65	450	1.00	1.00
24	F4#	120	980	1.00	0.70
25	E4	(1-256)	890	1.13	0.95
		(237-440)	1900	2.10	0.90
26	F4#	55	700	1.00	0.70
27	G4	63	1060	1.00	0.80
28	E4	59	540	0.80	0.80
29	G4	120	1650	0.80	0.40
30	F4#	(1-257)	1900	1.50	0.70
		(240-441)	2500	2.50	0.70
31	G4	50	1380	1.00	1.00
32	A4	60	2200	1.00	0.80
33	F4#	63	1400	0.95	0.70
34	A4	123	3150	1.00	0.40
35	G4	257	3000	1.60	0.50
P	-	15	0	0.00	0.00
36	B4	80	1500	0.90	1.20
37	G4	63	1200	1.00	1.00
38	F4#	63	1000	0.90	0.90
39	E4	63	800	1.00	1.00
40	D4	65	650	1.00	1.00
41	C4#	67	550	0.80	0.95
42	E4	350	860	1.75	0.78
P	-	47	0	0.00	0.00
43	G3	140	450	1.00	1.00
44	F3#	170	250	0.90	0.90

Table 7. For explanations see legend of Table 3.

Semitones tc next tone

Duration of tone, seconds	1	2	3	4	5	6	7	8	9	10	11	12
0.15:	1.151	1.325	1.524	1.754	2.019	2.324	2.675	3.078	3.543	4.077	4.693	5.401
0.20:	1.133	1 284	1.455	1.648	1.868	2.116	2.398	2.717	3.079	3.489	3.953	4.479
0.25:	1.117	1.249	1.396	1.559	1.743	1.947	2.176	2.432	2.718	3.037	3.394	3.793
0.30:	1.104	1.218	1.345	1.484	1.639	1.809	1.996	2.204	2.432	2.685	2.964	3.271
0.40:	1.081	1.169	1.264	1.366	1.477	1.597	1.727	1.867	2.019	2.183	2.360	2.552
0.50:	1.064	1.131	1.203	1.280	1.361	1.448	1.540	1.638	1.742	1.853	1.971	2.097
0.60:	1.050	1.102	1.158	1.215	1.276	1.340	1.407	1.477	1.551	1.629	1.710	1.795
0.70:	1.039	1.080	1.123	1.167	1.213	1.260	1.310	1.361	1.415	1.470	1.528	1.588
0.80:	1.031	1.063	1.096	1.130	1.165	1.201	1.238	1.276	1.316	1.356	1.398	1.441
0.90:	1.024	1.049	1.075	1.101	1.128	1.155	1.184	1.212	1.242	1.272	1.303	1.335
1.00:	1.019	1.039	1.059	1.079	1.100	1.121	1.143	1.164	1.187	1.210	1.233	1.257
1.20:	1.012	1.024	1.036	1.049	1.061	1.074	1.087	1.100	1.113	1.126	1.140	1.153

Semitones to next tone

Duration of tone, seconds	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12
0.15:	0.869	0.755	0.656	0.570	0.495	0.430	0.374	0.325	0.282	0.245	0.213	0.185
0.20:	0.883	0.779	0.687	0.607	0.535	0.473	0.417	0.368	0.325	0.287	0.253	0.223
0.25:	0.895	0.801	0.717	0.641	0.574	0.513	0.460	0.411	0.368	0.329	0.295	0.264
0.30:	0.906	0.821	0.744	0.674	0.610	0.553	0.501	0.454	0.411	0.372	0.337	0.306
0.40:	0.925	0.855	0.791	0.732	0.677	0.626	0.579	0.536	0.495	0.458	0.424	0.392
0.50:	0.940	0.884	0.831	0.781	0.735	0.691	0.649	0.610	0.574	0.540	0.507	0.477
0.60:	0.952	0.907	0.864	0.823	0.784	0.746	0.711	0.677	0.645	0.614	0.585	0.557
0.70:	0.962	0.926	0.891	0.857	0.825	0.794	0.764	0.735	0.707	0.680	0.654	0.630
0.80:	0.970	0.941	0.913	0.885	0.859	0.833	0.808	0.784	0.760	0.737	0.715	0.694
0.90:	0.976	0.953	0.930	0.908	0.887	0.865	0.845	0.825	0.805	0.786	0.767	0.749
1.00:	0.981	0.963	0.944	0.927	0.909	0.892	0.875	0.859	0.843	0.827	0.811	0.796
1.20:	0.988	0.976	0.965	0.954	0.942	0.931	0.920	0.909	0.898	0.888	0.877	0.867

Table 8. Amplitude shapes of melodic tones. Ratios modifying base values of $p_1$according to number of semitones to the next melodic tone (horizontal columns) and duration of the tone (vertical columns). For modifying the base values of p_2, recoprocal values apply (switch upper ald lower tables).

TCHAIKOWSKY: SYMPHONY NO 6, OP 74, 1ST MOV

Duration (sec) : 29.36
MM (100 pt tones/min): 110.00
Base P1, P2: 1.20 1.20

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	F5#	145	1600	1.18	0.90
2	E5	100	1300	1.12	0.95
3	D5	100	800	0.90	1.18
4	A4	120	1100	1.09	0.99
5	F4#	97	800	0.96	1.11
6	D4	94	500	1.78	0.60
7	F4#	120	650	1.76	0.61
8	B4	370	2000	1.29	0.83
9	A4	100	700	1.30	0.82
10	A4	500	500	1.32	0.81
11	A5	230	2400	1.25	0.85
12	G5	115	1600	1.22	0.87
13	F5#	100	1200	1.30	0.82
14	F5#	230	1600	1.25	0.85
15	E5	230	950	1.38	0.77
16	G5	230	1450	1.27	0.84
17	F5#	115	1000	1.15	0.93
18	E5	92	700	1.30	0.82
19	E5	230	1400	1.25	0.85
20	D5	240	750	1.30	0.82
21	R	127	0	0.00	0.00
22	F5#	155	3300	1.19	0.89
23	E5	110	1900	1.14	0.94
24	D5	110	1300	0.93	1.14
25	A4	140	1400	1.12	0.95
26	F4#	110	900	1.00	1.07
27	D4	110	700	1.70	0.63
28	F4#	112	900	1.80	0.59
29	B4	405	2550	1.29	0.63
30	A4	125	950	1.30	0.82
31	A4	320	700	1.00	1.00

Table 9. For explanations see legend of Table 3.

BACH: CHORAL "WACHET AUF" FROM CANTATA 140

Duration (sec) : 7.92
MM (100 pt tones/min): 232.00
Base P1, P2: 1.20 0.00

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	D5	200(182)	730	1.15	0.85
2	D5	400	1600	1.17	0.82
3	C5	100	970	1.08	0.89
4	B4	100	900	0.98	0.98
5	A4	100	730	0.98	0.98
6	G4	100	600	1.47	0.65
7	A4	100	910	0.98	0.98
8	G4	100	750	1.08	0.89
9	F4#	100	620	0.98	0.98
10	E4	100	480	0.98	0.98
11	D4	202	380	1.33	0.72
12	E4	100	400	1.47	0.65
13	F4#	100	360	1.33	0.72
14	G4	102	870	1.47	0.65
15	A4	100	700	1.47	0.65
16	B4	100	900	0.98	0.98
17	A4	100	680	1.63	0.59
18	C5	102	1000	1.08	0.88
19	B4	100	670	0.98	0.98
20	A4	100	600	0.98	0.98
21	G4	110	500	1.76	0.55
22	B4	215	990	1.09	0.88
23	A4	230	310	1.00	1.90

Table 10. For explanations see legend of Table 3. In this example, a DC component is introduced gradually, through a ramp function, in order to obtain a high legato; it is also removed by a ramp function.

BEETHOVEN: VIOLIN CONCERTO OP 61 1ST MOVT

Duration (sec) : 22.38
MM (100 pt tones/min): 168.00
Base P1, P2: 0.00 0.00

T#	NOTE	DUR (PTS)	AMPL	F1	F2
1	F4#	215	1000	1.14	0.91
			100	1.00	0.00
2	G4	193	720	1.21	0.85
			100	0.00	0.00
3	A4	205	980	1.20	0.86
			100	0.00	0.00
4	B4	107	900	1.31	0.79
			100	0.00	0.00
5	C5#	100	1200	1.20	0.86
			100	0.00	0.00
6	D5	430	2400	1.03	1.01
			100	0.00	0.00
7	A4	380	510	1.09	0.95
7			100	0.00	1.00
P	-	30	0	0.00	0.00
8	G4	210	900	1.04	1.00
			100	0.00	0.00
9	F4#	190	720	0.98	1.06
			100	0.00	0.00
10	E4	200	1100	1.21	0.86
			100	0.00	0.00
11	F4#	105	700	0.75	1.39
			100	0.00	0.00
12	D4	98	450	1.33	0.78
			100	0.00	1.00
13	E4	410	1335	1.00	1.04
14	A3	400	700	1.09	0.95
P	-	25	0	0.00	0.00
15	F4#	210	1000	1.14	0.91
			100	1.00	0.00
16	G4	192	700	1.21	0.85
			100	0.00	0.00
17	A4	203	1010	1.20	0.86
			100	0.00	0.00
18	B4	108	1000	1.31	0.79
			100	0.00	0.00
19	C5#	100	1250	1.20	0.86
			100	0.00	0.00
20	D5	440	2350	1.03	1.00
			100	0.00	0.00
21	A4	380	780	1.09	0.95
			100	0.00	1.00
P	-	25	0	1.50	0.69
22	B4	210	1050	0.90	1.15
23	G4	190	950	0.93	1.12
24	E4	230	880	1.34	0.77
25	A4	260	730	0.86	1.21
26	D4	420	390	0.70	1.05

Table 11. For explanations see legend of Table 3.

BEETHOVEN: PIANO CONCERTO NO 1 1ST MOVT

Duration (sec) : 6.52
MM (100 pt tones/min): 259.00
Base P1, P2: 1.18 0.82

T#	NOTE	DUR (PTS)	AMPL	F1	F2
1	D5	402	1000	1.15	0.84
2	C5#	106	1000	1.32	0.73
3	D5	89	390	1.51	0.64
4	E5	96	830	0.93	1.04
5	D5	111	810	1.18	0.82
6	D5	106	1000	0.94	1.03
7	C5	89	390	1.04	0.93
8	B4	96	830	0.93	1.04
9	A4	111	810	0.95	1.02
10	G4	106	850	1.05	0.92
11	F4#	89	333	0.92	1.05
12	E4	96	707	0.93	1.04
13	D4	111(87)	659	1.18	0.82
14	G4	106	1000	1.18	0.82
15	R	89	0	0.00	0.00
16	G4	96	831	1.18	0.82
17	R	111	0	0.00	0.00
18	A4,G4	24,82	1000	1.05	0.92
19	F4#	89	391	1.33	0.73
20	G4	96	831	1.90	0.51
21	B4	104	811	0.84	1.15
P	-	7	0	0.00	0.00
22	G4#	195	1000	1.26	0.77
23	A4	207	291	1.00	1.30

Table 12. For explanations see legend of Table 3.

BEETHOVEN: PIANO CONCERTO NO 3 1ST MOVT

Duration (sec) : 8.40
MM (100 pt tones/min): 215.00
Base P1, P2: 1.15 0.85

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	E5	402	1000	1.12	0.87
2	D5	106	1300	1.40	0.70
3	E5	89	507	1.29	0.76
4	F5	96	1079	0.84	1.17
5	D5	102	1053	0.94	1.04
P	-	9	0	0.00	0.00
6	C5	402	920	1.07	0.91
7	G4	291	418	1.33	0.73
8	C5	98	730	1.42	0.69
P	-	13	0	0.00	0.00
9	D5	195(179)	920	1.15	0.85
10	D5	207(191)	769	1.15	0.85
11	D5	195(179)	1270	1.22	0.80
12	D5#	207(191)	1215	1.15	0.85
13	D5#	402	1030	1.17	0.84
14	E5	195	375	1.10	1.15

1 pulse considered to be 1 half note

Table 13. For explanations see legend of Table 3. One pulse is considered to be one half note.

BEETHOVEN: NINTH SYMPHONY, OP 125, SCHERZO

Duration (sec) : 4.57
MM (100 pt tones/min): 320.00
Base P1, P2: 1.15 0.85

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	A4	159	2000	0.36	2.74
2	A3	43	401	1.15	0.85
3	A3	108	603	2.12	0.46
P		24	0	0.00	0.00
4	B4	106(85)	1000	1.51	0.65
5	E4	87(70)	458	1.33	0.73
6	F4	108(86)	747	1.00	0.97
7	E4	106(85)	1000	1.32	0.74
8	F4	87(70)	458	1.54	0.64
9	G4	108(86)	747	0.88	1.11
10	F4	106(85)	1000	1.00	0.97
11	E4	87(70)	458	0.86	1.14
12	D4	108(86)	747	1.01	0.98
13	B4b	106(85)	1000	1.00	0.97
14	A4	87(70)	458	0.86	1.14
15	G4	108(86)	747	0.88	1.11
16	F4	106(85)	1000	1.00	0.97
17	E4	87(70)	458	0.86	1.14
18	D4	108(86)	747	1.00	0.97
19	C4#	106(85)	1000	1.32	0.74
20	D4	87(70)	458	1.54	0.64
21	E4	108(86)	747	0.88	1.11
22	D4	106(85)	1000	1.00	0.97
23	C4#	87(70)	458	1.33	0.73
24	D4	108	747	1.00	1.00

1 pulse considered to be 1 bar

Table 14. For explanations see legend of Table 3. One pulse is considered to be one bar.

MOZART: HAFFNER SYMPHONY K385 2ND MOVEMENT

Duration (sec) : 15.36
MM (100 pt tones/min): 250.00
Base P1, P2: 0.90 1.10

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	F4#	210	1400	1.24	0.80
2	A4	190(95)	232	1.91	0.52
3	D5	210(105)	667	0.90	1.10
4	D5	190(95)	305	0.90	1.10
5	D5	400(135)	944	0.90	1.10
6	RRR	400	0	0.00	0.00
7	C5#	210	1284	1.24	0.80
8	E5	190(95)	298	1.42	0.70
9	G5	210(103)	808	0.90	1.10
10	G5	190(95)	371	0.90	1.10
11	G5	400(138)	1146	0.90	1.10
12	RRR	400	0	0.00	0.00
13	F5#	210	2447	1.00	0.99
14	G5	190(95)	535	1.22	0.81
15	A5	210(105)	1402	0.90	1.10
16	A5	190(95)	646	0.67	1.49
17	G5	210	1146	0.81	1.22
18	F5#	190(95)	231	0.67	1.49
19	E5	210(105)	517	0.67	1.47
20	D5	190(95)	220	0.90	1.10
21	D5	210	1221	0.81	1.22
22	C5#	190(95)	267	0.67	1.49
23	B4	210(105)	599	0.67	1.47
24	A4	190(95)	256	0.90	1.10
25	A4	210	693	0.73	1.36
26	G4	190(95)	135	0.77	1.28
27	F4#	210(105)	321	0.67	1.47
28	E4	190(95)	139	1.00	1.00

1 pulse considered to be 1 eighth note

Table 15. For explanations see legend of Table 3. One pulse is considered to be one eighth note.

MOZART: JUPITER SYMPHONY K551 3RD MOVEMENT

Duration (sec) : 10.49
MM (100 pt tones/min): 138.00
Base P1, P2: 1.03 1.05

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	G5	213	1271	0.98	1.11
2	F5#	97	967	0.93	1.16
3	F5	97	1115	0.94	1.15
4	E5	98	297	0.84	1.28
5	D5	98	277	0.84	1.28
6	C5	107(55)	558	0.91	1.19
7	B4	107(55)	140	1.18	0.92
8	C5	97(51)	211	1.70	0.64
9	E5	194	1000	0.93	1.17
10	D5	98(88)	241	1.03	1.05
P	-	18	0	0.00	0.00
11	A5	213	1497	0.93	1.17
12	G5	97	481	0.93	1.16
13	F5#	97	1238	0.94	1.15
14	F5	98	330	0.93	1.16
15	E5	98	352	0.84	1.28
16	D5	107(95)	732	0.80	1.36
17	C5	107(95)	165	1.34	0.80
18	D5	97(67)	277	1.50	0.72
P	-	20	0	0.00	0.00
19	F5	194	1115	0.98	1.11
20	E5	98(78)	269	1.00	1.00

1 pulse considered to be 1 bar

Table 16. For explanations see legend of Table 3. One pulse is considered to be one bar.

MOZART: QUINTET IN G MINOR, 1ST MOVEMENT *

Duration (sec) : 8.41
MM (100 pt tones/min): 221.00
Base P1, P2: 1.03 1.05

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	D4	95(76)	186	1.91	0.57
2	G4	105	910	1.40	0.77
3	B4b	95	218	1.59	0.68
4	D5	105(70)	644	1.03	1.05
5	D5	95(67)	292	1.03	1.05
6	D5	200	850	1.03	1.05
7	R	105	0	0.00	0.00
8	G5	95	374	1.03	1.05
9	G5	105	1618	0.93	1.16
10	F5#	95	322	0.92	1.17
11	F5	105(70)	747	1.03	1.05
12	F5	95(67)	338	0.90	1.20
13	E5	200	540	1.03	1.05
14	R	105	0	0.00	0.00
15	E5b	95	306	1.03	1.05
16	E5b	105	1300	0.93	1.16
17	D5	95	264	1.03	1.05
18	D5	105	644	1.14	0.95
19	E5b	95	306	1.03	1.05
20	E5b	105	670	0.93	1.16
21	D5	95	264	1.03	1.05
22	D5	105	467	0.84	1.29
23	C5	95	189	1.03	1.05
24	C5	200	300	0.92	1.17
25	B4b,C,Bb	50,52,51	232	0.96	1.13
26	A4,Bb	23,25	93	1.03	1.05
27	A4	200	160	0.88	1.12

* 1 pulse considered to be 1 half note

Table 17. For explanations see legend of Table 3. One pulse is considered to be one half note.

SCHUBERT: SONG FRUEHLINGSGLAUBE D686

Duration (sec) : 13.49
MM (100 pt tones/min): 143.00
Base P1, P2: 1.11 0.82

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	C5	91(81)	720	1.11	0.82
2	C5	103	1637	1.70	0.63
3	E5b	112	1350	0.92	1.02
4	D5b	99	741	1.00	0.91
5	C5	91(88)	1274	1.11	0.32
6	C5	210	1637	1.01	0.95
7	B4b	190	505	0.75	1.21
8	E4b	98	573	1.86	0.49
9	A4b	112	655	1.01	0.90
10	G4	99	353	1.23	0.74
11	A4b	95	695	0.95	0.65
P	-	3	0	0.00	0.00
12	B4b	270	980	1.37	0.91
P	-	53	0	0.0	0.00
13	B4b	91	750	1.11	0.82
14	B4b	309	1272	1.20	0.82
15	B4b	91	989	1.38	0.66
16	C6	309	1837	1.25	0.32
17	C5	91(87)	1274	1.24	0.74
18	D5b	210	2080	1.35	0.67
19	F5	227(217)	1302	1.10	1.08
20	D5b	103	875	1.00	0.81
21	C5	112	670	0.92	0.99
P	-	8	0	0.00	0.00
22	B4b	96	165	0.90	0.98
23	A4b	95(88)	385	1.10	0.82
24	A4b	309	850	1.13	0.82
P	-	24	0.	0.00	0.00
25	A4b	106(100)	570	1.00	0.91
26	G4	102	595	1.60	0.95
27	E5b	240	760	1.40	1.45
28	G4	96	343	1.24	0.74
29	A4b	400	255	0.85	1.80

Table 18. For explanations see legend of Table 3. One pulse is considered to be one quarter note.

SCHUBERT: TRIO IN Bb, 1ST MOV, 2ND SUBJ

Duration (sec) : 9.97
MM (100 pt tones/min): 188.00
Base P1, P2: 1.20 0.90

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	D5	403	1282	1.10	0.98
2	F4	213	700	1.73	0.63
3	D5	190	696	1.26	0.86
4	E5b	425	1805	2.95	2.32
5	F4	213	920	1.80	0.60
6	E5b	205	875	1.15	0.94
7	D5	213	1282	1.20	0.90
8	D5	230	1033	1.40	0.90
9	D5	98	220	1.60	0.68
10	F5	115	758	1.01	1.07
11	E5b	99	538	0.90	1.20
12	C5	91	830	0.98	1.10
13	B4b	403	950	1.19	0.91
14	A4	225	250	1.10	1.40

1 pulse considered to be 1 half note

Table 19. For explanations see legend of Table 3. One pulse is considered to be one half note.

SCHUBERT: SONATA IN A MAJ (POSTH) 4TH MOVT

Duration (sec) : 16.70
MM (100 pt tones/min): 231.00
Base P1, P2: 1.00 1.00

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	C4#	220(194)	1000	1.18	0.85
2	E4	400	445	1.07	0.93
3	A4	190	541	1.00	1.00
4	A4	210	1357	0.95	1.05
5	G4#	190(171)	518	1.07	0.94
6	A4	400	1142	1.03	0.97
7	B4	309	1472	1.00	1.00
8	B4	91	1176	1.24	0.80
9	C5#	219	1602	0.82	1.22
10	A4	190	540	1.00	1.00
11	A4	400	1350	0.99	1.01
12	G4#	98	516	0.81	1.23
13	F4#	112	333	0.83	1.21
14	E4	99	175	0.81	1.23
15	D4	91	328	0.90	1.11
16	C4#	210(185)	900	1.19	0.84
17	E4	400	445	1.07	0.93
18	A4	190	541	1.00	1.00
19	A4	210	1357	0.95	1.05
20	G4#	190(171)	518	1.07	0.94
21	A4	400	1142	1.03	1.28
P	-	20	0	0.00	0.00
22	B4	219	1472	1.10	0.91
23	C5#	99	638	1.11	0.90
24	D5	91	1337	0.90	1.11
25	C5#	219	1602	0.91	1.10
26	B4	190	596	1.00	1.00
27	B4	400	793	0.97	1.03
28	A4	400(350)	223	1.00	1.30

Table 20. For explanations see legend of Table 3. One pulse is considered to be one half note.

BEETHOVEN: OP 31 NO 3, 3RD MOVEMENT

Duration (sec) : 19.31
MM (100 pt tones/min): 156.00
Base P1, P2: 1.20 0.80

T#	NOTE	DUR (PTS)	AMPL	P1	P2
1	B3b	168	799	1.66	0.50
2	E4b	58	799	1.20	0.80
3	E4b	392	1000	1.27	0.76
4	G4	158	799	0.91	1.05
5	E4b	58	799	1.20	0.80
6	E4b	214	1000	1.14	0.84
7	D4	236	400	1.24	0.78
P	-	12	0	0.00	0.00
9	E4b	108	799	1.46	0.66
9	F4	293	1000	1.26	0.76
P	-	10	0	0.00	0.00
10	G4	99	399	1.34	0.72
11	A4b	108	799	1.46	0.66
12	B4b	108	799	0.99	0.97
13	A4b	214	1000	1.14	0.84
14	G4	199	320	1.10	1.50
P	-	20	0	0.00	0.00
15	G4	158	800	1.29	0.75
16	A4b	58	640	1.57	0.61
17	B4b	303	800	1.11	0.87
18	G4	110	380	2.08	0.46
19	C5	109	773	0.81	1.18
20	A4b	115	880	1.46	0.66
21	B4b	303	1150	1.23	0.78
P	-	12	0	0.00	0.00
22	B4	89	670	1.34	0.72
P	-	4	0	0.00	0.00
23	C5	135	1200	1.26	1.52
24	B4b	110	1250	1.20	0.80
P	-	28	0	0.00	0.00
25	B4b	115	360	0.99	0.97
26	A4b	198	265	1.02	0.94
P	-	16	0	0.00	0.00
27	F4	89	195	1.50	0.64
28	G4	106	393	1.61	0.60
29	B4b	52	314	0.91	1.06
30	A4b	58	393	1.05	0.92
31	G4	214	493	1.09	0.88
32	F4	169	146	1.00	1.00

Table 21. For explanations see legend of Table 3. One pulse is considered to be one quarter note.

<u>Lists of the sound examples in the grammophone records</u>

RECORD MAK 832, Side A:

Sound examples of Bengtsson & Gabrielsson: "Analysis and synthesis of musical rhythm":

Sound example 1. Three different versions of a theme by Mozart (see text for explanations)

Sound example 2. Nine different versions of Swedish folk melody ("Vårvindar friska")

Sound example 3. Successive construction of Vienna Waltz
Sound example 4. Different combinations of lengthening and shortening in an accompaniment

Sound example 5. Flat version of the Bat waltz
Sound example 6. Synthesized version of the Bat waltz
Sound example 7. Two bars from a real performance of the Bat waltz, first at normal tempo, then played at 1/4 of normal tape speed.

RECORD MAK 832, Side B:

Sound examples of Sundberg, Fryden & Askenfelt: "What tells you the player is musical?"

Sound example 1. Rule 1: The higher, the louder.
- a) without any rules
- b) with exaggeration of the rule
- c) with the rule according to the text

(G F Händel: Sonata E major for violin and continuo, op. 1:15)

Sound example 2. Rule 2: Sharpening of durational contrast
- a) without any rules
- b) with exaggeration of the rule
- c) with the rule according to the text

(C M Bellman: "Vila vid denna källa", Nr 82 in Fredmans epistlar)

Sound example 3. Rule 3: Acelerando in upwards motion of melody
- a) without any rules
- b) with exaggeration of the rule
- c) with the rule according to the text

(W A Mozart: <u>Alla turca</u> from Sonate fuer Klavier A major, K 331)

Sound example 4. Rule 4: Lengthening of target notes in leaps
- a) with exaggeration of the rule
- b) with the rule according to the text

(G F Händel: Sonata E major for violin and continuo, op. 1:15)

Sound example 5. Rule 5: Micropauses in melodic leaps
a) without any rules
b) with exaggeration of the rule
c) with the rule according to the text
(J S Bach: Sarabande from Suite c minor for cello solo, BWV 1011)

Sound example 6. Rule 6: Accents marking certain durational contrasts
a) with exaggeration of the rule
b) with the rule according to the text
(C. M. Bellman: "Vila vid denna källa", Nr 82 in Fredmans epistlar)

Sound example 7. Rule 7: Amplitude smoothing
a) without any rules
b) with the rule according to the text
(J S Bach: Theme of the first Kyrie of the b-minor Mass)

Sound example 8. Rule 8: Tuning of scale tones
a) without any rules
b) with exaggeration of the rule
c) with the rule according to the text

Sound example 9. Rule 9: Marking of harmonic progression
a) without any rules
b)with exaggeration of the rule marking harmonic distance by means of amplitude changes
c) with exaggeration of the rule marking tonic distance by means of amplitude changes
d) with exaggeration of the rule marking chord changes by lengthening of the first note after the change
e) Summed effects of harmony markers

10. Rule 10: Final lengthening
a) without any rules
b) with exaggeration of the rule
c) with the rule according to the text
(A Tegnér: "Ekorrn satt i granen", Nursery tune from Sjung med oss, Mamma, Vol. I)

11. Summed effect of all rules
(F. Schubert: Theme from 8th Symphony, Uncompleted, first movement

12. Rules or random? Melody played
a) without any performance rules
b) with performance rules 1 - 7
c) with performance rules 1 - 7 in randomized quantity each time the individual rule is applied
(J S Bach: Bourree from Suite C Major for cello solo, BWV 1009)

RECORD MAK 833, Side A:

Sound examples of Clynes: "Expressive microstructure in music, linked to living qualities".

The music example were performed in real time by the computer. Deliberately no timbral complexity has been included in the computer sound; only sinusoidal carrier tones, amplitude modulated, are used. Thus, the sound has a rather flute-like sonority. What is of importance here, however, is the expressive quality - the microstructure-

Examples of Group I (pertaining to Section III B)

In the first group of five examples each tone is shaped according to artistic judgement, entering parameter values for the amplitude shapes and for the timing of individual tones, involving a process of sculpting for several days on each melody, working like a sculptor in time until one has obtained the right shape for each tone, judged by repeated listening.

Sound example I:1, W. A. Mozart, Quintet in g minor
- a) played twice by the computer
- b) performed by the Pro Arte Quintet (COLH 42 Angel, Great recordings of the Century)

Four versions are now illustrated to show the increasing expressiveness as each new factor is added.
- c) flat version, without expressiveness
- d) with varying amplitude sizes
- e) with varying amplitude shapes also
- f) including time deviations

Sound example I:2, F Schubert, Fifth symphony
- a) played twice by the computer
- b) conducted by Karajan (Berlin Phil., EMI:ASD 3860 stereo/quadrophonic)
- c)conducted by Karl Boehm (Wiener POhil., Detsche Grammophon stereo 2531 373)

Four versions or stages of sound example I:2:
- d) the flat version
- e) with varying amplitude sizes only
- e) also with varying amplitude shapes
- f) including time deviations

Sound example I:3, F. Chopin, Ballade in A flat, Op. 47
- a) by computer (twice)
- b) played by Artur Rubinstein (RCA Red Seal L 16285)
- c) by computer

Sound example I:4, L van Beethoven, Violin Concerto, Op. 61, third movement
- a) by computer (twice)
- b) by David Oistrach (Columbia, SAXO - 2315)
- c) by Jasha Heifetz (RCA LCT 1010)
- d) by Yehudi Menuhin (EMI 2 C 051 - 01570)
- e) by Fritz Kreisler (Beril Staatsoper, conductor Leo Blech - 1926)
- f) by Wolfgang Schneiderhahn (Deutsche Grammophon Gesellschaft LPM 18 099)
- g) by computer

Sound example I:4, L. van Beethoven, Symphony No. 9, Op. 125, third movement
- a) by computer (twice)
- b) conducted by Arturo Toscanini (NBC Symph., RCA:AT -1014 Mono)
- c) conducted by Wilhelm Furtwängler (Wiener Phil., EMI Mono RLS727 HLM 7135, 7136)
- e) by computer

RECORD MAK 833, Side B:

Examples of Group II (pertaining to Section III C)

In the following three examples performed by the computer, the individual tone amplitude shapes are now calculated entirely by the computer derived from the structure of the melody, the slope of the pitch contour, following the formula given in Section III C.

Sound example II:1. P Tchaikowski, Symphony No. 6,
Sound example II:2. J S Bach, Choral from Cantata No. 140 "Wachet auf", played twice
Sound example II:3. L van Beethoven, Violin Concerto, Op. 61, first movement, played twice

Examples of Group III (pertaining to Section III E)

In the following 10 examples performed by the computer, the computer also utilises the composer's specific pulse forms, as given by the matrix in Sewction II D, to predict, in about one minute for each example - or even in real time if one wishes - the required modification of amplitude sizes and of timing of the individual tones, as well as calculating individual tone amplitude shapes as it did in Group II. Thus, a large part of the microstructure essential for expressiveness is predicted.

Sound example III:1 L van Beethoven, Piano Concerto No. 1, Op. 15, first movement, played twice

Sound example III:2 L van Beethoven, Piano Concerto No. 3, Op. 37, first movement

Sound example III:3 L van Beethoven, Symphony No. 9, Op. 125, Scherzo, played twice

Sound example III:4 W A Mozart, "Haffner" Symphony, K385, second movement, played twice

Sound example III:5. W A Mozart, "Jupiter" Symphony, K551, third movement,

Sound example III E:6, W A Mozart, g minor quintet, the same music as illustrated, in a different version, in sound example I:1

Sound example III E:7, F. Schubert's song "Fruhlingsglaube"

Sound example III E:8, F. Schubert, Trio in B flat

a) played by computer

b) as played by Pablo Casals from the recording with Schneider and Istomin (Columbia ML 4715/SL 183 SL 185)

Sound example III E:9, F. Schubert, Piano Sonata in A

Sound example III E:10, Minuet from Beethoven's Piano Sonata Op. 31 No. 3

a) played twice by the computer

b) played with the Mozart pulse and also with some notes altered, as one possibility more befitting the Mozart pulse

Sound example III E:11, F. Schubert's song "Fruhlingsglaube" (showing computer evolution of expressive qualities)

a) played flat

b) with the Schubert pulse only (wrong pulse)

c) with the Mozart pulse only (wrong pulse)

d) with the Schubert and individual amplitude shapes as predicted by formula

e) final version including also crescendo - diminuendo as a function of pitch, and micropauses.