730

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Further Perceptual Evaluations of Pulse Microstructure in Computer Performances of Classical Piano Music

BRUNO H. REPP
Haskins Laboratories

This research continues the perceptual evaluation of "composers' pulses" begun by Repp (1989a) and Thompson (1989). Composers' pulses are patterns of expressive microstructure (i.e., timing and amplitude modulations) proposed by Clynes (1983). They are said to convey individual composers' personalities and to enhance their characteristic expression when implemented in computer performances of their music. For the present experiments, the initial bars of five piano pieces by each of four composers (Beethoven, Haydn, Mozart, and Schubert) were generated with each of four pulse microstructures similar to Clynes's composer-specific patterns, and also in a deadpan version. Listeners representing a wide range of musical experience judged to what extent each computer performance had the composer's individual expression, relative to the deadpan version. Listeners showed an overall preference for the Beethoven and Haydn pulses. The pattern of pulse preferences varied significantly among individual pieces, but little among different composers. These results indirectly support the general notion that expressive variation is contingent on musical structure, but they offer little evidence in support of fixed, composer-specific patterns of expressive microstructure.

Introduction

Two recent studies (Repp, 1989a; Thompson, 1989) examined listeners' reactions to computer performances that implemented the "composers' pulses" proposed by Clynes (1983, 1986, 1987). These pulses are patterns of timing and amplitude modulations that are repeated cyclically throughout a performance. Clynes claims that different composers call for characteristic patterns of expressive microstructure and that introduction of these patterns in computer performances conveys the composers' personalities and "styles of movement" to listeners. For a more detailed discussion of these ideas, see the literature cited above.

Requests for reprints may be sent to Bruno H. Repp, Haskins Laboratories, 270 Crown St., New Haven, CT 06511-6695.

Thompson (1989) conducted perceptual tests with music students as subjects and compositions by Beethoven and Mozart as materials. The subjects' task was to rate computer performances as to how well they captured the composer's character. In two small experiments, Thompson showed that the subjects gave higher ratings to computer performances when they exhibited the "correct" pulse specified by Clynes than when the pulse was altered, absent, or interchanged between composers. In a third experiment, he presented three different versions of a Beethoven piece (synthesized with the Beethoven, Haydn, and Schubert pulses) to listeners under two kinds of instruction: to judge either the general musical quality of each performance or to indicate how "Beethovenian" each performance was. The highest ratings were given to the Haydn pulse performance with the first kind of instruction, but to the Beethoven pulse performance with the second. Thompson concluded that there was some support for Clynes's concept of composers' pulses, although his data must be considered rather preliminary.

In a somewhat more extensive study, Repp (1989a) used two sets of pieces, each containing one composition each by Beethoven, Haydn, Mozart, and Schubert. Each composition was synthesized with each composer's pulse, as well as in a deadpan version. Listeners representing a wide range of musical experience rated each pulsed performance relative to the deadpan one on an 11-point scale, with instructions that either emphasized general musicality or specific composer-appropriateness of the performance. In the first set of pieces, which were in even meter, listeners showed a preference for the "correct" pulse in the Haydn, Mozart, and Schubert pieces, but not in the Beethoven (which was the same piece as a in Thompson's third experiment). There was a general preference for the Haydn pulse. In the second set of pieces, which were in $\frac{3}{4}$ time signature (minuets), a consistent preference for the correct pulse emerged only in the Beethoven. Instructions had no clear effects on the results. Repp concluded that there was some support for the effectiveness of the proposed pulses in certain pieces, but that there was an equal number of failures to obtain the expected result.

Thus, the results so far are inconclusive. Numerous reasons could be imagined for why negative results were obtained in some instances (see Clynes, 1989, 1990; Repp, 1989a, 1990a): Certain pieces may not have been typical of their composer's style, the subjects may not have been sufficiently familiar with the composers' individuality, the methodology may not have been optimal, etc. More important, perhaps, is the argument that the expressive microstructure needs to be sensitive to the musical structure of a composition (see, e.g., Clarke, 1983, 1988; Gabrielsson, 1987; Palmer, 1989; Shaffer & Todd, 1987) and that the fixed pulse patterns devised by

Clynes, even if they do "capture the essence" of composers in some sense, simply may not fit all musical structures generated by these composers equally well. Therefore, to test whether they are representative of individual composers at all, it is necessary to draw a larger sample of pieces from each composer's oeuvre. This was done in the present study.

The most important and statistically highly reliable finding of Repp's (1989a) study was a *composer by pulse interaction* for each set of pieces. That is, listeners' judgments of the relative merits of the four pulses varied significantly from one composer to another, whether or not the correct pulse was favored. However, as each composer was represented by only a single piece in each set, this interaction can also be interpreted as a *pulse by piece interaction*. The very different results obtained for the two sets of pieces actually suggest this latter interpretation. It was the primary purpose of the present study to distinguish these two possibilities, and to examine whether there is a true composer by pulse interaction that generalizes across different sets of pieces.

The present materials, unlike the earlier ones, which had been created by Clynes, were generated by the author. They are simpler in three respects: First, they are much shorter in duration; while the earlier materials had mostly represented complete sonata movements, the present excerpts comprise just the initial bars of such movements. This can be justified on the grounds that the initial bars are essential for establishing the pulse (cf. Clynes, 1983, p. 131) and that the most important thematic material usually occurs right at the beginning of a composition. The pulse cycle was repeated 6–16 times in each excerpt, so there was sufficient opportunity for listeners to apprehend it. Second, the materials do not contain any expressive variation apart from the pulse (with one small exception mentioned below); in the earlier materials, Clynes had made some additional adjustments to improve the musical quality of all versions. Third, whereas the composers' pulses had been implemented at two hierarchical levels in the earlier materials (the basic pulse being nested within larger units that were subjected to similar, but attenuated, time and amplitude modulations), only the basic level comprising time cycles of approximately 1 sec is used in the present study. According to Clynes, that level is crucial for conveying composer-specific characteristics.

The present experiment went beyond the earlier work in that it included not only a test in which the full pulses were implemented, but also (for a small group of "expert" listeners) two additional tests in which only the amplitude pulse or only the timing pulse was applied, in an attempt to assess the contribution of these two semi-independent components to the perceptual effects of the full pulses. The general methodology was similar to that of Repp (1989a).

Methods

MATERIALS

Selection

Five piano compositions were selected from the oeuvres of each of four composers: Beethoven, Haydn, Mozart, and Schubert. None of these pieces had been used by Repp (1989a), although the four composers were the same. The music had to satisfy the following criteria: (1) even meter ($\frac{2}{4}$ or $\frac{4}{4}$); (2) conventional structure of the opening bars, usually an eight-bar phrase; (3) neither many rests nor many long notes, so the pulse could be fully represented; (4) no special accents marked in the score, nor any requests for gradual changes in loudness or tempo; (5) moderate to fast tempo, so a pulse could be carried by four notes within each time cycle of roughly 1-sec duration (slow movements were excluded for that reason).

Because of the restricted possibilities offered by the finite oeuvres of the composers, some of the pieces fell short of some requirements. On the whole, however, they seemed adequate for the purpose. The scores of all musical excerpts are presented in the Appendix, in the order in which they appeared in the test. (Individual pieces will be referred to as B1, H4, M2, etc.) Two pieces (B3 and S5) had introductory bars that were omitted. All excerpts ended on a cadence, so the last bar was usually incomplete in pieces whose theme began with an upbeat. Three pieces (S1, S3, S4) required the use of the sustaining pedal.

"Neutral" Performances

The computer performances were generated on a Roland 250S electronic keyboard connected by MIDI link to a microcomputer on which the FORTE sequencing program was installed. To enter the notes into the computer, the author (an amateur pianist) played the compositions on the keyboard. The FORTE program stored tone height, velocity, onset time, and duration of depression for each keystroke, as well as pedal on/off information. The temporal resolution was 5 msec, and the amplitude resolution was 0.27 dB (one velocity unit).[1] After checking for and correcting any technical mistakes with the FORTE editing commands, the natural variations in note onset timing and amplitude were eliminated by using appropriate commands in the FORTE program.

Timing was equalized by first dividing the total duration of each performance (from the onset of the first note to the onset of the last note) by the number of notes of equal value in it, choosing the fastest level of continuous movement in the music. The resulting value was then specified to the program as the equalization interval, so intervals between successive note onsets were made equal to that time value, or integral multiples of it. This procedure maintained very nearly the same overall duration of the performance. Misaligned notes—particularly those whose onsets needed to be separated by a fraction of the equalization interval—were identified and moved to their correct places by using editing commands. The note durations (i.e., the exact durations of key depression) were maintained unchanged from the original performance.[2] In those pieces that had been performed with pedal (S1, S3, S4),

1. The latter value was determined empirically by playing notes on the keyboard with varying force and registering the key velocities with the FORTE program while also measuring the voltage output on a voltmeter. After transforming voltages into decibels, a plot of key velocity against amplitude in decibels revealed a change in 3.7 velocity units to be equivalent to a change of 1 dB; the function was linear across the whole range examined (between velocities of 20–100).

2. Because of certain limitations of the FORTE program and the unavailability of other software, an excessive amount of hand editing would have been necessary to maintain note

misalignments of pedal instructions with time-shifted notes were identified by ear and corrected by shifting the pedal instructions accordingly.

Amplitude equalization of all notes was achieved by another simple command in the FORTE program. The level of equalization varied between pieces and occasionally changed within a piece if the composer had prescribed such a change. All levels were within a range of 20 velocity points, or about 5.4 dB; extremes were deliberately avoided to minimize distortion.

The resulting versions sounded rather dull, and it was soon discovered that amplitude enhancement of the melodic line improved the musical quality tremendously. Therefore, the melody notes were determined and enhanced by 5.4 dB in most pieces; in some pieces, where this seemed too much, only half that amount was used. In addition, in some pieces that ended with an appoggiatura, the final note was deemphasized because the cadence sounded offensive without this adjustment. This was the only adjustment of an expressive parameter in the neutral versions.

Performances with Pulse Microstructure

From each neutral version, three sets of four "pulsed" versions each were constructed. The pulse patterns resembled those specified by Clynes for the four composers in question (see below). Each pulse had a timing component and an amplitude component for a time unit with four subdivisions (beats). In one set (AT), both the timing and amplitude patterns of each of the four pulses were applied. In the other two sets, either only the timing component (T) or only the amplitude component (A) was applied. In each set there were therefore one "correct" and three "incorrect" pulsed versions. (These terms will be used for convenience, even though some questions about the correctness of the "correct" pulses will be raised later.)

For each piece a decision about the domain to which to apply the pulse (four quarter notes, eighth notes, or sixteenth notes) had to be made. Clynes (1983, p. 131) has stated that one basic pulse cycle generally occupies between 0.7 and 1.2 sec. These limits actually define the cycle duration for any given piece, because they cannot accommodate a doubling or halving of any duration. Although it is understood that musical considerations may occasionally force an exception to the rule, the author wanted to avoid subjective decisions and therefore applied the rule literally, in the hope that this would lead to musically correct pulse assignments in the majority of the pieces. Only one piece (S1) was assigned a pulse cycle duration longer than 1.2 sec, because of its paucity of faster notes. Subsequently, Clynes (personal communication) advised the author to shorten the pulse cycle durations in several pieces (B3, H3, M2, M3, M5), so that these durations were less than 0.7 sec. Table 1 shows the pulse domains, the duration of the pulse cycles, the number of cycles per piece, and the number of fully expressed cycles (i.e., that contained a note on each pulse beat). The pulse cycle coincided with either the bar or the half-bar, the only exception being S2 (two bars). Pieces differed considerably in the number of pulse cycles they contained. Two pieces (B4

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offset alignments while changing onset timing. Clynes's timing pulses are indifferent to note durations; the relative "note durations" referred to by Clynes in his pulse specifications really concern onset-to-onset intervals. By maintaining the original note durations, the author avoided having to make arbitrary decisions about this parameter; also, it was thought that the musical quality of the computer performances might be enhanced if a trace of the original human performance were retained. A slight disadvantage was that, as notes were shifted relative to each other in time during timing equalization and pulse implementation (see below), small gaps sometimes occurred between the offset of one note and the onset of the next, which reduced the smoothness of intended legato connections. These effects were rather minor, however, and a few noticeable ones were corrected by lengthening the note causing the trouble.

TABLE 1
Pulse Domain (Note Values), Pulse Cycle Duration, Number of Complete Pulse Cycles, and Number of Fully Expressed Pulse Cycles for Each Composition

Composition	Pulse Domain	Cycle Duration (msec)	Number of Cycles	Fully Expressed
Beethoven				
1. Sonata op.13	4/8	640	15	15
2. Sonata op.22	4/16	820	15	15
3. Sonata op.101	4/16	560	14	10
4. Bagatelle op.33, no. 4	4/16	1220	14	4
5. Sonata op.7	4/16	980	16	14
Haydn				
1. Sonata H.XVI/20	4/8	1120	8	4
2. Sonata H.XVI/48	4/8	800	11	10
3. Sonata H.XVI/32	4/8	660	12	12
4. Sonata H.XVI/37	4/8	880	7	7
5. Sonata H.XVI/34	4/8	1000	8	7
Mozart				
1. Sonata K.310	4/8	880	16	12
2. Sonata K.303	4/16	680	15	13
3. Sonata K.533	4/8	640	14	12
4. Sonata K.576	4/8	1200	8	7
5. Sonata K.281	4/8	600	15	10
Schubert				
1. Impromptu D.935, no.3	4/8	1640	16	16
2. Sonata D.845	4/4	1080	6	6
3. Sonata D.664	4/8	1120	15	15
4. Sonata D.959	4/8	1020	15	15
5. Mom. Mus. D.780, no.3	4/8	1060	8	7

and H1) were suboptimal in that they permitted only intermittent expression of the full pulse. (See the General Discussion for further discussion of the issue of pulse assignment.)

The *timing components* of the pulses were similar to those specified by Clynes (1983) for the four composers, as illustrated in Table 2. Clynes's specifications, expressed in percentages of the nominal onset-to-onset intervals (OOIs) between notes, are shown on line 1 for each composer (e.g., 106 means that the OOI is to be lengthened by 6%.) These percentages were first normalized so that the sum of all positive and negative changes was zero and the overall tempo remained unaltered (line 2). These changes were minor, as the apparent lack of normalization in Clynes's specifications just reflects omission of decimals (see Clynes, 1990). Subsequently, the percentages were expressed as deviations from 100 (line 3) and translated into shift factors for individual notes; the first note in each cycle remained fixed (line 4).

In applying these shift factors to each individual piece, the tempo needed to be taken into account. The tempo was expressed in terms of the number of "ticks" (1 tick = 5 msec) intervening between successive note onsets at the relevant level. This number was multiplied by

TABLE 2
The Timing Pulses (%)

	Beats			
	1	2	3	4
Beethoven				
Clynes (1983)	106	89	96	111
Normalized	105.5	88.5	95.5	110.5
Deviation	5.5	−11.5	−4.5	10.5
Shift factor	0	5.5	−6	−10.5
Haydn				
Clynes (1983)	108	94	97	102
Normalized	107.75	93.75	96.75	101.75
Deviation	7.75	−6.25	−3.25	1.75
Shift factor	0	7.75	1.5	−1.75
Mozart				
Clynes (1983)	105	95	105	95
Normalized	105	95	105	95
Deviation	5	−5	5	−5
Shift factor	0	5	0	5
Schubert				
Clynes (1983)	98	115	99	91
Normalized	97.25	114.25	98.25	90.25
Deviation	−2.75	14.25	−1.75	−9.75
Shift factor	0	−2.75	11.5	9.75

the shift factors, divided by 100, and rounded to the nearest integer numbers. Because of this rounding, the timing pulses used were not exactly identical with Clynes's specifications and also varied somewhat from piece to piece; however, the general properties of the patterns were preserved. (See Repp, 1990a, for additional details.)

In implementing the timing pulses, notes of longer duration than one pulse beat were shifted in accordance with the beat that coincided with their onset. Notes of shorter duration than the pulse beat were timed as evenly as possible (given the 5-msec quantization) between pulse beats; this means, for example, that a sixteenth note falling between two eighth notes in an eighth note pulse was shifted by an amount halfway between the shifts for the two adjacent eighth notes.

The *amplitude components* of the four composers' pulses were specified by Clynes (1983) in terms of proportions on a linear scale, relative to the first note (Table 3, line 1 for each composer). These values were first translated into decibels (line 2) and then normalized to keep the average amplitude in decibels constant (line 3). It was noted that the Mozart pulse not only used a much wider amplitude range (12.65 dB) than the other pulses (Beethoven: 8.18 dB; Haydn: 8.42 dB; Schubert: 7.96 dB) but also sounded exaggerated when implemented. It was decided, therefore, to attenuate the Mozart pulse to 60% of its decibel values (see Table 3), which made its dynamic range (7.59 dB) comparable to that of the other pulses. Finally, the decibel values were multiplied by the empirically determined factor of 3.7 (see footnote 1) and rounded to the nearest integer to obtain change of velocity values that were then applied to the notes in the computer score. These values, which were exactly the same for all pieces of a composer, are shown in Table 3 (last line).

TABLE 3
The Amplitude Pulses

	Beats			
	1	2	3	4
Beethoven				
% (Clynes, 1983)	1.00	0.39	0.83	0.81
dB	0	–8.18	–1.62	–1.83
Normalized (dB)	2.91	–5.27	1.29	1.08
Velocities	11	–20	5	4
Haydn				
% (Clynes, 1983)	1.00	0.42	0.68	1.11
dB	0	–7.54	–3.35	0.88
Normalized (dB)	2.50	–5.04	0.85	3.38
Velocities	9	–19	–3	13
Mozart				
% (Clynes, 1983)	1.00	0.21	0.51	0.23
dB	0	–13.51	–5.85	–12.65
Normalized (dB)	8.00	–5.51	2.15	–4.65
Attenuated to 60%	4.80	–3.31	1.89	–2.79
Velocities	17	–12	5	–10
Schubert				
% (Clynes, 1983)	1.00	0.65	0.40	0.75
dB	0	–3.74	–7.96	–2.50
Normalized (dB)	3.55	–0.20	–4.41	1.05
Velocities	13	–1	–16	4

These amplitude modifications were applied to all notes, whether melody or accompaniment. Notes longer than the pulse beat were changed according to the beat coinciding with their onset. Notes falling between pulse beats were assigned the amplitude change of the immediately preceding beat. Except for the attenuated Mozart pulse, these amplitude changes were in close accord with those prescribed by Clynes.[3]

Test Tapes

The music was played back on the Roland 250S electronic piano with "Piano 1" sound and intermediate brightness adjustment. The output was recorded electronically onto cassette tape. Three experimental tapes were recorded, the first containing the pieces with both amplitude and timing pulses applied (AT test), the second having only the amplitude pulses (A test), and the third having only the timing pulses (T test). On each tape, all Beethoven pieces came first, followed by Haydn, Mozart, and Schubert. For each piece, the neutral version was always first, followed by the four pulsed versions in some random order that

3. However, as Clynes (1990) has pointed out, they did not take into account nonlinearities in perceived loudness caused by variations in the spectrum of the electronic piano sounds with changes in amplitude. While the magnitude of this perceptual distortion is not known, the loudness variations did retain significant similarities to the patterns intended by Clynes.

was approximately counterbalanced across pieces within composers. (Because there were five pieces but only four pulses, counterbalancing could not be perfect.) The order of pieces was the same on all three tapes (see Table 1), but the order of pulsed versions for each individual piece was different across the three tapes. There were silent intervals of about 5 sec between different versions of the same piece, 10 sec between different pieces, and 20 sec between different composers. Each test took approximately 35 min and contained 100 stimuli.

INSTRUCTIONS AND PROCEDURES

The written instructions described the test as a mock piano competition in which four finalists should be evaluated with regard to their ability "to play expressively in a way that enhances the composer's individual characteristics." The composers were named on the answer sheets. Subjects were asked to listen to the initial, neutral version of each piece and to indicate whether or not the composition sounded familiar by circling "yes" or "no" on the answer sheet. Then, for each of the subsequent versions, they were asked to enter a judgement on a scale ranging from − 5 to + 5, by which they were to indicate the "degree to which the pianist has succeeded in expressing the composer's individual characteristics," with the neutral version as the standard (equivalent to a rating of 0) and with a positive or negative rating indicating relative success or failure, respectively. The subjects were informed that the performances were in fact computer-generated and should not be expected to approach human performances in quality.

SUBJECTS

Three groups of subjects participated, referred to in the following as "pilot," "student," and "expert" subjects.

Pilot Subjects

Extensive pilot data (95 subjects) were collected for the AT test in the course of lectures given by the author during a stay in Europe. The test was divided into five subtests, each containing a single piece by each composer. Each of these approximately 7-min demo-tests was played in a classroom over loudspeakers to a mixed audience mostly consisting of psychology faculty and students with widely varying musical experience. Answer sheets with abbreviated instructions were provided. The origins and numbers of subjects, as well as the items contained in each AT subtest are listed in Table 4.

TABLE 4
AT Subtests and Pilot Subjects

Subtest	Pieces				No. of Subjects	Locations
	B	H	M	S		
A	2	4	4	3	22	MRC Applied Psy. Unit, Cambridge
B	4	2	5	1	20	Dept. Psychology, U. of Exeter
C	5	3	1	2	13	Exp. Psychol. Lab., U. of Sussex
D	1	1	2	5	21	Dept. Psychology, U. of York
E	3	5	3	4	19	MPI for Psycholinguistics, Nijmegen

Student Subjects

The complete AT test was presented over loudspeakers to a group of 30 students attending a psychology of music class at the Catholic University of Nijmegen. The majority of these students had studied a musical instrument or listened to much classical music. The data of two additional subjects with quite extensive musical education, both Americans residing in Europe who were supposed to be members of the "expert" group but were able to complete only the AT test, were added to this group. These two subjects listened over earphones with their home stereo system.

Expert Subjects

Eight additional subjects listened to all three tests on their home stereo system, mostly with earphones. This international group included four graduate students of piano performance at the Yale School of Music (two Americans, one Chinese, one Korean) and four experimental psychologists (one Austrian, one British, and two Dutch) who are either active amateur musicians or have a strong interest in classical music performance. The author was one of them. Subjects listened to the tests in the order AT, A, T (with the exception of the author, who listened to the T test before the A test).

Results and Discussion

PILOT SUBJECTS

Before tabulating the pilot results, the data were checked for possible order effects. The four different pulsed versions had been presented in a fixed order for each piece, approximately counterbalanced across the pieces but not across subjects. If there had been a strong effect of stimulus order on subjects' ratings, this would have caused an artifactual piece by pulse interaction and could have camouflaged some positive results for individual pieces. An analysis of variance was therefore conducted, with composers, pieces, and ordinal position of pulsed versions (ignoring pulse type) as factors. Unexpectedly, there was indeed a highly significant main effect of position [$F(3,282) = 10.47$, $p < .0001$]: Ratings increased from the first to the fourth position. This trend was not consistent across composers, however, as shown by a significant position by composer interaction [$F(9,846) = 6.53$, $p < .0001$]: Beethoven (always first in each demo-test) showed a strong increase, Haydn a weak one, Mozart showed only elevated ratings for position 3, and Schubert showed an increase together with a dip for position 3. Even though these variations may in part have been due to imperfect counterbalancing, it seemed prudent to remove them from the data, together with the position main effect. In order to accomplish this, the average rating for each ordinal position was subtracted from the average rating for each pulsed version of each piece, separately for each composer. This transformation of the data had only a small effect on the composer averages, because of the reasonable counterbalancing used; however, the pattern of responses to individual pieces changed considerably in some instances, especially for Beethoven.

These adjusted results are shown in Table 5. Consider first the matrix of composer averages at the bottom, which was obtained by averaging the ratings across the five pieces of each composer, and hence also across the five groups of subjects. Clynes's theory predicts a composer by pulse interac-

TABLE 5
AT Test Results of Pilot Subjects: Average Ratings (Corrected for Order Effects) and Familiarity Scores

Composer	Pulse				Familiarity (% "yes")
	B	H	M	S	
Beethoven					
1 (York)	1.12	0.05	0.54	−0.95	57
2 (Cambridge)	−0.25	0.61	0.58	−0.19	64
3 (Nijmegen)	1.02	0.05	−0.26	−0.50	32
4 (Exeter)	0.48	0.01	0.26	−1.53	40
5 (Sussex)	1.30	−0.06	−1.03	−1.97	62
Haydn					
1 (York)	0.00	0.65	−0.31	−1.86	19
2 (Exeter)	0.56	0.87	0.62	−0.74	50
3 (Sussex)	−0.71	−0.23	0.31	−1.72	8
4 (Cambridge)	0.62	0.84	1.01	−0.42	50
5 (Nijmegen)	0.09	0.05	0.68	−1.22	42
Mozart					
1 (Sussex)	2.25	0.83	−0.81	−0.15	69
2 (York)	0.27	1.31	0.09	0.61	71
3 (Nijmegen)	−1.91	−0.20	−1.16	−0.58	42
4 (Cambridge)	0.03	0.47	0.24	−0.89	45
5 Exeter)	0.15	0.34	−0.93	0.43	35
Schubert					
1 (Exeter)	−0.90	0.48	−0.93	−1.52	80
2 (Sussex)	−0.73	1.16	0.27	0.13	8
3 (Cambridge)	0.27	1.14	0.62	0.09	36
4 (Nijmegen)	0.99	0.28	−0.06	−0.17	47
5 (York)	−0.33	−0.98	−0.30	−0.38	48
Composer averages					
Beethoven	0.73	0.13	0.02	−1.03	51
Haydn	0.11	0.44	0.46	−1.19	34
Mozart	0.16	0.54	−0.51	−0.12	52
Schubert	0.06	0.42	−0.08	−0.37	44

tion, such that the "correct" versions in the diagonal of the matrix receive the highest ratings in each row and column. As can be seen, however, this prediction was not confirmed: Only Beethoven's music was rated highest with the Beethoven pulse, and vice versa. For both Mozart and Schubert, the performances with the "correct" pulse received the lowest average ratings, and the Mozart pulse was also rated lower in Mozart than in any other composer's music. The upper parts of the table reveal substantial variation between pieces of the same composer (confounded here with different subject groups). Four of the five Beethoven pieces (B1, B3, B4, B5) received the highest rating when played with the correct pulse; however, the same was true for only two of the Haydn pieces (H1, H2), and for none of the Mozart and Schubert pieces. Preferences for incorrect pulses were sometimes pronounced (e.g., for the Beethoven pulse in M1).

Two analyses of variance were conducted on these data, one taking individual subjects as the random variable and the other taking composers' individual pieces (confounded with subject groups) as the random variable. There was a highly significant main effect of pulse, both across subjects [$F(3,270) = 12.60$, $p < .0001$] and across pieces (groups) [$F(3,12) = 31.24$, $p < .001$], due to an overall preference for the Haydn and Beethoven pulses, and a general dislike for the Schubert pulse. There was also a significant composer by pulse interaction across subjects [$F(9,810) = 3.45$, $p < .0003$], but it was only barely significant across pieces (groups) [$F(9,36) = 2.27$, $p < .05$], owing to the substantial variation from piece to piece (or from group to group). In any case, the interaction did not reflect the pattern predicted by Clynes's theory, with the exception of Beethoven. In fact, the results are not unlike those obtained for the set of minuets in Repp (1989a).

An additional analysis was conducted to assess the role of the listeners' musical experience, which covered a very wide range in the present subject group. Although no direct estimate of musical experience was obtained, the subjects did indicate whether or not they were familiar with each of the four pieces they listened to. Individual familiarity scores (total number of "yes" responses) thus ranged from 0 to 4, and it may be assumed that a high score indicates greater musical experience. The overall analysis of variance was repeated with familiarity (low = 0, 1; medium = 2; high = 3, 4) included as an additional between-subjects factor. However, none of the effects involving familiarity came even close to significance. Nor was it the case that the pieces in which the correct pulse was preferred were much more familiar overall than the rest. The last column of Table 5 lists the average familiarity scores (the percentage of subjects who said "yes") for each piece. The most familiar pieces were S1, M2, and M1, none of which showed the predicted pattern of pulse preferences.

STUDENT SUBJECTS

A second set of data for the AT test were derived from 32 subjects who listened to the whole test, so differences between pieces were no longer confounded with differences between subject groups. First the data were examined for order effects. There was again a main effect of ordinal position [$F(3,93) = 21.20$, $p < .0001$], due to an increase in ratings across positions; and there was also a significant position by composer interaction [$F(9,279) = 8.35$, $p < .0001$], similar to that obtained for the pilot subjects, even though the student subjects listened to five pieces per composer. The order effects were removed from the data by subtraction, as before. The corrected data are shown in Table 6.

Analyses of variance on these data showed again a highly significant pulse main effect, both across subjects [$F(3,93) = 31.59$, $p < .0001$] and across pieces [$F(3,48) = 33.76$, $p < .0001$]. The rank order of pulse preference was the same as for the pilot subjects: Haydn, Beethoven, Mozart, Schubert. Importantly, however, the composer by pulse interaction was not significant, neither across subjects [$F(9,279) = 1.49$, $p < .1517$] nor across pieces [$F(9,48) = 0.56$, $p < .8245$]. In this set of data, it was also possible to test the pulse by piece interaction, which was highly significant [$F(48,1488) = 2.84$, $p < .0001$]. Subjects' judgments thus varied reliably among pieces (treated here as a fixed factor nested within composers), but not among composers. The ratings for individual pieces were similar to, although not always congruent with, those given by the pilot subjects. The correct pulse was preferred in three Beethoven pieces (B1, B3, B5) and in two Haydn pieces (H2, H5), but in no Mozart or Schubert pieces. This pattern is almost certainly a consequence rather than a cause of the pulse main effect: For example, the Beethoven pulse was also preferred in H4, M2, S4, and S5.

The data were reanalyzed with subjects' musical experience as an additional between-subjects variable. The subjects were divided into three groups based on their overall familiarity with the 20 pieces in the test (0–6 "yes" responses = low, $n = 8$; 7–12 = medium, $n = 14$; 13–20 = high, $n = 10$). This analysis showed no significant interaction involving pulses and familiarity. It may be concluded, therefore, that familiarity with the music did not influence listeners' responses to the pulses.

The average familiarity scores for the 20 pieces are shown in the last column of Table 6. They showed some resemblance to those obtained for the pilot subjects ($r = .49$, $p < .05$), even though the pilot subjects were mostly British whereas the student subjects were mostly Dutch. In particular, the two most familiar pieces (S1, M2) were the same, and substantial differences occurred only for several Haydn pieces.

TABLE 6
AT Test Results of Student Subjects: Average Ratings (Corrected for Order Effects) and Familiarity Scores

Composer	Pulse B	Pulse H	Pulse M	Pulse S	Familiarity (% "yes")
Beethoven					
1	0.53	0.35	−1.29	−1.12	59
2	0.00	1.24	−0.52	−1.47	41
3	2.71	1.76	−0.31	−0.65	31
4	0.09	1.29	0.00	−1.48	22
5	1.01	−0.13	−1.17	−0.82	66
Haydn					
1	−1.52	−0.06	−1.62	−2.75	72
2	0.95	1.81	0.45	0.31	19
3	0.75	0.01	−0.21	−0.97	50
4	1.07	0.41	0.19	−0.21	50
5	0.53	1.07	−0.25	−0.02	47
Mozart					
1	−0.45	−0.13	−2.15	−1.47	63
2	0.97	0.38	−0.44	−0.01	75
3	−0.12	0.34	−1.42	−1.54	38
4	0.22	2.32	1.24	−0.97	66
5	1.34	1.91	0.43	−0.43	56
Schubert					
1	−0.25	0.86	−0.87	−1.31	88
2	−1.42	1.32	−0.53	−0.50	16
3	0.57	0.79	−1.21	−1.42	34
4	1.64	1.22	0.00	−0.65	38
5	1.44	0.33	0.04	−0.03	66
Composer averages					
Beethoven	0.87	0.90	−0.66	−1.11	44
Haydn	0.36	0.65	−0.29	−0.73	48
Mozart	0.39	0.96	−0.47	−0.88	60
Schubert	0.40	0.90	−0.51	−0.78	48

In summary, these data offered a comparison of the various conditions within subjects but provided no evidence for a composer by pulse interaction. There was only an overall preference for certain pulses over others and significant changes in this pattern across different compositions.

EXPERT SUBJECTS

These eight subjects provided data for all three tests: AT, A, and T. An initial overall analysis of variance showed all effects involving tests to be significant; thus there were substantial differences in response patterns across the three tests. Therefore, each test will be considered separately.

AT Test

Once again, there was an effect of ordinal position [$F(3,21) = 7.64, p < .0021$] which interacted with composers [$F(9,63) = 6.19, p < .0001$]. Its pattern was not unlike that observed previously. The corrected data are shown in Table 7, together with the average familiarity ratings. These musi-

TABLE 7
AT Test Results of Expert Subjects: Average Ratings (Corrected for Order Effects) and Familiarity Scores

Composer	Pulse B	Pulse H	Pulse M	Pulse S	Familiarity (% "yes")
Beethoven					
1	2.45	−0.40	−0.37	−1.97	100
2	0.22	−0.50	−1.22	−2.17	75
3	3.87	2.70	1.10	0.03	88
4	−0.27	2.90	−0.17	−1.25	38
5	0.28	−0.65	−1.75	−2.80	88
Haydn					
1	0.17	0.38	−1.74	−2.44	50
2	2.25	1.93	−0.07	−1.37	75
3	0.05	0.55	0.00	−2.49	25
4	0.17	−0.32	1.63	−1.24	75
5	1.88	0.75	0.80	−0.82	63
Mozart					
1	−1.19	−1.60	−1.77	−1.52	100
2	1.68	1.35	−1.14	−1.47	75
3	2.10	−0.39	−1.07	−1.22	63
4	0.35	0.48	2.15	−1.32	75
5	2.73	1.93	2.15	−2.14	88
Schubert					
1	1.65	2.45	−0.92	−2.27	100
2	−2.29	0.70	−0.64	−1.72	38
3	1.60	1.40	−0.80	−2.54	88
4	2.58	−0.02	−0.22	−1.30	88
5	2.32	0.08	1.10	−1.10	100
Composer averages					
Beethoven	1.31	0.81	−0.48	−1.63	78
Haydn	0.90	0.65	0.12	−1.67	58
Mozart	1.13	0.35	0.06	−1.53	80
Schubert	1.17	0.92	−0.29	−1.78	83

cally experienced listeners gave much more negative ratings overall than the previous subjects, although the order effect correction removed that trend. There was also a wider range of scores, suggesting that these subjects were more confident and more consistent than the earlier groups. They were also more familiar with the music (see the last column of Table 7).

In the statistical analysis, there was a highly significant pulse main effect, both across subjects [$F(3,21) = 42.21$, $p < .0001$] and across pieces [$F(3,48) = 26.55$, $p < .0001$]. In contrast to the earlier subjects, the "experts" showed a clear preference for the Beethoven over the Haydn pulse; otherwise, the rank order was the same as previously. The critical composer by pulse interaction, however, was far from significance, even across subjects [$F(93,63) = 0.70$, $p < .7081$]. The pulse by piece interaction was highly significant [$F(48,336) = 3.07$, $p < .0001$]. Thus, the subjects' judgments varied only from piece to piece, but not from composer to composer.

A Test

As with the AT test, there was a significant effect of ordinal position [$F(3,21) = 5.71$, $p < .0051$], again reflecting a tendency for ratings to increase across the four positions, as well as a composer by position interaction [$F(9,63) = 4.93$, $p < .0001$]. It should be noted that the order of the pulsed versions for individual pieces was different in this test from that in the AT test; however, the overall distribution of pulses across positions was the same because a permutation of the AT design was used. The corrected data are shown in Table 8.

There was a highly significant pulse main effect across subjects [$F(3,21) = 23.19$, $p < .0001$] and across pieces [$F(3,48) = 14.69$, $p < .0001$]. Again, the Beethoven pulse was preferred most, and the Haydn pulse was second. A major difference with respect to the AT test was the relatively higher (but still low) rating of the Schubert pulse, which was preferred to the Mozart pulse here. The composer by pulse interaction fell short of significance, even across subjects [$F(9,63) = 1.81$, $p < .0843$]. The pulse by piece interaction was highly significant, however [$F(48,336) = 2.31$, $p < .0001$].

T Test

In contrast to the other two tests, there was no significant main effect of ordinal position here, even though another permutation of the AT test design was used. If anything, ratings tended to decrease across test positions. The composer by position interaction was significant, however [$F(9,63) = 3.26$, $p < .0026$], although its pattern was quite different from that found in the other two tests. A correction for order effects was nevertheless applied, and it resulted in the data shown in Table 9.

TABLE 8
A Test Results of Expert Subjects: Average Ratings (Corrected for Order Effects)

Composer	Pulse B	Pulse H	Pulse M	Pulse S
Beethoven				
1	0.83	0.72	−1.17	−0.50
2	0.10	−1.25	−3.04	−2.05
3	1.58	2.57	3.50	2.60
4	1.07	1.08	−1.77	−2.25
5	0.50	−0.42	−1.52	−0.42
Haydn				
1	1.53	−0.42	−2.95	0.62
2	1.45	2.30	−0.72	0.37
3	0.05	−0.80	−2.12	−0.09
4	1.25	0.53	−0.67	0.30
5	0.30	−0.12	−1.22	0.45
Mozart				
1	−0.45	−2.04	−1.47	−0.89
2	0.83	−0.59	−0.95	−1.77
3	0.65	−0.79	0.10	−0.70
4	1.28	0.55	−0.27	2.83
5	1.55	2.85	−0.79	0.15
Schubert				
1	1.37	1.72	−1.90	0.52
2	0.97	−0.22	−0.77	−1.13
3	0.24	0.85	−1.22	−1.40
4	0.47	0.12	−0.90	−0.85
5	1.77	−0.63	−0.02	0.97
Composer averages				
Beethoven	0.81	0.54	−0.80	−0.52
Haydn	0.91	0.29	−1.53	0.33
Mozart	0.77	0.00	−0.67	−0.07
Schubert	0.96	0.36	−0.96	−0.37

There was a highly significant main effect of pulse across subjects [$F(3,21) = 63.36$, $p < .0001$] and across pieces [$F(3,48) = 70.31$, $p < .0001$]. The ranking of composers' pulses was quite different from that in the **A** test: The Mozart pulse was preferred most, with the Haydn pulse a close second, the Beethoven pulse third, and the Schubert pulse last. Ratings were also more positive overall than in the A test, although this trend was eliminated by the order correction, which effectively normalized the data. In contrast to the AT and A tests, there was a significant composer by pulse interaction across subjects [$F(9,63) = 4.28$, $p < .0002$], although it did not

TABLE 9
T Test Results of Expert Subjects: Average Ratings (Corrected for Order Effects)

Composer	Pulse B	Pulse H	Pulse M	Pulse S
Beethoven				
1	0.99	1.52	−0.45	−0.85
2	−0.33	1.02	1.40	−3.25
3	1.27	0.92	1.87	0.52
4	−0.10	0.79	0.74	−0.97
5	−0.95	−0.38	−0.47	−3.35
Haydn				
1	−0.32	0.02	−0.55	−1.42
2	0.89	1.30	1.45	−2.05
3	−0.55	0.32	0.67	−1.35
4	−0.73	2.20	2.07	−2.45
5	0.19	0.80	1.14	−1.67
Mozart				
1	−2.37	0.40	2.07	−2.55
2	0.02	1.25	1.57	−1.55
3	0.40	1.70	2.32	−1.87
4	−2.17	−0.92	1.38	−2.72
5	−0.05	1.63	1.90	−0.42
Schubert				
1	−1.67	1.10	1.35	−2.45
2	−1.70	0.70	1.48	−3.02
3	0.35	2.30	1.32	−1.89
4	0.48	2.30	0.85	−1.67
5	−0.45	0.47	1.32	−1.14
Composer averages				
Beethoven	0.17	0.77	0.61	−1.58
Haydn	−0.10	0.92	0.95	−1.79
Mozart	−0.83	0.81	1.85	−1.82
Schubert	−0.59	1.37	1.26	−2.03

reach significance across pieces [$F(9,48) = 1.84, p < .0852$]. Mozart was liked best with the Mozart timing pulse, and vice versa. The Haydn timing pulse was tied with the Mozart timing pulse for preference in Haydn's music. The Beethoven timing pulse was liked best in Beethoven, although the reverse did not apply. The Schubert timing pulse was universally disliked. Ratings varied substantially across pieces. The pulse by piece interaction was highly significant [$F(48,336) = 2.22, p < .0001$].

Relation of the AT Results to the A and T Results

The purpose of separating the amplitude and timing components of the pulses was to get some indication of their relative contributions to the perception and evaluation of the complete pulses. For that purpose, a multiple regression analysis was conducted on the average ratings of all 80 performances (Tables 7–9). The multiple correlation was .70; that is, about half of the variance in the AT data could be accounted for by a linear combination of the A and T data, with the contributions of the two components being nearly equal. A similar analysis on the composer averages (the bottom parts of the tables) yielded a multiple correlation of .90. Separate analyses on each individual composer (20 performances each) revealed multiple correlations of .75–.77 for three composers and a lower value (.60) for Mozart. Interestingly, in Haydn the timing component was much more important than the amplitude component, whereas in the other composers the two components made equal contributions (Beethoven) or amplitude was slightly more important (Mozart, Schubert). The reasons for these variations are not clear, however.

On the whole, these analyses show that amplitude and timing modulations both influenced listeners' responses when they occurred in combination and that their relative importance was roughly equal for the settings used here.

INDIVIDUAL PIECES

A challenge posed by the present data was to explain why certain pulse patterns fit some pieces better than others (i.e., the pulse by piece interaction). Three possibilities were considered: First, it is possible that pulse preferences interacted with pulse cycle duration, which varied substantially across pieces (cf. Table 1). Second, the interaction could be an artifact of having maintained the original note durations in the stimuli. Finally, and most interestingly, there may be structural aspects of the music (rhythm, melodic contour, harmonic progression) that account for the differential effects of the pulses.

Cycle Duration

The possible role of pulse cycle duration was investigated by computing the multiple correlation between pulse cycle duration and the ratings elicited by the four pulses across the 20 pieces. Four such correlations were computed: one for the student subjects (Table 6), and one for each of the three tests completed by the expert subjects (Tables 7–9). None of them was significant, which suggests that pulse cycle duration was not an important variable.

Note Durations

It will be recalled that, in generating the stimulus materials, the note durations of the original performances (by the author) were maintained. After the equalization of OOIs, the offsets of notes were slightly misaligned with the onsets of following notes, with some consequences for the perceived smoothness of articulation, although they were judged to be negligible. The introduction of the timing pulses resulted in further misalignments, similar for all pieces. However, if any of the author's original performances had contained a timing "pulse" resembling one of Clynes's pulse patterns, then introduction of that pattern would have brought the notes into better alignment than introduction of some other pulse. The hypothesis to be investigated was, consequently, that the piece by pulse interaction might reflect the presence of timing pulses in the original performance that resembled one or another of the Clynes pulses.

Information about the timing of the original performances was available in their MIDI scores. The proportions of the four OOIs within each full pulse cycle (defined as in the computer performances) were calculated, averaging the onset times of notes intended to be simultaneous and omitting cycles containing very large expressive deviations. These included, as a rule, the first and last cycles, in which a respective lengthening of the first and last notes was often observed (cf. Gabrielsson, Bengtsson, & Gabrielsson, 1983). The resulting data were subjected to a repeated-measures analysis of variance with the factors composer, piece (treated as a dummy factor), and OOI. Cycle-to-cycle variations within pieces provided the error estimate. A highly significant main effect of OOI was obtained [$F(3,447) = 20.70, p < .0001$], indicating a reliable "pulse" pattern overall. However, this pattern did not vary significantly across composers: The OOI by composer interaction was nonsignificant. In a second analysis, the composers were disregarded and pieces were substituted as a factor, omitting two pieces (B4, H1) for which insufficient data were available. Besides the OOI main effect, a significant OOI by piece interaction emerged [$F(51,444) = 2.07$, $p < .0002$], indicating that the timing pattern varied among pieces.

Each of the 18 pieces was then subjected to an individual one-way analysis of variance to determine the reliability of its timing pattern across time cycles. Five pieces (B2, M5, S1, S3, S4) showed a highly reliable timing pattern ($p < .0004$), and two additional pieces (B5, M2) a marginally reliable one ($p < .05$). The significant "pulse" patterns all had in common a reduction of the third OOI and a prolongation of the fourth, much like Clynes's Beethoven pulse (cf. Table 2). Only one of them (S3), however, showed the prolongation of the first OOI at the expense of the second that characterizes the Beethoven pulse; another (B2) exhibited the opposite pattern, and the rest had fairly equal durations of the first two OOIs.[4] Inspection of the most relevant perceptual data (those for the T test, Table 9) suggests no systematic differences in subjects' responses to those pieces that did or did not show a significant pulse pattern in the original performances; in particular, there is no obvious difference in subjects' response to the Beethoven pulse. This effectively rules out the hypothesis that the pulse by piece interaction in the perceptual data was an artifact of stimulus construction.

Musical Structure

The possible role of musical structure in the piece by pulse interaction is much more difficult to assess. Not only does it resist quantification, but it is not even clear what structural aspects are relevant. Informal inspection of the data suggested a possible structural basis only for the Mozart pulse, which has the simplest (essentially bipartite) structure. In the student and expert data for the AT test (Tables 6 and 7), the Mozart pulse received relatively favorable ratings in H4, M4, M5, and S5, whereas it was disliked in B2, B5, H1, M1, M3, and S3. The pieces in the first set tend to use short (two-note) motives within the melodic line, whereas the latter tend to use longer motives and, in several cases, appoggiaturas. Also, the pieces in the first set tend to be brisk and lighthearted, whereas those in the second set tend to be more lyrical and expressive. It makes good sense that the Mozart pulse, with its somewhat bouncy quality, fits the first set better than the second. No such differentiating characteristics were detected in the music relative to any of the other pulses, although the search was certainly not exhaustive.

General Discussion

As a test of Clynes's theory of composers' pulses, the present study provides negative results. The crucial composer by pulse interaction did not emerge; instead, there were strong pulse by piece interactions, indicating that pulse evaluations depended on the individual composition but not on its composer. The composer by pulse interactions obtained in the earlier study of Repp (1989a), where each composer was represented by only a

4. The cause for these "pulses" in the author's playing is unknown (they were not consciously intended), but it might be noted that six of the seven pieces with a significant pulse had an arpeggiated accompaniment in the left hand (exception: M5) and that the only other two pieces with such a left-hand part (B1, M3) in fact showed a similar pulse pattern, although not reliably.

single piece (in each of two sets), may well represent pulse by piece interactions also. Therefore, there is still no convincing evidence for the perceptual effectiveness of Clynes's pulses. This conclusion, however, should not be interpreted as showing Clynes's theory to be invalid. This study and its predecessor (Repp, 1989a) took a relatively simple-minded approach, and it is becoming increasingly clear that the theory is much more difficult to test that it seemed at first (to this author, at least).

Somewhat unconventionally, the present study has already been preceded by an extensive critique in this journal: Clynes (1990), referring to earlier conference reports of the present data (e.g., Repp, 1989b) and to a draft of this manuscript, has pointed out a number of methodological problems, which the author has acknowledged and responded to in considerable detail (Repp, 1990a). The reader interested in this exchange is referred to the papers cited. Only a brief summary of some major points is provided here.

Some of Clynes's criticisms concern the insufficient precision with which the composers' pulses were realized in the present materials. As acknowledged in the Methods section, there was some temporal distortion due to rounding error and loudness distortion due to nonlinearities in the electronic piano sound. Clearly, the pulses implemented here were not identical with those specified by Clynes, but they were still *similar* to them; they never violated the ordinal relationships among OOI durations or note amplitudes. Even though Clynes (1990) has seriously proposed that even small deviations from the pulse patterns specified by him may lead to musically meaningless microstructure, it is not clear whether the deviations perpetrated in the present materials would even be discriminable from the originals by most listeners. Even if they were discriminably different, however, their relative similarity to the "correct" composers' pulses (whose optimal shape, moreover, may vary to an unknown degree from listener to listener) should have led to a composer by pulse interaction in the data, albeit an attenuated one.

Clynes's most serious criticism concerns the pulse assignment in the present materials. Even though the author had consulted with him during construction of the materials, Clynes (1989) examined a subset of 12 of the 20 pieces and found the pulse assignment to be musically incorrect in 8 of them. Although Clynes's musical insights deserve the highest respect, it should be noted that in 9 of the 12 pieces he assigned the 4-beat pulse a cycle duration outside the range of 0.7 to 1.2 sec, which had served as a guideline in the construction of the present materials. Thus Clynes overturned the only quasi-objective guideline proposed by himself (Clynes, 1983) and opened the doors wide for subjective musical judgment in stimulus construction, which this author had been at pains to avoid.

Four pieces that, according to Clynes, had the correct pulse assignment in the present study were B3, H2, H4, and M4. In two of these (B3, H2) the correct pulse indeed received rather high ratings; this was not so for the other two pieces, however. Moreover, it is not clear why even in those pieces that, according to Clynes, had incorrect pulse assignments, the composers' individual characteristics were not conveyed by the pulses to some extent. Misassigned pulses might be expected to be rated lower across the board, but why does the misassignment nullify their composer-specific qualities?

Additional criticisms raised by Clynes concern the unsuitability of certain pieces because of uneven note densities that interact with the pulse, the relatively short duration of the excerpts, and (indirectly) the insufficient musical sophistication of the subjects. These points are reinforced by new data collected by Clynes and reported very cursorily in the oral version of Clynes (1989). That study, which was stimulated by a preview of the present negative findings, used materials constructed according to Clynes's subjective criteria and obtained results supporting the pulse theory, with most of the positive evidence coming from a listener group of world-famous musicians. Hopefully, these data will be published soon.

If having provoked Clynes's astute criticism and ambitious follow-up study were the only merit of the present study, this detailed report would hardly be necessary. However, the results may be of some value even without reference to the concept of composers' pulses. They add to the growing evidence (Repp, 1989a; Thompson, 1989; see also Clarke, 1989) that listeners, even those without extensive musical training, can readily discriminate different patterns of time-amplitude modulation in real music and can make reasonably consistent aesthetic judgments about them. They show that some of these patterns are preferred over others and that their order of preference depends to a considerable extent on the musical structure of a composition, in a way that remains to be elucidated further. Finally, they also show that timing and amplitude modulations of the magnitude used here contribute about equally to listeners' judgments when they occur in conjunction. Findings such as these provide a useful basis for more detailed investigations of the parameters of music performance appreciation.

However, these findings were obtained with pulse microstructure and need to be generalized to more realistic performance patterns. The concept of a pulse in performance remains controversial, apart from its composer-specific aspect. Its very exactness and rigidity defeat the effect it is meant to achieve, namely a deviation from the exact and rigid. Studies of music performance uniformly suggest that expressive deviations are flexibly adapted to the musical structure of a composition (see, e.g., Clarke, 1983, 1988; Gabrielsson, 1987; Palmer, 1989; Repp, 1990b; Shaffer & Todd, 1987). Great composers have at their command a large palette of structural and expressive devices that call for a corresponding diversity of appropriate performance variations. How rigid pulse microstructure can coexist with all this diversity remains one of the unsolved puzzles surrounding the concept of composers' pulses. It is hoped that the present study, despite its negative aspects, will provide a stimulus for further examinations of Clynes's intriguing ideas and of their place in a general theory of music performance.[5]

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Appendix: Musical Materials

Beethoven:

B1. Sonata op.13, mvmt. 4

B2. Sonata op.22, mvmt. 4

B3. Sonata op.101, mvmt. 4

B4. Bagatelle op.33, no. 4

B5. Sonata op. 7, mvmt. 4

Haydn:

H1. Sonata H.XVI/20, mvmt. 1

H2. Sonata H.XVI/48, mvmt. 2

H3. Sonata H.XVI/32, mvmt. 3

H4. Sonata H.XVI/37, mvmt. 1

H5. Sonata H.XVI/34, mvmt. 3

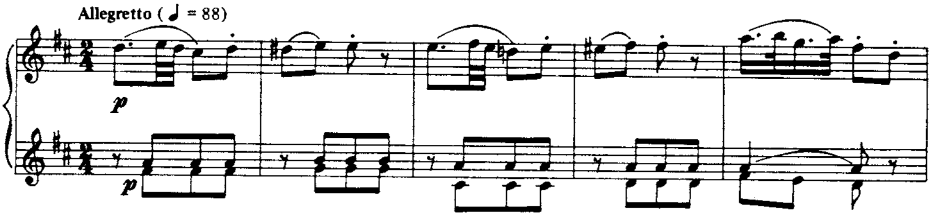
Mozart:

M1. Sonata K.310, mvmt. 1

M2. Sonata K.303, mvmt. 3

M3. Sonata K.533, mvmt. 1

M4. Sonata K.576. mvmt. 3



M5. Sonata K.281, mvmt. 3

Schubert:

S1. Impromptu D.935, no. 3

S2. Sonata D.845, mvmt. 4

S3. Sonata D.664, mvmt. 1

S4. Sonata D.959, mvmt. 4

S5. Moment Musical D.780, no. 3