
Expressive Microstructure in Music: A Preliminary Perceptual Assessment of Four Composers' "Pulses"

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According to a provocative theory set forth by Manfred Clynes, there are composer-specific cyclic patterns of (unnotated) musical microstructure that, when discovered and realized by a performer, help to give the music its characteristic expressive quality. Clynes, relying mainly on his own judgment as an experienced musician, has derived such personal "pulses" for several famous composers by imposing time and amplitude perturbations on computer-controlled performances of classical music and modifying them until they converged on some optimal expression. To conduct a preliminary test of the general music lover's appreciation of such "pulsed" performances, two sets of piano pieces by Beethoven, Haydn, Mozart, and Schubert, one in quadruple and the other in triple meter, were selected for this study. Each piece was synthesized with each composer's pulse and also without any pulse. These different versions were presented in random order to listeners of varying musical sophistication for preference judgments relative to the unpulsed version. There were reliable changes in listeners' pulse preferences across different composers' pieces, which affirms one essential prerequisite of Clynes' theory. Moreover, in several instances the "correct" pulse was preferred most, which suggests not only that these pulse patterns indeed capture composer-specific qualities, but also that listeners without extensive musical experience can appreciate them. In other cases, however, listeners' preferences were not as expected, and possible causes for these deviations are discussed.

Introduction

It is widely agreed that, in the performance of notated music, particularly Western art music from the eighteenth and nineteenth centuries, literal reproduction of the written score does not result in a very satisfying experience. The notation, in its rigid subdivision of note values and its lack of dynamic instructions for individual notes, omits many of the composer's intentions. To make the performance interesting, expressive, and musically satisfying, much variation not conveyed by the written score must be introduced by the performer. This variation may be relatively small (but nev-

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ertheless important) with respect to timing of note onsets, relative note durations, and pitch, where the score makes specific prescriptions; it may be much larger with respect to relative note intensities and other aspects of articulation, where the notation provides few constraints. All this variation constitutes the "expressive microstructure" (Clynes, 1983) of a performance. The principles musicians follow in generating this microstructure are not well understood and are only to a very limited degree made explicit in traditional music instruction. A great interpreter's skills may seem mysterious and beyond explanation. The psychology of musical expression is still in its infancy, but there is a rich lode waiting to be mined.

Performers' expressive devices may be divided roughly into four categories according to their origin and motivation:

(1) First, there are those variations that are contingent on local musical events, such as the structure of phrases, the shape of the melodic line, and the harmonic progression. These deviations emphasize structural properties and thus help realize some of the expressive potential inherent in a musical composition. They are relatively amenable to introspection, instruction, and scientific investigation, as they are likely to follow certain *general* rules that are observed, more or less, by all competent musicians. They also apply to a wide range of music by different composers. Progress toward understanding these rules has been made by several researchers (e.g., Bengtsson & Gabrielsson, 1980; Clynes, 1983; Gabrielsson, Bengtsson, & Gabrielsson, 1983; Shaffer, 1981; Shaffer, Clarke, & Todd, 1985; Sundberg, Frydén, & Askenfelt, 1983; Sundberg & Frydén, 1985; Todd, 1985).

(2) Second, there are those aspects of expressive microstructure that reflect a performer's understanding of a composer's individual characteristics as they are conveyed in his musical oeuvre as a whole. These aspects are much more elusive and difficult to investigate, because they seem to be the province of truly gifted interpreters whose performances have the "ring of authenticity." Nevertheless, one very intriguing attempt to understand these *composer-specific* principles of expressive microstructure has been made (Clynes, 1969, 1983, 1986, 1987).

(3) Third, there are those deviations that reflect an *individual performer's* style and, perhaps, mannerisms. It is these characteristics that shape distinctive interpretations and that enable the experienced listener to recognize certain artists from their performances. To a large extent, they may reflect the specific use a performer makes of the rules mentioned under (1) and (2), but there may also be genuinely personal patterns of expression. This is uncharted territory for the music psychologist.

(4) Finally, there are various *piece-specific* factors which may derive from notated dynamic instructions, performance conventions, explicit "programs," and also from instrumentalists' motoric limitations in executing difficult passages.

In general, therefore, the expressive microstructure of a musical performance reflects general, composer-specific, performer-specific, and piece-specific factors. The present investigation is concerned with only one of these factors, the composer-specific one, based on the theory of expressive microstructure developed by Clynes (1983, 1986).

The idea that different composers have different personalities that are conveyed in their music and that need to be understood and expressed by performers is very old, of course; it is part of the general lore of music history, performance, and criticism. Until recently, however, these composer-specific characteristics, especially as they go beyond the printed score, have eluded quantification. Extending the method of “accompanying movements” (*Begleitbewegungen*) developed by the German philologist Eduard Sievers (1924), the German musicologist Gustav Becking (1928) made an interesting, although still very rough and introspective, attempt at more precise description by observing his own movements as he conducted while listening (more precisely, as he “let himself be conducted by the music”). He found characteristic movement trajectories of his conducting index finger for music by different composers, which he interpreted as reflections of the composers’ personality and general attitude to the world. However, he did not relate these dynamic patterns to performance microstructure, which at the time was only beginning to be measured objectively (e.g., Hartmann, 1932; Seashore, 1938/1967). It remained for Manfred Clynes, a noted inventor, neuroscientist, and musician, to achieve a more precise quantification of these dynamic characteristics, thus making them amenable to scientific investigation.

Clynes’ initial step, some two decades ago, consisted in going from movement to pressure, using a pressure-sensitive recording device called the sentograph (Clynes, 1969). At that time, Clynes asked several prominent musicians (including Pablo Casals and Rudolf Serkin) to “conduct” by rhythmically pressing the sentograph with their finger about once a second while mentally rehearsing specific compositions of several different composers. The resulting periodic pressure curves were averaged to yield a single “pulse” shape for each musician and each composition. It emerged that these pulse shapes were remarkably similar across several different compositions (both slow and fast) by the same composer, and also across different musicians imagining the same piece. They were very different for different composers, however. These rather limited but striking observations confirmed Becking’s idea of composer-specific “pulses” that can be externalized as movement patterns.

The second important step taken by Clynes more recently was his investigation of how these pulses might be conveyed in the actual microstructure of music performance (Clynes, 1983, 1986, 1987). The central assumption underlying this effort is that composer-specific pulses are not restricted to

people's musical thought and accompanying movements, but that they can be *physically instantiated* in the musical sound pattern, with benefits for the listener. These pulses are defined as patterns of systematic deviations from the notated relative durations¹ and (usually unspecified, hence nominally equal) relative loudnesses of the notes within a time unit (e.g., one bar). Thus there are two independent components in each pulse pattern. According to Clynes' theory, the pattern applies throughout a composition; that is, it repeats itself in a cyclical fashion (e.g., bar by bar) from beginning to end. The motivation for this requirement lies in earlier ideas of Clynes (see Clynes & Walker, 1982) concerning "time form printing": Recurring time-amplitude patterns are assumed to set up expectancies in the central nervous system for the patterns to continue. The pulse, despite its rigid recurrence, is assumed to imbue music with "living qualities" that specifically reflect the composer's personality and that may also enhance the expressiveness of his characteristic melodic contours. Clynes (1983) has likened the pulse to such other individual motor characteristics as gait, handwriting, and speech. As a personal "style of movement," it is assumed to apply to all works of a composer.

Rather than measuring the time-amplitude patterns of actual performances by great artists, Clynes has developed composer-specific pulses by means of computer synthesis, relying mainly on his own judgment as an exceptionally sensitive musician. He has developed software² that enables him to enter a musical score into the computer and to specify a pattern of relative durations and intensities, which then determines the exact values of the notes within each time unit (chosen to coincide with a notated time unit close to 1 sec in duration). Depending on the time signature of the composition, the time units are divided into either three or four (sometimes two) subunits, with separate corresponding pulse patterns. Notes lasting longer than one subunit are assigned the sum of the component durations and the amplitude of the first component they occupy.³ The pulse is often also implemented at a second, higher level, with three or four time units as subunits. Thus, for example, in a fast piece in $\frac{3}{4}$ measure, the basic three-pulse would comprise one bar and the higher level plus (usually a four-pulse, reflecting the phrase structure) would comprise four bars. In a slower piece in $\frac{3}{4}$ measure, on the other hand, there would be a basic four-pulse for the

1. The term "duration" is used by Clynes, although it is meant to refer not to the time from the onset of a note to its offset (which depends on the degree of legato or staccato) but to the time from the onset of one note to the onset of the next note, or the *onset-to-onset interval* (OOI).

2. Part of a "Computerized System for Imparting an Expressive Microstructure to Succession of Notes in a Musical Score" that was awarded U.S. Patent No. 4,704,682 (November 3, 1987).

3. Shorter notes within a pulse beat are treated according to a pulse at that level (M. Clynes, personal communication).

sixteenth notes within each quarter note and a higher level three-pulse comprising one bar.

By experimenting with many different compositions and pulses and by carefully listening to the results (see Clynes, 1983), Clynes has arrived at what he considers appropriate pulse specifications for a number of famous composers. Four of these—the Beethoven, Haydn, Mozart, and Schubert pulses—are illustrated in Table 1, each in a quadruple-meter, a triple-meter, and (if used in the present study) a duple-meter version. In each pulse specification, the first line indicates the relative durations (in percentages) of successive notes (i.e., onset-to-onset intervals) of equal nominal durations, and the second line indicates their relative amplitudes (in linear proportions). The duration and amplitude components do not follow the same pattern; they are independent parameters. In the Beethoven four-pulse, for example, the rank order of the four beats is 4–1–3–2 in terms of duration, but 1–3–4–2 in terms of amplitude. The four-pulse, three-pulse, and two-pulse patterns for the same composer are related (see Clynes, 1987). For a detailed discussion of the characteristic features of these composers' four pulses and their interpretation in terms of dynamic qualities, see Clynes (1983, pp. 134–135).

Clynes' pulse patterns reflect the musical insight and extensive efforts of one individual; they quantify a subjective experience. It remains to be shown that the pulse patterns chosen generalize to other listeners; perhaps they require exceptional musical sensitivity to be appreciated at all, and perhaps they are entirely idiosyncratic. At public occasions and on recordings

TABLE 1
Pulse Specifications in Quadruple, Triple,
and Duple Meter for Four Composers

| Composer | Quadruple meter | | | | Triple meter | | | Duple meter | |
|-----------|-----------------|------|------|------|--------------|-------|------|-------------|------|
| Beethoven | 106 | 89 | 96 | 111 | 105 | 88 | 107 | (not used) | |
| | 1.00 | 0.39 | 0.83 | 0.81 | 1.00 | 0.46 | 0.75 | | |
| Haydn | 108 | 94 | 97 | 102 | 108 | 95 | 103 | 100 | 97 |
| | 1.00 | 0.42 | 0.68 | 1.11 | 1.03 | 0.35 | 0.60 | 1.00 | 0.65 |
| Mozart | 105 | 95 | 105 | 95 | 106.5 | 102.5 | 97.5 | 100 | 100 |
| | 1.00 | 0.21 | 0.51 | 0.23 | 0.78 | 0.25 | 0.30 | 1.00 | 0.51 |
| Schubert | 98 | 115 | 99 | 91 | 103 | 114 | 97.5 | (not used) | |
| | 1.00 | 0.65 | 0.40 | 0.75 | 0.92 | 0.45 | 0.72 | | |

NOTE. The first line indicates relative note durations (i.e., onset-to-onset intervals) in percent; the second line represents relative amplitudes on a linear scale. These pulses are the ones actually applied in the present materials (Clynes, pers. comm.); the triple-meter pulses differ from the preliminary specifications of Clynes (1983, 1986). Note that triple-meter timing pulses are not normalized, so that slight tempo changes result, and that all amplitude pulses result in various degrees of attenuation.

accompanying some of his publications (Clynes, 1983, 1985, 1987), Clynes has presented many examples of music synthesized with appropriate composers' pulses, although their impressions on listeners were never documented in a formal way. Some recent demonstrations (Clynes, 1987) have included the same piece synthesized with several different composers' pulses, including the "correct" one. In the fall of 1985, the author received such a demonstration tape from Clynes containing the final movement of a Haydn Piano Sonata synthesized with six different composers' pulses. A small informal group of listeners agreed that the "Haydn pulse" version indeed was the most pleasing of the lot, whereas several other versions were perceived as rhythmically irregular and/or inappropriately accented. That one set of time-amplitude irregularities sounded "normal" while others sounded uneven was an interesting experience; it suggested that even the average listener could appreciate the appropriate expressive microstructure. However, it could have been that the Haydn pulse was simply perceptually more regular than the others on psychoacoustic or general musical grounds. If so, it might also have been preferred if the piece had been by Mozart or Beethoven. For a rigorous test of the prediction that, for each of several composers' music, that composer's pulse should be perceived as more appropriate than any other composer's pulse, a set of balanced materials was required in which each composer's piece was performed with each composer's pulse. The author, not having the necessary synthesis capabilities at the time, approached Clynes, who agreed to generate two such sets of materials for the experiments described below.

The experiments tested the following five predictions:

(1) Listeners' preferences for individual pulses should vary as a function of composer. That is, with composer and pulse as orthogonal factors in the experimental design, a statistical interaction should be obtained. Conversely, the null hypothesis was that, although some pulses may be preferred over others, these preferences would hold regardless of composer. Rejection of the null hypothesis would support the general claim of Clynes' theory that different composers require different pulses.

(2) For each composer, listeners should prefer the "correct" pulse over all others. This hypothesis concerns the validity and generality of the specific pulse patterns devised by Clynes.

(3) Listeners should also prefer the correct pulse over a literal rendition of the score that has no pulse applied to it. Such "neutral" versions were included in the present materials. Clynes' theory admits the possibility that other pulses besides the correct one are preferred over a neutral version, but it seems essential that the correct pulse be perceived as an improvement over no pulse at all.

(4) The correct pulse should be preferred in all compositions by the same composer. This hypothesis, which concerns the generality of the pulses

across each composer's oeuvre, could be tested only to a very limited extent in the present experiments, because of the small sample of materials.⁴

(5) The degree to which listeners are able to appreciate the correct pulse and, more generally, expressive microstructure in music, may be a function of their musical training and experience with classical music. That is, the strongest support for Clynes' theory might come from the most sophisticated listeners, although the responses of less experienced subjects were also of interest in this study.

Experiment 1

Experiment 1 used a set of pieces with even ($\frac{2}{4}$) time signature, to which Clynes' four-pulses (and two-pulses) had been applied. The experiment was conducted in two versions, referred to as 1a and 1b. It was initially assumed that the performances with the "correct" pulse should be the most satisfying on general musical grounds; thus, the subjects in Experiment 1a were instructed to indicate simply how much they liked each version. It was later pointed out to the author by Clynes (personal communication) that the correct pulse may not always be the most pleasing one, especially to the less experienced listener; for example, the rough Beethoven pulse may be less pretty than the gentle Haydn pulse when applied to a Beethoven piece, but it nevertheless characterizes the composer better. Some data collected independently by Thompson (in press) with some of the same materials (the Beethoven piece) reinforced this point. Therefore, the experiment was repeated with modified instructions that emphasized composer-appropriate expression as the criterion for subjects' judgments (Experiment 1b). In addition, the quality of sound reproduction was improved in that experiment.

METHODS

Subjects

Experiment 1a

Sixteen unpaid volunteers (seven women and nine men, including the author) served as listeners.⁵ All were investigators or graduate students in psychology or related areas at Haskins Laboratories or Yale University, mostly 25–35 years old, although two were in

4. Nevertheless, the fact that the present materials (with one exception) had not been tried out previously with composers' pulses made these experiments a test of the generality of the pulses.

5. Although the author had made up the stimulus tapes and thus was the only subject to have heard the materials before, he had no recollection of the test order at the time of testing and had not yet learned to identify the individual pulse patterns.

their forties. Most of them had received a musical education, and the majority were active amateur musicians and/or spent much time listening to classical music. A few musically less experienced subjects were included to extend the range for purposes of correlational analyses. According to a questionnaire filled out by the subjects at the end of the experiment, they had had between 0 and 25 years (summed over all instruments) of formal instruction on various instruments (including piano, violin, cello, guitar, saxophone, and voice), spent between 0 and 23 hours a week playing their instruments, and listened to serious music 0 to 15 hours per week.

Experiment 1b

Thirteen different subjects participated here; their age and gender were not recorded. Four were faculty members at Trinity College (Hartford, CT); most of the others were undergraduate students enrolled in a music course there; one was a researcher at Haskins Laboratories. They included a professional pianist, a composer, an accomplished organist, several musical amateurs, and a few musically naive individuals. According to the questionnaire, they had had between 0 and 23 years of formal musical instruction, played their instruments from 0 to 14 hours per week, and listened to classical music between 0 and 45 (!) hours per week.

Materials

Four piano compositions, one each by Beethoven, Haydn, Mozart, and Schubert, were selected by the author. All were in $\frac{2}{4}$ time signature and had a fast tempo, except for the Schubert, which was both longer and slower than the other pieces. They were

Beethoven: last movement (Presto) of the Piano Sonata in F major, op. 10, No. 2 (complete, without repeats);

Haydn: last movement (Presto) of the Piano Sonata in F major, HV XVI/23 (complete, without repeats);

Mozart: exposition (i.e., the first part) of the last movement (Allegro) of the Piano Sonata in C major, K. 279 (without repeat);

Schubert: Moment Musical No. 4 (Moderato) in c-sharp minor, op. 94, D. 780 (complete, without repeats; the contrasting middle section is in D-flat major).

The initial bars of these pieces are shown in Figure 1.

All computer performances were generated by Manfred Clynes at the Music Research Institute of the New South Wales State Conservatorium of Music in Sydney, Australia, using his special software developed there. These computer realizations, in contrast to earlier recorded examples (e.g., Clynes, 1983), included all the notes, not just the melody. Each piece was recorded on cassette tape (with Dolby B noise reduction) in five versions: without any pulse (the "neutral" version) and with each of the four composers' pulses. The pulse patterns used are shown in Table 1. They were applied at two hierarchical levels, the lower (main) level comprising four sixteenth notes and the higher level comprising two or four quarter notes (i.e., one or two bars). In a number of instances, an "attenuation factor" was applied to the timing pattern at the higher level, which changed the depth of modulation while keeping the specified relationships constant.⁶ The pulses applied, together with these attenuation factors, are shown in Table 2. The choice of attenuation factors reflects Clynes' artistic judgment. In addition, a few manual adjustments (such as appropriate ritardandos and micro-

6. Because of these attenuation factors, the higher level pulses were not strictly the same across the different compositions. This methodological complication had to be ignored for purposes of analysis. It might also be noted that the basic pulse patterns for different composers (Table 1) are not equal with respect to average modulation depth.

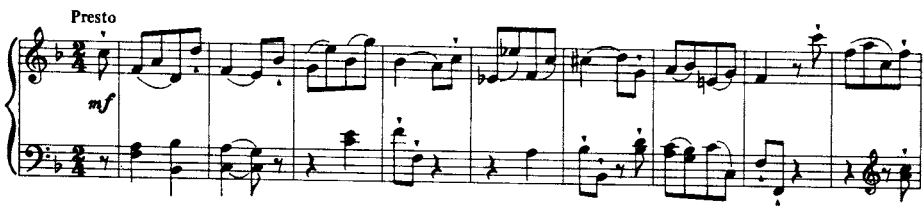
Beethoven

Presto



Haydn

Presto



Mozart

Allegro



Schubert

Moderato

legato

p

staccato



Fig. 1. Initial bars of the four pieces used in Experiment 1.

pauses) were made by Clynes to enhance the general musical quality of the performances; these were common to all versions, including the neutral one.

The Mozart and Schubert pieces were reproduced on a Roland MKS-20 piano sound module, the Beethoven on a Prophet 2000 synthesizer with an “early nineteenth century pianoforte” sound.⁷ Because the Haydn piece was already available on the demonstration tape mentioned in the introduction, it was not resynthesized by Clynes. Because computer-generated sinusoids were used in its synthesis, it had a more artificial sound quality; on the other hand, since it was free from the envelope constraints of a simulated piano, it included “predictive amplitude shaping” (see Clynes, 1983) of individual tones in all versions. Unfortunately, the demonstration tape did not include a “neutral” version of the Haydn, but versions with two other composers’ pulses instead; so the version with the Schumann pulse was substituted for the neutral version.

An experimental tape was generated by dubbing from the master tapes. The order of the four pieces was: Haydn, Mozart, Schubert, Beethoven. The five versions of each piece occurred in succession, separated by approximately 10 sec of silence. The first version was always the neutral version, and the four pulsed versions followed, in an order that was different for each piece and represented a 4×4 Latin square design.

Procedure

Experiment 1a

Some subjects were tested at Haskins Laboratories, others at Yale University. The subjects were seated in a quiet room and listened to the music over a single loudspeaker connected to a high-quality cassette deck (at Haskins) or over the stereo loudspeakers of a portable cassette recorder (at Yale). Each subject received detailed written instructions, including the following:

You will hear a number of short piano pieces reproduced by a synthesizer. Each of these pieces will be played in *five versions*. The first, “neutral” version will be an almost literal rendition of the score, with only a few essential deviations from the written notation. The four subsequent versions will include additional adjustments in the timing and relative loudness of the individual notes. Each version will follow a different pattern, and some versions may be more successful than others. That is, while some versions may sound *more lively, expressive, and idiomatic* than the neutral version, others may sound slightly distorted in rhythm and accent pattern. (One way of thinking about these versions is that they represent performances by four different pianists of equal technical competence but different musical sensibilities.) Your task will be to indicate whether or not each particular version constitutes an improvement over the neutral version.

Your judgments are to be made on an 11-point *rating scale* ranging from -5 to $+5$. The neutral version of any piece is identified with the midpoint (zero) on this scale, so you don’t have to give any rating after hearing this first version. For each of the following four versions, you should enter your rating of that version, circling *one* number on the rating scale. Please, make your judgment *relative to the neutral version*: Assign a positive rating if you *prefer* the version just heard over the neutral version (because it seems more lively, expressive, and idiomatic) and a negative rating if you prefer the neutral version over it (because it seems irregular, distorted, and unidiomatic).

7. The Mozart-pulse version of the Beethoven, however, was recorded in regular piano sound; this did not seem to affect listeners’ judgments. The other versions were also used by Thompson (in press, Exp. 3) and can be heard on the record accompanying Clynes (1987).

TABLE 2
 Hierarchical Pulse Patterns^a and Attenuation Factors for the Timing
 Pulses Used in Synthesizing the Pieces of Experiment 1^b

| Composer | Lower Level | Higher Level |
|-----------|------------------|-------------------|
| Beethoven | Four-pulse (1.1) | Four-pulse (0.6) |
| Haydn | Two-pulse (1.0) | Four-pulse (1.0) |
| Mozart | Two-pulse (1.0) | Four-pulse (1.0) |
| Schubert | Four-pulse (1.0) | Four-pulse (0.15) |

^aSee Table 1.

^bM. Clynes, personal communication.

The answer sheet illustrated the rating scale and listed the numbers -5 through $+5$ for each version, one of which the subjects were to circle. For the neutral version, the subjects were to indicate instead their familiarity with the piece by circling "very," "moderately," "barely," or "not at all." The composer of each piece was named on the answer sheet. The whole session lasted about one hour.

Experiment 1b

One possible concern with Experiment 1a (Clynes, personal communication) was that the sound reproduction equipment was not optimal; in particular, the portable recorder used at Yale did not have the Dolby B option, which distorted the amplitude profiles of the pulses. In Experiment 1b, the tapes were played with Dolby B noise reduction, either at Trinity College or on one subject's home stereo equipment. More importantly, there was a change in instructions, as follows:

While some versions may sound *expressive in a way that seems to befit the composer*, others may sound less convincing or even ridiculous. (. . .) Your task will be to indicate whether or not each particular version constitutes an improvement over the neutral version in that it captures some of the composer's characteristic expression—that is, whether each version sounds more or less "Beethovenian" or "Haydnian" or "Mozartian" or "Schubertian" than the neutral version.

RESULTS AND DISCUSSION

Experiment 1a

One initial question was whether the subjects would be able to make consistent judgments at all. Not only were they not professional musicians, but also musical tastes are often said to be highly variable and idiosyncratic. The statistical analysis dispelled these fears. In a repeated-measures analysis of variance (ANOVA) on the subjects' ratings with two crossed factors, composer and pulse, the main effect of pulse was highly significant [$F(3,45) = 10.09, p < .0001$], which indicates that there were consistent preferences for certain pulses over others. Moreover, and much more importantly,

there was a significant composer by pulse interaction [$F(9,135) = 4.43$, $p < .0001$]. Thus the pattern of pulse preferences varied reliably with composers (pieces), which supports the first of the five predictions made in the introduction. There was no significant main effect of composer.

The average ratings are represented in Table 3, with the italicized numbers in the diagonal representing the "correct" composer-pulse combinations. It is evident that in three of the four pieces (Haydn, Mozart, Schubert) the correct pulse was indeed the one preferred most, although in the Mozart piece the Mozart and Haydn pulses were tied. Moreover, in each of these three cases the correct pulse received positive ratings that clearly exceeded the neutral baseline (subjects tended to be conservative in their ratings, using mostly the range between -3 and $+3$), although this difference is not meaningful in the case of the Haydn piece, whose "neutral" version really had an inappropriate pulse in it. Only the Beethoven piece produced disappointing results. For it, the listeners clearly preferred the Haydn pulse (which perhaps can be explained by the somewhat Haydn-like quality of that movement—Clynes, personal communication), whereas the Beethoven pulse received a negative average rating. Thus, in three out of four cases the results provide support for Predictions 2 and 3, which concern the adequacy of the composers' pulses.

A look down the columns of Table 3 reveals that the Beethoven pulse was not liked much in any piece, whereas the Haydn pulse was liked in *all* compositions. Listeners' judgments of the Beethoven and Haydn pulses thus did not seem to vary much across compositions. This was confirmed by conducting an ANOVA on these two pulses only: The pulse main effect was highly significant [$F(1,15) = 28.73$, $p = .0001$], indicating that the Haydn pulse was preferred over the Beethoven pulse, but the composer by pulse interaction fell short of significance. Thus it could be argued that listeners' preference for the Haydn pulse in the Haydn piece was due to a general preference, not to composer-specific factors.

The situation was different for the Mozart and Schubert pulses, however. Although the Mozart pulse was tied with the Haydn pulse as the preferred

TABLE 3
Average Ratings of the Computer Performances in Experiment 1a

| Composer | Pulse | | | |
|-----------|-----------|-------|--------|----------|
| | Beethoven | Haydn | Mozart | Schubert |
| Beethoven | -1.13 | 2.25 | -1.13 | -0.13 |
| Haydn | 0.06 | 1.69 | 0.69 | -0.69 |
| Mozart | 0.38 | 1.56 | 1.56 | -0.75 |
| Schubert | -0.25 | 1.19 | -0.38 | 1.94 |

pulse for the Mozart piece, it was liked better in the Mozart than in any other piece. Even more strikingly, the Schubert pulse was liked *only* in the Schubert, being mildly disliked with all other composers. The reliability of this interaction was confirmed in an ANOVA on this half of the data: There were no significant main effects, but a significant composer by pulse interaction was obtained [$F(3,45) = 6.90, p = .0006$]. This part of the data, therefore, provides unequivocal support for Clynes' Mozart and Schubert pulse patterns, as well as for the present subjects' ability to appreciate them.

The data were analyzed in yet another way, by first averaging the ratings of the three incorrect pulses for each piece and then entering the data into a 4×2 ANOVA with composer and correct/incorrect pulse as factors. There was a significant main effect of pulse [$F(1,15) = 10.96, p = .0048$], which confirms that, overall, correct pulses received higher ratings than incorrect pulses. However, since this was not true in the Beethoven piece, there was also a highly significant composer by pulse interaction [$F(3,45) = 9.43, p = .001$]. In a separate analysis of the correct pulse ratings only, the grand mean was significantly larger than zero [$F(1,15) = 8.67, p = .0101$], which confirms that, overall, correct pulses were preferred over no pulse at all, again with the exception of the Beethoven, which resulted in a significant effect of composer [$F(3,45) = 8.64, p = .0001$].

Prediction 4 (generality of pulses) could not be addressed within the present experiment, since only a single piece of each composer was used. (However, see footnote 4.) Therefore, we turn to Prediction 5, concerning the role of subjects' musical experience. As pointed out earlier, the 16 subjects represented a rather wide range of musical experience, with only the professional level missing. For each subject, a measure of the degree to which he or she appreciated the correct pulses (a "pulse appreciation index" or PAI) was computed by subtracting the average rating of the 12 incorrect composer-pulse combinations from the average rating of the 4 correct combinations. (Thirteen of the 16 subjects had positive indices.) Three indices of musical experience were available: number of years of musical education, added up over all instruments studied; number of hours spent playing music per week; and number of hours spent listening passively to serious music. Correlations were computed between all three measures and the PAI. The first and third measures did not correlate at all with the PAI,⁸ whereas the second (active playing hours) showed a small positive correlation ($r = 0.36$) that, however, fell short of significance. Thus there

8. This was also true when years of musical education were computed for the dominant instrument only or for piano only. To illustrate some of the individual variability: The subject with the highest PAI (3.00) is an active amateur cellist; the person with the second-highest PAI (2.52) never had any music education; the person with the lowest PAI (-1.33) had the longest music education of all, although she no longer plays her instruments (piano and violin).

was only a hint that listeners with greater *active* musical experience might show greater appreciation for composers' pulses.

Two subsidiary questions were addressed in similar correlational analyses. First, it was noted that some subjects gave mostly positive ratings, while others gave mostly negative ratings. A subject's overall average rating is an indirect measure of the extent to which he or she liked the neutral version, relative to the pulsed versions. The correlations between subjects' average ratings and the three measures of musical experience were mildly negative and nonsignificant. If musically more experienced subjects liked the neutral version somewhat more than did musically inexperienced subjects, a reason for this may have been that the more sophisticated subjects expected too much from the pulsed versions as "performances." This point will be taken up in the general discussion. Second, a familiarity index was computed for each subject by averaging his or her familiarity ratings for the four pieces (very = 3, moderately = 2, barely = 1, not at all = 0). On the whole, the subjects were not very familiar with the pieces: Twelve subjects had average ratings of 1 or less, and only two subjects (the author being one) were at least moderately familiar with all of them. No piece was much more familiar than the others. The correlation between the familiarity index and the PAI was -0.06 , indicating that familiarity did not increase the appreciation of the correct pulses.

Experiment 1b

Experiment 1b, it will be recalled, presented the same test to a comparable group of subjects with new instructions that emphasized composer-specific expression, and with Dolby B sound reproduction. It is clear from Table 4, however, that these combined changes did not lead to results that were more favorable to Clynes' theory—on the contrary. In the Beethoven piece, the Beethoven pulse was disliked even more than previously, in striking contrast to findings of Thompson (in press), which showed a preference for the Beethoven pulse in the very same materials under similar instructions. (The reason for this discrepancy is not clear.) The Haydn pulse, which listeners had liked in Experiment 1a, was not preferred significantly over the neutral version, although it still came out on top. In the Haydn piece, the previous preference for the appropriate pulse was no longer evident, and the listeners showed a preference for the Beethoven pulse instead. In the Mozart piece, where in Experiment 1a the Haydn and Mozart pulses had been preferred equally, the Haydn pulse was now preferred over the Mozart pulse. Only in the Schubert piece did the Schubert pulse still come out on top, but it was virtually tied with the Haydn pulse and rated only slightly above the neutral version.

A look down the columns of Table 4 is only slightly more encouraging. At least it was still the case that the Mozart pulse was liked best in Mozart,

TABLE 4
Average Ratings of the Computer Performances in Experiment 1b

| Composer | Pulse | | | |
|-----------|-----------|-------|--------|----------|
| | Beethoven | Haydn | Mozart | Schubert |
| Beethoven | -3.08 | 0.15 | -1.31 | -1.69 |
| Haydn | 1.62 | 0.15 | 0.08 | 0.08 |
| Mozart | 0.08 | 1.54 | 0.62 | -0.46 |
| Schubert | -0.31 | 0.69 | 0.00 | 0.77 |

and the Schubert pulse in Schubert. However, the Beethoven pulse was liked best in Haydn (and was strongly disliked in Beethoven), and the Haydn pulse was liked best in Mozart.

The data were also less consistent in this experiment. The ANOVA showed a marginally significant main effect of pulse [$F(3,36) = 3.07, p = 0.0399$], due to a general preference for the Haydn pulse, and a marginally significant composer by pulse interaction [$F(9,108) = 1.97, p = 0.0492$]. In contrast to Experiment 1a, there was a highly significant main effect of composer [$F(3,36) = 7.16, p = 0.0007$], which reflected the strongly negative ratings for the Beethoven piece. Moreover, correlational analyses of average ratings and individual PAI values (five positive, eight negative) in relation to indices of musical experience and familiarity ratings revealed not a single significant correlation. Thus, the more experienced listeners did not give responses that were more in conformity with Clynes' theory. At the same time, the present group of subjects gave higher familiarity ratings than that of Experiment 1a, so the results cannot be attributed to general inexperience.

In summary, this experiment showed that instructions to rate the composer-specific expressive quality of the computer performances did not increase subjects' appreciation of composers' pulses. If anything, responses were more variable, which suggests that the instructions proved confusing. Whereas it is relatively easy to express a simple preference for one or another performance, it is much more difficult (and perhaps presumptuous) to make judgments about the "Beethovenian" or "Mozartian" quality of expression. The subjects may have felt that they should not trust their immediate response to each performance, but they apparently had no consistent criteria for composer-specific qualities of expression.

Experiment 2

Experiment 1 had used a somewhat heterogeneous set of materials. Experiment 2 used a different, more controlled set of pieces, all Minuet movements from piano sonatas by the same four composers, selected by the au-

thor. Each movement had three sections: Minuet, Trio (or second Minuet), and repeat of the Minuet. Each section had a two-part structure, each part typically comprising eight bars. In several ways, this choice of materials provided a rather extreme test of subjects' ability to appreciate composers' pulses. First, the basic meter was $\frac{3}{4}$ time, so a three-pulse was used for at least one level of the pulse hierarchy (the higher level, because of the moderately slow tempo of Minuets). Three-pulses have one degree of freedom less than four-pulses and therefore are less effective in differentiating individual composers (Clynes, 1987). Second, the Minuet is a traditional dance form and thus not only imposes some constraints on the expression of a composer's individual characteristics, but also may require an additional "Minuet pulse" that was not implemented in the present materials (M. Clynes, personal communication). Third, the pieces were all similar in structure, tempo, duration, key signature, and sound quality. Finally, judging from Clynes' publications, the microstructure of the three-pulses may not be as confidently established as that of the four-pulses.

Experiment 2 was conducted in three versions, referred to as 2a, 2b, and 2c. Experiment 2a took advantage of the possibility that the Trio (or second Minuet), whose character was generally quite different from that of the (first) Minuet, could be considered a separate composition. By conducting separate tests for Minuet and Trio, Experiment 2a examined whether the same pulse preferences would be obtained for these different parts and thus tested the hypothesis (Prediction 4 in the introduction) that a composer's pulse should apply to all of his music. (For some qualifications of that hypothesis, see below.) In addition, the Minuet test was repeated to assess the reliability of subjects' judgments and possible effects of test sequence. The instructions were the same as in Experiment 1a. To counter possible objections against the separation of Minuet and Trio from a musical (rather than methodological) perspective (M. Clynes, personal communication), Experiment 2b replicated Experiment 2a using the integral Sonata movements as well as (in part) improved sound reproduction and modified instructions. Experiment 2c, finally, was a replication of Experiment 2b using amended versions of two pieces, further improvements in sound reproduction, and the instructions of Experiment 1b.

METHODS

Subjects

Experiment 2a

Twelve subjects (four women, eight men) participated in this experiment. Eight of them (including the author), all with musical experience, were also subjects in Experiment 1a (which, chronologically, followed Experiment 2a). The other four subjects were two pro-

ficient amateur musicians (French horn, trumpet) and two relatively inexperienced individuals, all graduate students or young researchers. In this subject group, years of musical education ranged from 0 to 25, active playing hours from 0 to 11, and passive listening hours from 1 to 20. In addition, four professional pianists were tested. Three of them (one woman, two men) were young performers and teachers residing in New Haven; the fourth was an experienced, middle-aged, female piano instructor at a local music school.

Experiment 2b

Five of the most reliable amateur subjects participated here, all of whom had been subjects in Experiment 2a.

Experiment 2c

Eleven of the subjects of Experiment 1b, plus three new subjects from Trinity College, participated here.

Materials

The four pieces selected by the author were Minuet movements from piano sonatas by Beethoven, Haydn, Mozart, and Schubert. Thus they were all of similar form, duration, and time signature ($\frac{3}{4}$), and they even had similar key signatures, although this was an irrelevant fact. Specifically, they were

Beethoven: Menuetto (Moderato e grazioso) from the Sonata in E-flat major, op. 31, No. 3 (with Trio in the same key and a Coda after the repeat of the Minuet);

Haydn: Menuetto (no tempo indication) from the Sonata in E-flat major, HV XVI/28 (with Trio in e-flat minor);

Mozart: Menuetto (Allegretto) in B-flat major from the Sonata in E-flat major, K. 282 (with Menuetto II in E-flat major);

Schubert: Menuetto (Allegretto) from the Sonata in E-flat major, op. 122, D. 568 (with Trio in A-flat major).

The initial bars of the Minuets and Trios (or second Minuet in the Mozart) are shown in Figure 2.

All pieces were generated at the author's request by Clynes in Sydney with Roland MKS-20 piano sound, without any repeats. As in Experiment 1, each piece was recorded (with Dolby B) in a neutral version and in four pulsed versions. The pulses used and their attenuation factors are shown in Table 5. It should be noted that although a three-pulse (see Table 1) was employed at the higher level (comprising the three quarter-notes within a bar), a four-pulse was used at the lower level (sixteenth notes). (For the treatment of triplets, see Clynes, 1987, p. 214.) Thus the lower level pulses were largely the same as in Experiment 1, although there were far fewer notes at that level in the Minuets.

Procedure

Experiment 2a

The experimental tape contained three tests, each structured like the single test in Experiment 1. The first test contained only the Minuets, the second the Trios (or second Minuet), and the third the Minuets again (identical except in the case of the Beethoven, where the Coda was included). Each test had a different order of composers and a different order

Beethoven

MENUETTO
Moderato e grazioso

p

This musical score shows the first part of Beethoven's Minuet in G major. It is in 3/4 time and G major. The tempo is 'Moderato e grazioso'. The piece begins with a piano (*p*) dynamic. The right hand plays a melody of eighth and quarter notes, while the left hand provides a rhythmic accompaniment of eighth notes.

TRIO

p *f* *p*

This musical score shows the Trio section of Beethoven's Minuet in G major. It is in 3/4 time and G major. The tempo is 'Moderato e grazioso'. The piece begins with a piano (*p*) dynamic, then moves to a fortissimo (*f*) dynamic, and returns to piano (*p*). The right hand plays a melody of eighth and quarter notes, while the left hand provides a rhythmic accompaniment of eighth notes.

Haydn

MENUETTO

f

This musical score shows the first part of Haydn's Minuet in G major. It is in 3/4 time and G major. The tempo is 'Moderato e grazioso'. The piece begins with a fortissimo (*f*) dynamic. The right hand plays a melody of eighth and quarter notes, while the left hand provides a rhythmic accompaniment of eighth notes.

TRIO

p

This musical score shows the Trio section of Haydn's Minuet in G major. It is in 3/4 time and G major. The tempo is 'Moderato e grazioso'. The piece begins with a piano (*p*) dynamic. The right hand plays a melody of eighth and quarter notes, while the left hand provides a rhythmic accompaniment of eighth notes.

Fig. 2. Initial bars of both parts of the pieces used in Experiment 2.

of versions for each piece, following a different Latin square design in each test. As in Experiment 1, the neutral version always preceded the four pulsed versions. Instructions and answer sheets were the same as in Experiment 1a, with only minor changes reflecting the different materials. The procedures were also the same. The nonprofessional subjects were tested at Haskins and Yale using a portable stereo cassette recorder without Dolby B. Three professional pianists were tested in a studio or in their home using the same equipment; the fourth used her home stereo system. The repeat of the Minuet test was omitted for the professionals in view of their busy schedule.

Mozart

MENUETTO I

Allegretto

MENUETTO II

Schubert

MENUETTO

Allegretto

TRIO

pp

Figure 2 continued.

Experiment 2b

Here a single test was employed, using a new Latin square design. Each presentation of each piece was to consist of Minuet, Trio (or second Minuet), and repeat of the Minuet (plus Coda in the Beethoven). The Beethoven and Haydn were available in this integral form on the master tape. For the Mozart and Schubert, however, the master tape omitted the Minuet repeat. In a first version of the test tape, the pieces were played in this form, that is, without the Minuet repeat in the Mozart and Schubert, using a portable cassette recorder without

TABLE 5
 Hierarchical Pulse Patterns^a and Attenuation Factors for the Timing
 Pulses Used in Synthesizing the Pieces of Experiment 2^b

| Composer | Lower Level | Higher Level |
|-----------|------------------|--------------------|
| Beethoven | Four-pulse (1.0) | Three-pulse (0.5) |
| Haydn | Four-pulse (1.0) | Three-pulse (1.0) |
| Mozart | Four-pulse (1.0) | Three-pulse (0.75) |
| Schubert | Four-pulse (1.1) | Three-pulse (1.1) |

^aSee Table 1.

^bM. Clynes, personal communication.

Dolby B and the same instructions as in Experiment 2a. Subsequently, because precisely the Mozart and Schubert pieces did not yield the predicted results, a new test tape was created in which the Minuet repeats of the Mozart and Schubert were dubbed in from the master tape. That second version was presented to the same subjects a few months later using a different portable stereo cassette recorder with Dolby B and attached mini-loudspeakers. (One subject listened at home using his stereo equipment, with Dolby B.) The instructions were modified somewhat in the direction of those employed in Experiment 1b by omitting the term "lively" and emphasizing the term "idiomatic" (defined explicitly as "expressive in a way appropriate for that composer").

Experiment 2c

A new test tape was created with the same test sequence as in Experiment 2b, but with newly recorded versions of the Mozart and Schubert pieces furnished by Clynes, which avoided some amplitude distortions that had occurred in the earlier versions because of a nonlinear response of the sound module at high intensities (M. Clynes, personal communication). The tapes were played back on equipment at Trinity College with Dolby B. The instructions were those of Experiment 1b, which emphasized the criterion of "composer-appropriateness."

RESULTS AND DISCUSSION

Experiment 2a

The overall repeated-measures ANOVA in this experiment included not only composer and pulse as factors but also test (Minuet, Trio, Minuet). As in Experiment 1a, there was a highly significant main effect of pulse [$F(3,33) = 13.45, p < .0001$], indicating that some pulses were generally preferred over others. In addition, there was a highly significant composer by pulse interaction [$F(9,99) = 5.64, p < .0001$], which shows that pulse preferences changed reliably with composer, as in Experiment 1a. Thus, Prediction 1 was again upheld, even for pulse patterns that were less differentiated and operated on similar time scales. There was also a marginally

significant main effect of composer [$F(3,33) = 3.15, p = .0377$], and a significant composer by test interaction [$F(6,66) = 6.75, p < .0001$]; both are of little interest. Importantly, however, the triple interaction was highly significant [$F(18,198) = 3.82, < .0001$], suggesting that pulse preferences changed not only with composer, but also between Minuets and Trios.

Since this last interaction may also have reflected, in part, a change in judgments between the two presentations of the Minuet, a separate analysis was conducted on the Minuet data only. Significant effects included the main effects of both composer and pulse, as well as the crucial composer by pulse interaction [$F(9,99) = 5.26, p < .0001$]. Test had no main effect, interacted only weakly with composer, and engaged in a triple interaction that fell just short of significance [$F(9,99) = 1.96, p = 0.515$]. It may be concluded, therefore, that the pulse preference pattern did not change substantially between the two presentations of the Minuets. Since the two Minuet tests followed different Latin square designs, this result also means that there were no obvious artifacts of test order. These conclusions were further supported by a significant correlation ($r = 0.74, p < .01$) between the average ratings for the 16 pulsed versions in the two Minuet tests, which gives some indication of the reliability of the judgments of the subject group as a whole. Considering that there was only a single judgment per stimulus and subject, the reliability is quite satisfactory.

A separate analysis of the Trio data revealed, besides a pulse main effect, a significant composer by pulse interaction [$F(9,99) = 5.36, p < .0001$]. This interaction thus held for both Minuet and Trio separately and combined, but its precise pattern was different for the two. This was confirmed by low and nonsignificant correlations between the average Trio ratings and the first and second Minuet ratings, respectively ($r = 0.18$ and 0.32).

The response patterns may be examined in Table 6. It is evident that Prediction 2, that the correct pulses would receive the highest ratings, was not well supported by these results. Only the Beethoven pulse "worked," both in the Beethoven Minuet and in the Trio. (Paradoxically, it was precisely the Beethoven pulse that caused problems in Experiment 1; note the differences in meter and tempo, however.) In none of the other pieces did the correct pulse come out first or even receive very positive ratings. Some clear preferences for *incorrect* pulses emerged in the Haydn Trio (Mozart pulse) and their Mozart Trio (Haydn pulse). Some striking dislikes must also be noted, especially for the Mozart pulse in the Beethoven Minuet and in the Schubert Trio, and for the Schubert pulse in the Haydn and Mozart Minuets. At least, no strong dislikes occurred for correct pulses anywhere.

The patterns described above were all significant when tested for each composer separately: The pulse main effects were significant in each case, and the pulse by test interaction was significant for all pieces except the Mozart. Thus there were reliable dependencies of pulse preferences on com-

posers *and* pieces (Minuet vs. Trio), which implies that the pulses do not apply equally to all parts of a musical composition.

Even though there was little support for the specific predictions overall, an overall PAI was nevertheless computed for each subject, and its relation to the three measures of musical experience was examined, just as in Experiment 1. Half the subjects had positive PAIs, half had negative ones. Although the correlations with years of musical education and hours of passive listening were negligible, the correlation with active playing hours per week reached significance ($r = 0.61, p < .05$). This correlation reinforced a weak trend in the same direction observed in Experiment 1a, suggesting that listeners with more active musical experience are more appreciative of the correct pulses. This raised the question of whether professional musicians might give judgments that are more in conformity with the predictions.

The average judgments of the four professional pianists are shown in Table 7. Because of the small number of subjects, only a qualitative comparison can be made with the data in Table 6. Clearly, there are some similarities and some differences. In the Beethoven, the professionals, too, showed a consistent preference for the Beethoven pulse. A striking difference from the earlier data is their liking of the Schubert pulse in the

TABLE 6
Average Ratings of the Computer Performances in Experiment 2a:
Twelve Nonprofessional Subjects

| Composer | Pulse | | | |
|-----------|-----------------|-------|--------|----------|
| | Beethoven | Haydn | Mozart | Schubert |
| | Minuet | | | |
| Beethoven | 1.33 | 0.75 | -3.25 | -1.42 |
| Haydn | 0.58 | -0.08 | 0.25 | -2.33 |
| Mozart | 0.58 | 0.58 | 0.17 | -1.33 |
| Schubert | 1.50 | 1.42 | 1.08 | 0.75 |
| | Trio | | | |
| Beethoven | 2.33 | 0.33 | 0.92 | 0.08 |
| Haydn | -1.00 | 0.42 | 1.83 | -0.83 |
| Mozart | 0.17 | 1.42 | -0.50 | -1.08 |
| Schubert | 1.17 | 1.17 | -1.67 | -1.08 |
| | Minuet (Repeat) | | | |
| Beethoven | 1.33 | -0.42 | -1.75 | -0.42 |
| Haydn | 1.25 | 0.58 | 0.33 | -1.33 |
| Mozart | -0.83 | 0.33 | 0.08 | -1.83 |
| Schubert | 0.75 | 1.42 | 0.83 | -0.42 |

TABLE 7
Average Ratings of the Computer Performances in Experiment 2a:
Four Professional Pianists

| Composer | Pulse | | | |
|-----------|-----------|-------|--------|----------|
| | Beethoven | Haydn | Mozart | Schubert |
| | Minuet | | | |
| Beethoven | 0.75 | -1.25 | -4.00 | -3.50 |
| Haydn | 0.25 | 0.50 | -2.00 | -2.00 |
| Mozart | -0.50 | -1.25 | -1.75 | -0.75 |
| Schubert | 0.00 | -0.25 | -2.00 | 0.75 |
| | Trio | | | |
| Beethoven | 3.00 | 1.25 | 0.00 | 2.50 |
| Haydn | -1.25 | -0.25 | -1.75 | 0.00 |
| Mozart | 0.00 | 0.00 | -1.50 | -1.00 |
| Schubert | 1.25 | -1.75 | -3.00 | -1.25 |

Beethoven Trio, to which the nonprofessional subjects had been indifferent. Their opposite reactions to the Schubert pulse in the Beethoven Minuet and Trio are interesting. In contrast to the nonprofessional subjects' results, the Haydn pulse came out best in the Haydn Minuet, but not impressively so, as it was not much preferred over the neutral pulse. (Also, only one subject actually gave the Haydn pulse the highest rating; each of the other three subjects preferred a different pulse, and one of them ranked the Haydn pulse last.) In the Haydn Trio, the Haydn pulse ranked second to the Schubert pulse, but neither was preferred over the neutral version. The professionals disliked the Mozart pulse in the Haydn Trio, in stark contrast to the nonprofessional subjects. No clear preferences emerged in the Mozart pieces, but in both the Mozart pulse ranked last. In the Schubert Minuet, the Schubert pulse, which had ranked last with the nonprofessional subjects, came out first. (However, only one of the four professionals actually preferred the Schubert pulse, for two it was tied with other pulses for first place, and one ranked it last.) In the Schubert Trio, the Beethoven pulse was clearly preferred.

In summary, the four professional musicians' results yielded a somewhat more positive response to the Haydn and Schubert pulses in the Minuets, but not the Trios. The Mozart pulse remained unsuccessful throughout. There were also large individual differences among the professionals. In terms of the PAI, the measure of individual conformity to Prediction 2, two of the four professionals would have ranked among the top four subjects, had they been included with the other subjects; the other two, however, would have ranked at the low end. Therefore, inclusion of their data would

not have increased the correlation between the PAI and musical experience.⁹

Several additional correlations were computed for the 12 nonprofessional subjects. Their average ratings (i.e., their overall tendency to give positive ratings, or to dislike the neutral version) correlated positively with years of music instruction but negatively with active playing hours ($r = -0.51, p < .10$) and passive listening hours. Although none of these correlations reached conventional levels of significance, they support a tendency observed in Experiment 1a for musically more active subjects to like pulsed versions less. This tendency is further supported by the results of the professional musicians (see Table 7), who tended to give even more negative ratings overall. Perhaps, these subjects expected more "interpretation" from the pulsed versions than they actually provided. The subjects' familiarity ratings were also examined. A somewhat wider range than in Experiment 1a was found, although the pieces were again relatively unfamiliar to most subjects. There was no correlation between familiarity and the average PAI (averaged over Minuet and Trio). Finally, for those eight subjects who participated in both Experiments 1a and 2a, the correlation of PAIs across the two experiments was computed and found to be significant ($r = 0.74, p < .02$). Thus there seemed to be reliable individual differences in the extent to which subjects gave judgments in agreement with Prediction 2—that is, in the degree to which they agreed with Clynes.

Experiment 2b

One possible concern with the results of Experiment 2a was that the Trios might be less characteristic of a composer's style, and that their separation from the Minuet may have disrupted the continuity of the musical composition and impeded listeners' appreciation of the pulses. Of course, the Minuet results in the first third of the test cannot be explained away in this fashion. However, it is conceivable that judgments of the Trio would change when it follows immediately upon the Minuet; and it could also be that subjects modify their judgments of the Minuet after hearing the Trio. It is also possible that the absolute duration of the music plays a role in stabilizing the pulse. Therefore, Experiment 2b presented the integral Sonata movements. In the first version of the test, the Minuet repeats of the Mozart and Schubert were missing. In the second version, all pieces were complete, and there were modified instructions and Dolby B playback.

9. It was not attempted to estimate numerically the musical experience of the professionals. Clearly, it was far above that of the other subjects; therefore, computation of correlations across all subjects was not advisable.

The data from both versions of the test (presented to the same group of subjects) were submitted to a repeated-measures ANOVA with the factors version, composer, and pulse. There were two significant effects: a main effect of pulse [$F(2,12) = 7.79, p = .0038$], due to a general preference for the Haydn pulse, followed by Beethoven, Mozart, and Schubert, and a composer by pulse interaction [$F(9,36) = 4.09, p = .0011$]. None of the effects involving versions was significant; thus it may be concluded that addition of Minuet repeats in two of the pieces, changes in instruction, and Dolby B had little effect on subjects' judgments.

The results are shown in Table 8. They are not unlike the average results of the 12 subjects in Experiment 2a (cf. Table 6), with one striking exception: The Haydn pulse suddenly emerged as a clear winner in the Haydn piece. The magnitude of the effect seems almost miraculous; since it was present in both versions of Experiment 2b, it can only be attributed to the integrity of the Sonata movement. For none of the other three pieces, however, did the integrity of the composition have a similarly enhancing effect on the appreciation of the correct pulse. In fact, in the Beethoven piece, the Beethoven pulse was now liked less than the Haydn pulse, and the Mozart and Schubert pulses remained quite ineffective for their respective composers.

Even though the statistical analysis did not reveal any significant differences between the two versions of Experiment 2b, this could have been because of the small number of subjects. Therefore, the average ratings for the two versions were also compared by eye. Compared to Version 1, the ratings for Version 2 were lower overall; this difference actually approached significance. This was particularly true for the correct pulses in all four pieces; there was no indication whatsoever that any correct pulse

TABLE 8
Average Ratings of the Computer Performances in Experiment 2b

| Composer | Pulse | | | |
|------------------------|-----------|-------|--------|----------|
| | Beethoven | Haydn | Mozart | Schubert |
| First Version of Test | | | | |
| Beethoven | 0.83 | 1.00 | -2.83 | 0.33 |
| Haydn | -0.50 | 3.00 | -0.17 | -2.83 |
| Mozart | 0.67 | 0.33 | -0.17 | -2.67 |
| Schubert | 1.33 | 1.67 | -0.83 | 0.67 |
| Second Version of Test | | | | |
| Beethoven | 0.67 | 1.00 | -1.50 | 0.00 |
| Haydn | 0.67 | 2.17 | -0.67 | -2.33 |
| Mozart | -0.17 | -0.67 | -0.17 | -2.00 |
| Schubert | 0.67 | 0.17 | -0.17 | -2.00 |

was appreciated more in Version 2 than in Version 1. Thus the experiment was entirely negative with respect to possible effects of addition of the Minuet repeat in the Mozart and Schubert, instructions, and Dolby B playback.

Experiment 2c

The results of this further replication, with modified instructions and technically improved versions of the Mozart and Schubert pieces, are shown in Table 9. In the Beethoven piece, a preference for the Beethoven pulse emerged again, as in Experiment 2a. In the Haydn piece, the Beethoven pulse was preferred somewhat over the Haydn pulse, which also resembles the results for the Haydn Minuet in Experiment 2a (nonprofessional subjects, Table 6); the striking preference for the Haydn pulse obtained in Experiment 2b (Table 8) was not replicated, even though the integrality of the composition was preserved. In the Mozart piece, there was a marginal preference for the Mozart pulse, although it was not rated much above the neutral version. Relatively speaking, this constitutes a slight improvement over the previous results. Finally, in the Schubert piece the Schubert pulse received a positive rating but ranked behind the Haydn and Beethoven pulses. This may also be taken as a slight improvement, but it is certainly not impressive.

As in Experiment 1b, which employed the same instructions with largely the same subjects, the results were less consistent than in previous runs of the test. In the ANOVA there was a significant main effect of composer [$F(3,39) = 5.51, p = 0.0030$] resulting from higher ratings for Schubert and Haydn than for Beethoven and Mozart. There was no significant main effect of pulse, but the crucial composer by pulse interaction did reach significance [$F(9,117) = 2.47, p = 0.0130$]. As in Experiment 2b, there were no significant correlations between average ratings, familiarity ratings, PAI scores, and the several indices of musical experience.

TABLE 9
Average Ratings of the Computer Performances in Experiment 2c

| Composer | Pulse | | | |
|-----------|-----------|-------|--------|----------|
| | Beethoven | Haydn | Mozart | Schubert |
| Beethoven | 1.71 | -0.50 | -1.00 | 0.50 |
| Haydn | 1.57 | 1.21 | 0.50 | 0.50 |
| Mozart | -1.00 | 0.29 | 0.43 | -0.50 |
| Schubert | 1.50 | 1.57 | 0.43 | 1.36 |

General Discussion

The results of these very preliminary experiments establish quite clearly that listeners' relative preferences for different pulse patterns vary with the piece they are listening to. Whether or not this composition by pulse interaction is caused by listeners' appreciation of composer-specific characteristics, it is an important finding in itself. It indicates that the listeners judged the time-amplitude deviations in relation to the musical content of each piece (i.e., as the expressive variations they were intended to be), not just as physical deviations of varying magnitude. Their judgments presumably represent some measure of the degree to which the pulses fit the musical structure.

The pulses devised by Clynes were, of course, intended to provide an optimal fit for each composer. Experiment 1a indeed revealed largely the expected pattern of pulse preferences (with only the Beethoven pulse being unconvincing), although the results of Experiment 1b were less encouraging. Nevertheless, these data may be taken to provide some support for Clynes' choice of time-amplitude patterns for quadruple meter, at least for Mozart and Schubert. Curiously, the results of Experiment 2 were complementary to those of Experiment 1 in that they provided clear support for the Beethoven pulse and occasional support for the Haydn pulse, but little evidence in favor of the Mozart and Schubert pulses. Moreover, in Experiment 2a listeners' judgments differed for the Minuet and Trio parts.

Most of the present subjects were moderately competent judges of the general quality of a musical performance. They may be considered representative of that valuable subpopulation of concert (or radio) audiences whose members actually attend to the music and to the manner in which it is performed. Moreover, their judgments were reasonably consistent; clearly, they were not just guessing. Possible weaknesses in the methodology (memory requirements, less than perfect sound reproduction) cannot be held responsible for consistent response patterns, only for noise in the data. Although an inappropriate pulse (i.e., that of a composer other than the composer of the piece) may occasionally have a positive effect, it is not clear why the appropriate pulse microstructure should ever be *less* appealing than an inappropriate or neutral one to the moderately sophisticated listener. Such reversals of judgment may be caused by *general* pulse preferences or aversions, but the negative findings in the present study cannot be explained on these grounds. Therefore, these findings indicate problems with the pulses themselves and their implementation, or possibly with the musical pieces chosen.

As to the pulses themselves, Clynes (1983, 1987) has stated that they are subject to continuing refinement and improvement (although presumably by artists, not by the consensus of ordinary music lovers). The three-pulses

especially were called “tentative” by Clynes (1983), although some have been revised by him in the meantime. These patterns are still not optimal, and perhaps they have some idiosyncratic features that are unacceptable to other listeners. Each of the two independent parameters of the pulse, duration and amplitude, has a certain depth of modulation; that is, each pulse is a member of a whole family of similar patterns varying in the magnitude of the prescribed deviations. Even if the basic pattern is right, the modulation depth may be either too large or too small, with the resulting pulse either sounding exaggerated or being ineffective. It may be noted, in that connection, that Clynes developed the pulses using sine wave synthesis, whereas most of the present pieces were performed with a synthetic piano sound. The different sound quality, with its different overtone structure and spectral balance, may require an adjustment in the pulse modulation depth. The pulse may also need to adjust somewhat to different tempos, overall loudnesses, and the presence of multiple voices. Clynes’ “attenuation factors” attempted to achieve these goals, but perhaps not with full success.

Another relevant issue concerns the maintenance of the pulse throughout a piece. As pointed out in the introduction, this follows from Clynes’ earlier ideas on “time-form printing” in the central nervous system and is an important part of the theory. Clynes (1986) links it to psychobiological clocks and repetitive motor activities such as walking; he claims that listeners expect repetition of the pattern and would consider substitution of a different pattern disturbing. Essentially, the physical pulse, as instantiated in computer performances, is modeled after the *inner* (mental, subjective) pulse, which [according to Becking’s (1928) and Clynes’ introspections] does possess the postulated constancy. However, Clynes (1987) also notes that actual performances are likely to contain “noise” in the form of random and planned deviations from the pulse, as one should expect from a human performer. Also, Becking (1928) commented that a composer’s characteristic dynamics are not expressed equally throughout a composition, so the modulation depth of a pulse may have to vary in the course of a piece. In addition, of course, there are many other expressive devices (e.g., crescendi and diminuendi, special accents, ritardandi and accelerandi, phrase-final lengthening) that would be laid on top of a pulse in an actual performance. Few of these devices were used in the present computer performances, so as not to introduce too many complexities. However, the result may have been that the pulses were too obvious and exposed to be wholly pleasing. The precise, naked repetition of the pulse identifies the performance as that of a machine, even though the pulse itself is intended to impart “living qualities.” Although expert listeners (such as Clynes himself) may be trained to evaluate such bare pulses in terms of the musical thought they evoke, other listeners may appreciate pulses, if at all, only as the background carrier for other, structurally determined modulations of the musical flow. All this

goes to say that the present materials were deliberately simple performances for laboratory use, and that perhaps a sweeping success of the pulses with untrained listeners should not have been expected, particularly in Experiment 2, where the Minuet dance characteristics were deliberately absent.

Finally, we turn to the issue of the generality of the pulses across all works of a composer. Although Clynes has likened composers' pulses to stable individual characteristics such as handwriting or voice quality (Clynes, 1986) and has stated that they do not seem to change with a composer's age (Clynes, 1987), in personal communications he has expressed reservations about some of the present pieces on the grounds that they represent compositions from the composer's youth (e.g., Beethoven's Op. 10, No. 2, used in Experiment 1). He has also pointed out to this author that, in his opinion, the Trio sections of Minuet movements are often not characteristic of their composers' style and that this may explain some of the poor results in Experiment 2a. However, although random results would be consistent with this suggestion, systematic preferences for inappropriate pulses are more difficult to explain. Moreover, the suggestion that a pulse applies only to music that is characteristic of its composer threatens to make the theory circular, because there is no objective measure of "characteristicness." An unlimited number of pieces could be exempted on these grounds. Similarly, it is not clear where to draw the line between early and mature compositions. (Mozart, for example, had written almost 300 other works before the piano sonatas from which the present excerpts were taken, and he surely had developed his personal style by that time.) It would be quite reasonable to amend Clynes' theory by allowing composers' pulses to become more pronounced and clearly defined with age; thus listeners may have greater difficulty appreciating the "correct" pulse in earlier compositions. It seems, however, that even such an amended theory would not allow for preferences of *other* composers' pulses over the correct one, as occurred in several instances.

The generality of a composer's pulse over his whole oeuvre is clearly implied by Clynes' theory as presently stated. Obviously, a much larger set of compositions will be needed to test this part of the theory thoroughly. However, it is clear that the idea of a single characteristic pulse for a composer is an *abstraction* derived from intimate familiarity with his total oeuvre. This ideal pulse can perhaps be appreciated by artists who are able to experience any given piece in the context of stored knowledge about the composer's total output. Knowing that a piece is by Beethoven, say, they would find the Beethoven pulse appropriate because they *recognize* it as "Beethovenian." Individual compositions of a composer, however, may require an expressive microstructure that deviates more or less from the ideal composer's pulse, in accordance with the specific structural properties of

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the piece. (An analogy to the mean and variance of a statistical distribution might be appropriate.) Depending on the composer's expressive range and stylistic consistency, that piece-specific pulse may be a variant of the ideal pulse, or it even may be in conflict with it. Moreover, it may vary in the course of a piece as the musical structure unfolds.¹⁰ The subjects in the present experiments may have judged the performances in such a piece-specific frame of reference, despite the revised instructions in Experiments 1b and 2c. If so, their ratings may indeed be a measure of the "typicality" of a piece among all compositions of a composer, assuming that Clynes' pulse patterns are close to the true ideal. The negative results in Experiment 2, for example, could be interpreted as suggesting that the Mozart and Schubert Minuet movements were not typical of their respective composers, that the Mozart Trio could be mistaken for Haydn, the Haydn Trio for Mozart, and so on. Some independent perceptual or musicological criterion will be needed to judge whether these suggestions are tenable.¹¹

References

- Becking, G. *Der musikalische Rhythmus als Erkenntnisquelle*. Augsburg: Benno Filser, 1928.
- Bengtsson, I., & Gabrielsson, A. Methods for analyzing performance of musical rhythm. *Scandinavian Journal of Psychology*, 1980, *21*, 257–268.
- Clynes, M. Toward a theory of man. Precision of essentic form in living communication. In K. N. Leibovic & J. C. Eccles (Eds.), *Information processing in the nervous system* (pp. 177–206). New York: Springer-Verlag, 1969.
- Clynes, M. *Sentics. The touch of emotions*. Garden City, NY: Anchor Press/Doubleday, 1977.
- Clynes, M. Expressive microstructure in music, linked to living qualities. In J. Sundberg (Ed.), *Studies of music performance* (pp. 76–181). Publication issued by the Royal Swedish Academy of Music No. 39 (Stockholm, Sweden), 1983.

10. It would exceed the scope of the present study to investigate this hypothesis further, in view of the length and complexity of the musical materials. It was observed informally by the author and other listeners that the positive or negative impressions evoked by a pulse did vary in the course of a piece. A more detailed investigation of the interaction of structural properties and pulse effectiveness would require tracking listeners' judgments continuously or presenting shorter, structurally homogeneous musical excerpts for evaluation.

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- Clynes, M. Secrets of life in music. In *Analytica. Studies in the description and analysis of music in honor of Ingmar Bengtsson* (pp. 3–15). Publication issued by the Royal Swedish Academy of Music No. 47 (Stockholm, Sweden), 1985.
- Clynes, M. Generative principles of musical thought: Integration of microstructure with structure. *Communication and Cognition AI*, 1986, 3, 185–223.
- Clynes, M. What can a musician learn about music performance from newly discovered microstructure principles (PM and PAS)? In A. Gabrielsson (Ed.), *Action and perception in rhythm and music* (pp. 201–233). Publication issued by the Royal Swedish Academy of Music No. 55 (Stockholm, Sweden), 1987.
- Clynes, M., & Walker, J. Neurobiologic functions of rhythm, time, and pulse in music. In M. Clynes (Ed.), *Music, mind, and brain: The neuropsychology of music* (pp. 171–216). New York: Plenum Press, 1982.
- Gabrielsson, A., Bengtsson, I., & Gabrielsson, B. Performance of musical rhythm in $\frac{3}{4}$ and $\frac{6}{8}$ meter. *Scandinavian Journal of Psychology*, 1983, 24, 193–213.
- Hartmann, A. Untersuchungen über metrisches Verhalten in musikalischen Interpretationsvarianten. *Archiv für die gesamte Psychologie*, 1932, 84, 103–192.
- Seashore, C. E. *Psychology of music*. New York: McGraw-Hill (original), Dover (reprint), 1938/1967.
- Shaffer, L. H. Performances of Chopin, Bach, and Bartók: Studies in motor programming. *Cognitive Psychology*, 1981, 13, 326–376.
- Shaffer, L. H., Clarke, E. F., & Todd, N. P. Metre and rhythm in piano playing. *Cognition*, 1985, 20, 61–77.
- Sievers, E. *Ziele und Wege der Schallanalyse*. Heidelberg: Carl Winter, 1924.
- Sundberg, J., & Frydén, L. Teaching a computer to play melodies musically. In *Analytica. Studies in the description and analysis of music in honour of Ingmar Bengtsson* (pp. 67–76). Publications issued by the Royal Swedish Academy of Music No. 47 (Stockholm, Sweden), 1985.
- Sundberg, J., Frydén, L., & Askenfelt, A. What tells you the player is musical? In J. Sundberg (Ed.), *Studies of music performance* (pp. 67–75). Publication issued by the Royal Swedish Academy of Music No. 39 (Stockholm, Sweden), 1983.
- Thompson, W. F. Composer-specific aspects of musical performance: An evaluation of Clynes' theory of pulse for performances of Mozart and Beethoven. *Music Perception*, in press.
- Todd, N. A model of expressive timing in tonal music. *Music Perception*, 1985, 3, 33–58.