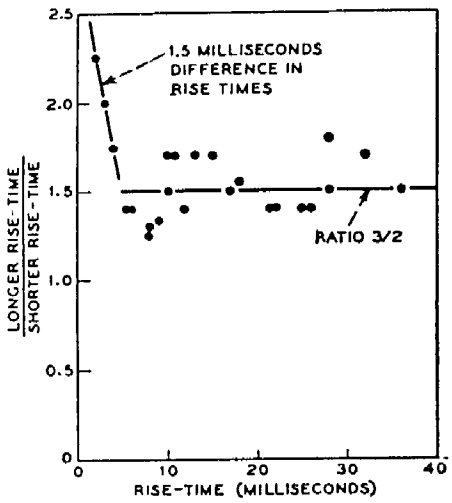

Fig. 4. Ratios of two rise times that are just discriminable (discriminable 75 percent of the time) as a function of the shorter of the two rise times. For times greater than 5 milliseconds, the ratio of discriminability is about 3/2. For times shorter than about 5 milliseconds, the ratio corresponds to a difference of 1.5 milliseconds in rise times.

the instrument-unit, almost any sound effect can be produced, provided the wave form of the sound can be described.

It is very easy to use the computer in this way. The electronic equipment (computer and output equipment) has been constructed once and for all. There are no soldering irons, tape-splicings, or even knob-twistings involved, as there are with other electronic equipment for producing music. No manual dexterity is required. Instead, one writes down and gives the computer a sequence of numbers.

The computer has proved to be of more use to the composer who wishes to produce new compositions with new sounds than to the performer who wishes to duplicate existing music. It is difficult and expensive to copy all the acoustic details of conventional instruments well enough to produce excellent instrumental sounds. Hence, the playing of pieces already written for existing instruments seems better left to the instrumental performer.

The most apparent limitation in the field of computer music results from lack of adequate knowledge of the sound of a given pressure wave. The computer sounds are described in terms of the waveshapes produced by the unit generators in the instrument-units. This method for describing sound is quite different from the method of ordinary music, in which the sound is specified by the instrument which produces it, when certain instructions have been received by the performer. Musicians have had a great deal of experience in listening to the sounds produced by violins, oboes, horns, and other instruments and are well able to predict the contribution of these instruments to the total sound. By comparison, computer musicians have had very little experience in trying to predict the effect of a given harmonic-composition factor or a given attack-and-decay function on the timbre of a note.

An example of a psychoacoustic surprise is the dominance of the rates of attack and decay in determining the character of a sound. These rates are a much more significant factor than the harmonic composition. Thus, a "violin," if artificially given the attack-and-decay characteristic of a piano, sounds much more like a piano than a "piano" does when it is given the attack-and-decay characteristic of a violin.

Another unexpected result is the importance of suitable random variations in almost all parameters of a note for introducing richness and interest. A sound which is otherwise quite plain can be greatly improved by introducing a random variation of up to 50 percent in its amplitude, at an average rate of something between 8 and 20 cycles per second, and by introducing a random variation of perhaps 1 percent in its frequency, at a similar rate.

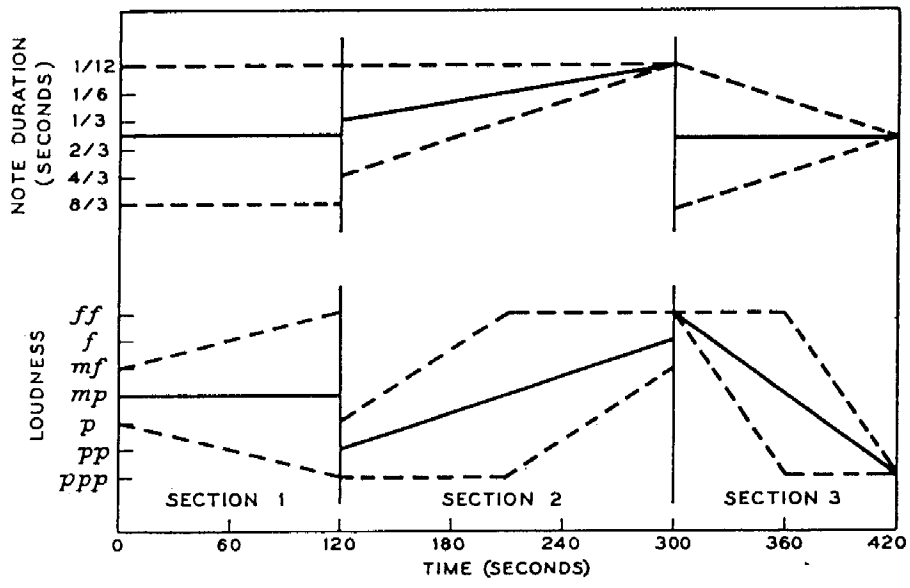

Fig. 5. Section of a score prepared for a study by J. C. Tenney. The average values for note-duration and loudness are shown by the solid lines as functions of playing time. The allowable range of variation of these parameters is shown by the dashed lines surrounding the solid lines.

Psychoacoustic Questions

Our musical studies with the computer indicate that, in this area, the major problem to be overcome by a composer concerns the relation of the physical description of the sound waves to the psychoacoustic effects which he desires. Contrary to the situation with conventional instruments, with the computer the composer himself is solely responsible for the sound. He has no conductor to interpret his composition. He himself must give careful consideration to even such a simple matter as the relative loudness of the instruments in a group.

Our experience has shown how little we now know about the relation of the quality of sound to various features of waveform. A new body of psychoacoustic data is necessary. These data should relate the properties of the acoustic waves of music to perceived qualities of sound. Part of the task of assembling these data can, of course, be given to the composer, and part of the data can be supplied by interested psychologists. An increase in knowledge in this field is bound to be of value and interest in other fields, including those of speech and hearing.

Typical of the sort of new knowledge that is needed is knowledge concerning the rate of attack of a note. As already noted, this parameter has a strong influence on the timbre, and if the composer is to make use of it he must know how small a change in rate is perceptible. Not being able to