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PIANO LEARNING AND PROGRAMED INSTRUCTION

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In musical education, the use of principles of programed instruction is still largely confined to proficiencies in musical perception and to the provision of the basic rules of music theory. Ihrke was the first to take a decisive step beyond this, in that he required an immediate musical response from pupils and subjected this response to objective control.[1] A further step in this direction was the computer-controlled device for the automatic control of pitch, which was developed by Kuhn and Allvin and used at first for problems of intonation in singing.[2] Finally Herberger, who drew on Ihrke's idea in formulating his own technique of the automatic control of rhythm, mentions in a survey of the present stage of development a teaching device, also computer-controlled, that is used in the U.S.S.R. as an introduction to the elements of piano playing.[3]

An attempt to develop methods of programed instruction for more advanced levels of instrumental instruction results in a number of difficult problems. The more demanding the musical exercise, the more complicated becomes the sensorimotor process of translating written music into sound. Specific difficulties of technique associated with a particular instrument also come to the fore. Those pupils who fail to surmount those specific difficulties after the learning of basic skills are still in the majority.

[1] W. R. Ihrke, "Automated Rhythm Training," progress report, *Council for Research in Music Education Bulletin*, No. 7 (1966), pp. 34-37.

[2] W. E. Kuhn and R. L. Allvin, "Computer-Assisted Teaching: A New Approach to Research in Music," *Journal of Research in Music Education*, Vol. 15 (Winter 1967), pp. 305-315.

[3] R. Herberger, *Möglichkeiten und Grenzen der Programmierung des Musikunterrichts* (doctoral dissertation, Leipzig University, German Democratic Republic, 1970); Ihrke.

The pupil who is learning an instrument is confronted with the problem of what is right and what is wrong, not only from a musical but also from a motoric standpoint. He also requires specific information in order to have a direct influence on the learning process. But even if such information could be obtained by using suitable measuring devices, it would still be uncertain which features of the motor process should be described as correct or as optimal and whether any universally valid optimums could be recognized at all, so that a possible basis for a desired value/actual value comparison might be provided. But even the definition "desired musical values"—applied to pitch, duration, and loudness—becomes more problematical as the musical exercise becomes more demanding. There is also the problem of deciding which pieces of information are of primary importance and to what extent and at what point of time they should be supplied, so that they can actually be processed. Finally a solution has to be found to the problem of effecting the reduction of the measurement data supplied, to manageable proportions capable of assessment. Some solutions to the problems involved in piano playing will be provided in this article.[4]

The piano was used as the test instrument in this study because it is felt to be the most suitable medium for special research in the field of programed music instruction. Compared with sound production by string and wind instruments and the singing voice, the process of sound production by the piano is relatively simple. The pitch of the piano does not have to be regarded quantitatively but only as right or wrong. Physical movements of pianists can be seen more easily than those of string or woodwind instrumentalists, and extreme joint positions do not occur so frequently when one plays the piano as when one plays the violin. In addition, the installation of the measuring equipment can be effected the most suitably without having an adverse bearing on the function of the instrument. With the piano, the whole complex of technical and musical exercises—from the most simple to the most complex—is at one's disposal. Consequently, learning processes at all stages of piano-playing ability can be examined comparatively.

The most restricting factor in piano playing is one's commitment to the tempo specified in the musical text. Irrespective of the type of instrument, the assessment of tempo and rhythm is of primary importance in the evaluation of musical performances. For this reason the investigations were begun by analyzing the time structure of playing. The original aim was not to develop a training device for piano playing that could be programed. Too little was known about what else is involved beyond acoustic, optical, and kinesthetic perception when written music is translated into sound. As it became clear that important assertions could be made about both the musical and the sensorimotor learning processes simply by recording the time structure of playing, it was obvious that suitable experimental equipment could be developed.[5] Furthermore,

[4] The research reported here was supported by the Volkswagen Foundation.

[5] C. Wagner, "Untersuchungen zur Ergonomie des Klavierspiels," *Biomechanics I*

before this objective can be reached, a number of other problems—particularly that of dynamic control—will have to be solved. It is precisely in exercises that go beyond the beginner's stage that the time and dynamic structures of playing should not be regarded separately from each other.

The Experimental Equipment

A clear view of the time structure of piano playing is obtained when the intervals of time that elapse between the beginning of one note and the beginning of the succeeding note are recorded. The time-interval measuring equipment (see Figure 1) contains a quartz oscillator with a basic frequency of 100 ks and an accuracy of $\pm 10^{-5}$. The basic frequency

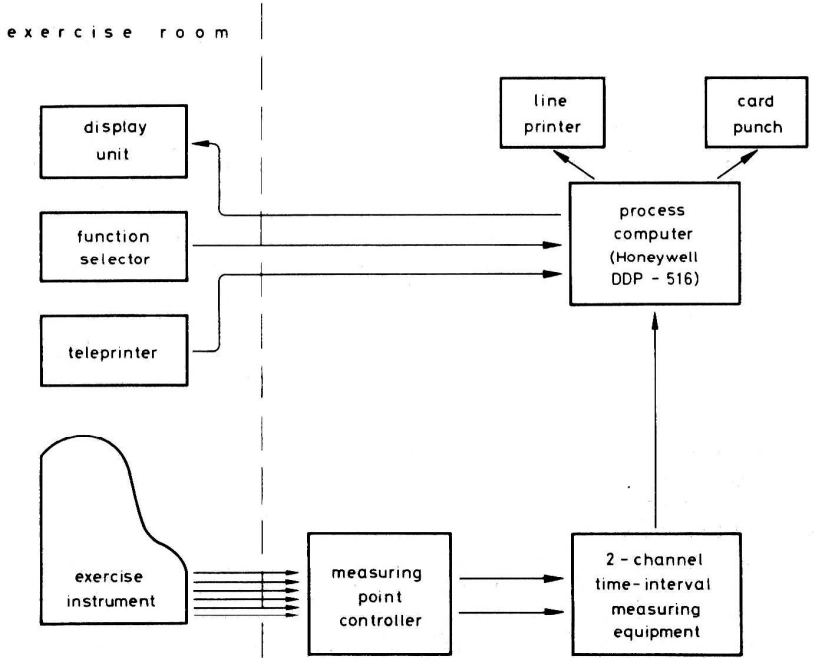


Figure 1. System for Automatic Control of Time Structure of Piano Playing

(First International Seminar, Zürich, Switzerland, 1967) (Basel, Switzerland: Karger, 1968), pp. 264-270; "Zum Problem des Übens in der Musik," *Musik im Unterricht* (Allgemeine Ausgabe), Vol. 59 (1968), pp. 3-8; "The Influence of the Tempo of Playing on the Rhythmic Structure Studied at Pianist's Playing Scales," *Medicine and Sport*, Vol. 6 (*Biomechanics II*, Basel, Switzerland: Karger, 1971), pp. 129-132.

is subdivided into units of 1 kc, so that the integrating meter is regulated in time measurements of 1 ms. In the test instrument, a Bechstein piano, an electric impulse that sets the meter in motion by means of an on-off switch is produced at the moment when a hammer strikes a piano string. The impulse caused by the next impact stops the meter, its content is registered on a buffer storage device, the meter content is cancelled, and the meter is started up again. The process between stopping and starting of the meter requires 10μs which, bearing in mind the magnitude of the readings, can be dismissed as infinitesimal.

To be able to control each hand separately in two-hand playing, a measuring point controller was inserted between the test instrument and the measuring equipment. It thus was possible for each of the eighty-eight keys to be provided alternately with two different measuring channels, each with a meter. There is, of course, no way of identifying by this means when certain keys are struck by the two hands successively. This was borne in mind in choosing the exercise pieces and in the evaluating. However, there is nothing to prevent experiments with exercises involving crossing-over of hands.

The data provided by the two buffer storage devices are fed continuously into a process computer, Honeywell DDP-516. After the function selector has been set in motion, the computer expresses the readings and their parameters in chart form, and stamps them on punched cards for further analysis. The original or reduced data or relevant diagrams are then shown on a display device. The test subject can use a teleprinter to give details of the exercise record, and can himself determine the tolerance limit in the assessment of his performance. Furthermore, he can stipulate by means of the function selector the form of feedback most suited to his information requirements, if there are different forms available in the computer program. The equipment works reliably for more than a year. It is tested at regular intervals with a device constructed for this purpose. The accuracy of the entire experimental equipment, including the piano, amounts to ± 1 ms. The only exceptions are the time intervals of less than 10 ms, which are not registered due to the extent of the control impulses.

The relatively precise measurement of time intervals to ± 1 ms might be regarded as unnecessary in the first instance, as the ear scarcely can be aware of time differences of this magnitude. The investigations showed, however, that beyond this threshold there can or perhaps must exist a complex of infrastructures that are the immediate expression of the motoric event. These infrastructures may also be of use as specific information for the control of the sensorimotor learning process and will remain imperceptible in an analysis that is ten times less detailed.

Quantitative Evaluation of Time Intervals

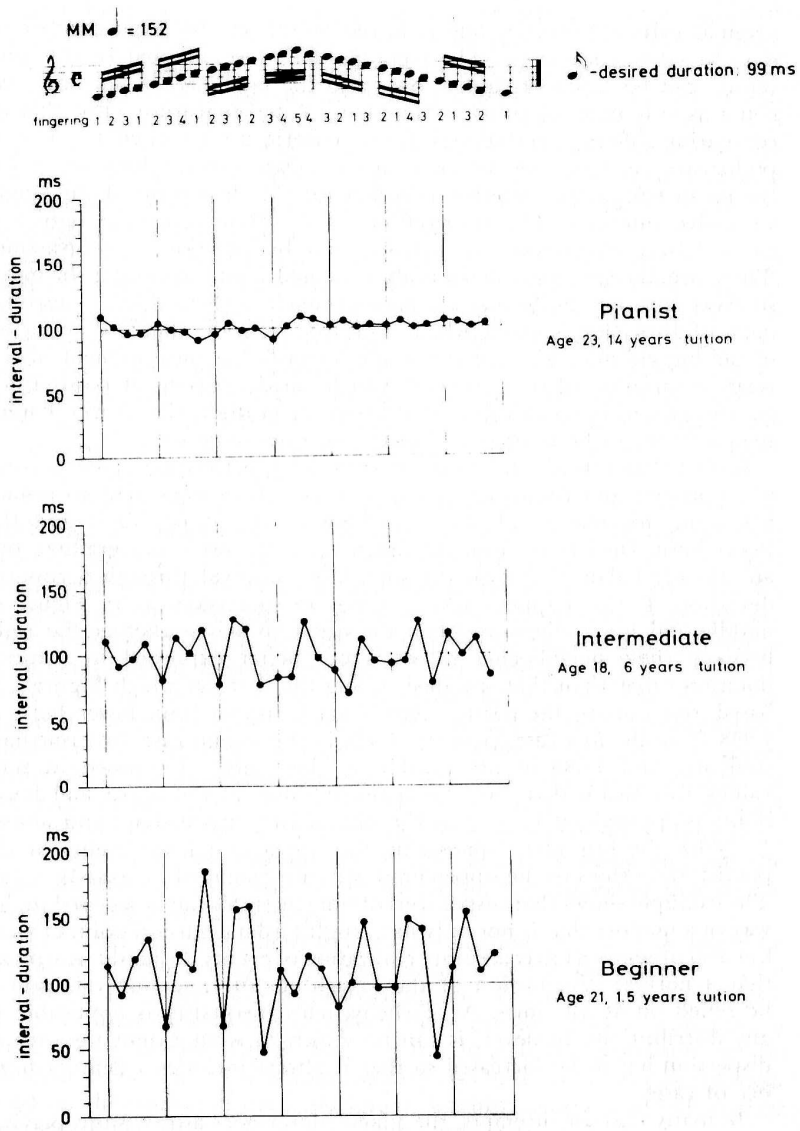
In the evaluation of the time structure of piano playing, it is only in exceptional cases that one can be content with a consideration of the

original values. Normally one is forced to reduce the large number of data to a few parameters. The methods that were adopted in this procedure can be easily explained, owing to the fact that the musical text contains only notes of equal value. Figure 2 makes it quite clear that in comparing different performances, two criteria are required for a comprehensive analysis: one criterion for the mean interval duration or for the mean tempo, and another criterion for the dispersion of the single successive intervals. The distribution of the time process in music is effected by multiplication or division, not by addition or subtraction. Therefore, the geometric mean is always stated when expressing the mean interval duration. Following a suggestion made by Schneider, a measurement of dispersion is stated, which is derived from the standard deviation of the logarithmic values of the single intervals.[6] A measurement of the relative variation of time intervals can be made, making it possible for the dispersions in mean values of different magnitude, that is in different tempo levels, to be compared directly with one another.

Rather than consider the ratio between the upper respective lower limit of dispersion and the mean value, it is sometimes expedient to obtain first-hand information of the ratio between the upper limit and the lower limit. Deviations from the mean value are often not gradual, but are already balanced out in the succeeding interval through a counter deviation. If this happens several times in succession—as in Figure 2, middle and lower diagrams—then the question arises whether the ratio between these neighboring values is not better expressed by using a notation other than that specified. Using the data on which Figure 2 is based, one obtains the results 1.098 (that is, upper limit:lower limit = 1.098:1) in the first case (pianist), 1.426 in the second case (intermediate student), and 1.985 in the third case (beginner). Expressed in note values, this means that the ratio between values at the upper and lower limits is approximately ♪. : ♪ in the case of the intermediate and almost ♪ : ♬ for the beginner. Comparing the upper and lower limits of the pianist, the values in the upper limit area are extended by exactly 1/163. The example shows that dispersions of time intervals can be assessed in this way in a manner that is not only meaningful from a musical point of view, but also provides a fairly accurate realization of events. It should be stressed that a normal distribution of the logarithms of time intervals cannot be relied on at all times. As Tschebycheff's inequality is applicable to any distributions, however, it can be shown to what extent the area of dispersion has to be increased so that it always includes a definite number of cases.

In many exercise attempts, the piano player goes astray, stops playing, and makes a fresh start. The time intervals that result have a different origin from the motorically conditioned deviations and are immediately

[6] B. Schneider, "Ausgleichsfunktionen und Transformationen," *Aufnahme und Auswertung forstlicher Versuchsflächen* (Giessen Congress, 1965) (Bad Godesberg, 1966).



igure 2. Time Intervals of Successive Notes in Playing a Scale

recognizable as mistakes to the player. If these abortive attempts are also to be suitably assessed, time intervals of this nature must be excluded, as they have a considerable influence on the mean value and the dispersion factor. Time intervals resulting from errors normally differ appreciably in size from the other time intervals. An automatic examination of the data material is carried out with regard to the minimum and maximum values at the beginning of the analysis of the computer program. Test quotients from Geigy are used.[7] This test also is carried out with the logarithms of the original values and is repeated until the quotient no longer exceeds the pertinent chart value. In the exercise report, the number of outliers is expressed as a percentage of the number of the values played, and can be drawn upon later in the assessment of the learning procedure. A further problem in quantitative analysis arises when there is a discernible trend in the sequence of readings. In this situation, a somewhat incorrect picture is presented by the mean value and the dispersion factor.

Piano Technique: Evenness

"A good pianist," writes H. Neuhaus, "must be able to play literally everything *evenly*, from the most simple elements of technique (scales, arpeggios, passage work of any kind, thirds, double thirds and sixths in particular, octaves) to the most complicated chordal combinations."[8] The study literature of the last two hundred years bears witness to the role that this problem has played in piano instruction. These elements of technique are found in various forms throughout the literature, and indeed they are notated almost exclusively in notes of the same value, the tempos being fast in most cases. An important aim of the sensorimotor part of piano instruction is thus clearly defined: evenness of time intervals in conjunction with a constant volume level, both in accordance with and within the limits of the requirements of the musical ear.

Experimental exercises that use this definition as their goal are carried out as follows. After the piano player has acquainted himself with the system, he provides information—his name, the date, the exercise piece (including the time signature)—through the teleprinter for recording purposes and establishes the tolerance limit to be used in the assessment of his performance. He then begins the data recording process by means of a push button on the function selector. A light signal indicates when the computer is ready. He then plays the scheduled piece, stops the data recording process on completing it, and at the same time sets the assessment mechanism in motion. According to the range of the computer program, the first information appears on the screen a second or so later.

[7] Geigy, *Documenta Geigy: Wissenschaftliche Tabellen*, seventh edition (Basel, Switzerland: Geigy AG, 1968).

[8] H. Neuhaus, *Die Kunst des Klavierspiels* (Russian edition), A. Schmidt-Neuhaus, ed., German edition (Cologne, German Federal Republic: Gerig, 1967).

The exercise consists of single passages for the right or left hand, to which the device is mainly used at the present time. The player is provided with four types of information, to which he can refer in succession.

The first type of information consists of two numbers. The higher number indicates the mean tempo played. The individual values are integrated into time units and their geometric mean converted into frequency per minute, so that this value can be compared directly with the intended metronome number. The lower number gives the dispersion of the individual values.

The second type of information (see Figure 3) takes the form of the representation of the quotients individual value/mean value in a system of coordinates. The y-axis is marked in such a way as to show the ratios

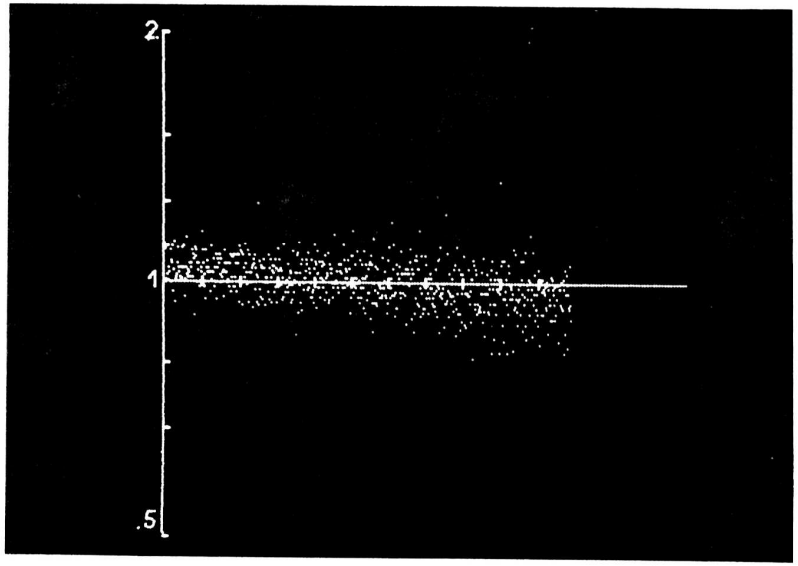


Figure 3. Performance of Scale Exercise with Right Hand: Duration of Time Intervals of Successive Notes in Relation to Mean Value of Intervals on Training Device Screen

1:1, 1:1.25, 1:1.5, and 1:2 as well as their inversions. The x-axis is subdivided into four-bar units. The significance of the extent of dispersion, detached from an absolute time scale here, can be easily appraised at all tempo levels. Positive deviations with the amplitude 1.25, 1.5, and 2.0 would correspond to note values. This representation makes possible a quick survey of the entire exercise process. In particular the player's

attention is directed to a possible tendency towards fluctuations in the mean tempo or in the dispersion that, under the circumstances, could be the first sign of fatigue before he himself is aware of it. He therefore obtains a general indication of his need to continue practicing and of the form this should take.

The third type of information draws attention to the passages where there have been more acute deviations from the mean value. The computer investigates the bars in which the quotients individual value/mean value exceed the specified tolerance area. "Practice bars 7, 8, 15, 29," for example, then appears on the screen. It is necessary to carry out this test with each interval individually because there is a danger that certain deviations, even though very conspicuous, can become established quickly when a series of notes is repeated with the same fingering.[9] This course of events is quite independent of the musical structure of the passage (compare Figure 2, middle and lower diagrams).

In the fourth type of information, the quotients individual value/mean value of each of the bars mentioned above are represented (see Figure 4).

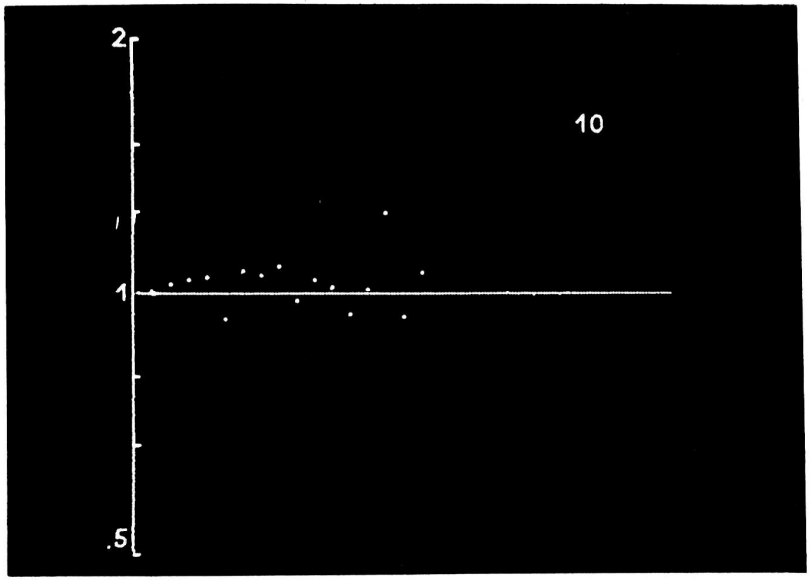


Figure 4. Detail of Figure 3: One Bar in Which Ratio of Individual Value/Mean Value Exceeded Tolerance Area

[9] Wagner, "Untersuchungen zur Ergonomie des Klavierspiels," and "Zum Problem des Übens in der Musik."

The representation of one bar is maintained until the next bar is recalled. The player has time, therefore, to consider the mistake in conjunction with the music or to try out the fingering at the keyboard. This way he can amend his performance accordingly when the bar is repeated. If the specified tolerance limit has not been exceeded in any bar, the word "complete" will appear earlier on the screen as part of the third type of information. One can return to the starting point of the program immediately after each stage of the information process if no further information is desired.

A special program for the intensive practicing of short passages is also provided. The feedback information provided consists simply of the metronome number of the passage played and the dispersion value, or only one of the two. In this program, the player has nothing to do with the appearance of the numbers, which takes place no later than one time unit after the final note. The numbers remain visible for about two seconds, after which the computer is ready again to receive data. The idea of this program is to spare the player all manipulations that might weaken his memory of the immediately preceding acoustical and motoric process, or interrupt his concentration on the musical target. He can read the information in tempo without raising his hands from the keyboard, and can resume playing precisely after one or two bars' rest.

It might be feared that aids of this kind will induce the player to depend eventually on external information only, without listening critically to his playing and controlling it independently. This danger is certainly present, but one must consider that only a very few pupils are capable of independent critical listening while they are playing. As a rule, the pupil has no clear awareness even of those mistakes that are audible, and his concentration on the acoustical and motoric processes quickly wanes. By means of the information made available by this program, one's attention is directed continually towards the crucial passages. Even the possibility of realizing at an early stage when improvement in performance cannot be obtained by further practice could be an important help. The control of complicated movements by the central nervous system is usually the quickest to tire, and this is reflected in the decreasing precision of the movements.[10] To continue an exercise in this situation is not only physiologically futile but also harmful, and it is in appraising this type of situation that the pupil lacks experience. Probably the most important function of instructional equipment in instrumental tuition is that it helps the pupil learn how to practice purposefully.

Tempo and Rhythm

Another group of programs is directed towards the control of tempo and rhythmic distribution in texts with unequal note values. These

[10] W. T. Singleton, "Deterioration of Performance on a Short-Term Perceptual-Motor Task," *Fatigue* (London: W. F. Floyd and A. T. Welford, 1953).

programs are less concerned with specific problems of piano technique than the exercise program previously described, but are directed more towards the cultivation of skills that are a prerequisite of every form of good musical performance. In this group of programs, nine types of information are available. These also depend, to some extent, on the evaluation of mean values and dispersion factors. As this is only possible in the case of equal values, of course, the single values are combined or reduced to provide time units of equal magnitude when the tempo of the exercise as performed is assessed. On the other hand, every single value is brought to a uniform level by multiplication or division when the rhythm is assessed. In contrast to the operations described in the previous section, one is required to adapt a part of this computer program to the specific exercise piece in each case. The student then proceeds as described in the previous section.

The first type of information takes the form of three numbers that appear on the screen. The highest number indicates the tempo played in the form of metronome number, which has been calculated from the geometric mean of the time units. The pupil sees how far he has diverged from the intended tempo. The middle number indicates the dispersion of the time units and the stability of the tempo. The lowest number shows the dispersion of the (standardized) individual values, that is the degree of precision attained in the performance of the prescribed rhythm. The two features of performance—stability of tempo and rhythmical precision—are assessed separately, as rhythmical inaccuracies can be balanced out within the time units. On the other hand, it is the primary purpose of certain exercises to train the pupils to maintain a steady tempo, without placing any particular emphasis on rhythmical accuracy.

The second type of information draws the piano player's attention to the passages where there have been greater deviations from the mean tempo. The computer calculates the individual quotients time unit/mean value, and specifies the bars in which a prescribed tolerance limit was exceeded. Otherwise, the word "complete" appears. Each individual deviation in short exercises is specified; but circumstances permitting, the average can be taken of two or more time units in longer pieces.

A survey of the entire process and the direction of the deviations is provided by the third type of information, in which the individual quotients time unit/mean value are represented (see Figure 5). While the y-axis is the same length here as it is in Figure 3, it only spans the area 0.66 to 1.5, so that fluctuations in tempo can be distinguished more clearly. In this case, they lie roughly between 0.88 and 1.125; that means, between ♩ = 88.8 and ♩ = 112.5, if a tempo of ♩ = 100 was desired.

The next two types of information are concerned with the question of how far the performer has retained his own starting tempo during the course of the piece. This is also one of the basic musical skills that, under normal circumstances, must be cultivated separately. The com-

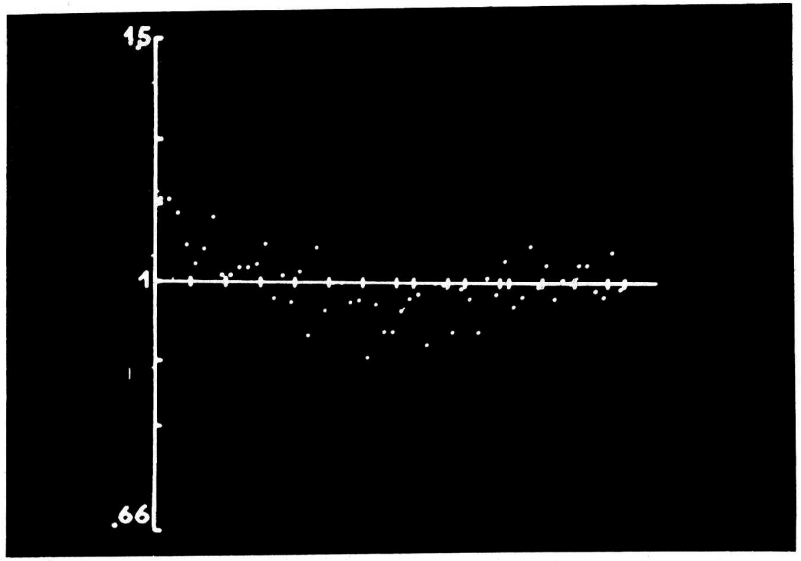


Figure 5. Performance of One-Part Rhythmical Exercise: Duration of Successive Time Units in Relation to Mean Value of Time Units on Screen

puter process is the same as in the two previous operations, except that the mean value of the time units of the first bar is given instead of the mean value of all the time units. Not until more extensive tests have been carried out with professional musicians will it be finally shown how demanding the standard applied here should be. Such tests will also indicate whether the opening tempo should be deduced from the first bar, from the first musical period, or even simply from the first interval (two notes) played.

The other types of information are concerned with the performance of the rhythms specified. The computer calculates the quotients of the standardized individual values/mean value, and marks on the screen the bars in which one or more quotients exceed a specified value. Otherwise, the word "complete" appears again. It is obvious that a greater degree of tolerance should be allowed in the assessment of the rhythm played than in the assessment of the tempo played. Consequently, two tolerance limits are stipulated at the beginning of these exercises. The performer is then apprised of the extent and direction of the deviations in other diagrams, which reproduce the individual quotients in the same way as illustrated by Figures 3, 4, and 5. If the correction of rhythmical inaccuracies entails greater difficulties, a complementary program can be

used in which only the rhythmical distribution within a unit—a time unit, a half bar, or whole bar—is analyzed without considering the influence of tempo fluctuations. The sum of the values that make up a unit is regarded as 100, and the deviation of the constituent note values from their corresponding theoretical percentages ascertained. The feedback information then follows.

Allowance is made for the different information requirements of the pupils in the sequence of the feedback information. Under normal circumstances, the indication of the two dispersion values at the beginning of the program is quite sufficient for the experienced piano player. However, the less advanced pupil is not aware, perhaps, of the cause of his tempo fluctuations until he sees the relevant diagram. When the pupil has obtained sufficient information for his requirements, the sequence can be interrupted at any point desired. An immediate return can be made to the starting point.

It is planned to extend the equipment by means of a computer-controlled metronome in order to provide the pupil with information during performance in addition to the information after the performance, just as Ihrke has done with optical signals.[11] One result would be the possibility of distinguishing analytically between fluctuations of short duration and a general tendency towards alterations in tempo. The player would also be given timely warning of the latter. Apart from the task of retaining the tempo, the information supplied after the performance appears to be even more important, provided that it involves the correction of the musical and not the motoric process. Parallel information concerning aspects of performance dependent on technical or physiological considerations is too late to be of any value, particularly because of the interval of time that the player is thinking ahead. As regards reading from music, one knows from experience, and Jacobsen has shown, that the more advanced the player is the greater is the interval of time.[12] There would be no purpose in disturbing the pupil's concentration in this respect. It is also necessary, of course, to think ahead when correcting a mistake. The pupil must have an opportunity, therefore, of becoming aware of the direction and extent of the deviations in his playing before he repeats the test.

Proposals for a Performance Diagram

Besides the direct control of the learning process, there is another task: to obtain an objective picture of the pupil's long-term development by means of regular tests. To facilitate the survey of the level attained in the different skills, a system of deviation diagrams is used. Diagrams of

[11] Ihrke.

[12] O. I. Jacobsen, "An Analytical Study of Eye Movements in Reading Vocal and Instrumental Music," *Journal of Musicology*, Vol. 3 (1941-1942), pp. 1-32, 69-100, 133-164, 197-226.

two-finger exercises as played by a pianist are shown in Figure 6 and by a much less advanced piano player in Figure 7. Several distinctive features are recorded in these diagrams. Deviation of the mean tempo (traced line) and the opening tempo (dots) from a specified tempo (median line) are depicted in the left upper panels of Figures 6 and 7. In the right upper panels of Figures 6 and 7, mean positive and mean negative deviation from the opening tempo (median line) are shown. The values of the time units are divided into those that are greater and those that are smaller than the value established in the first bar. The geometric mean for both groups is ascertained. The fact that there can be a different number in both groups is not taken into account. The amount is given in metronome units, as this corresponds to the time scale normally used in musical performance.

Dispersion of the time units around the mean value as a measurement of the stability of the tempo is shown in the left lower panels of Figures 6 and 7. The ratio between the upper limit of the dispersion area and the mean value, or between the mean value and the lower limit, is derived from the dispersion factor (scale on bottom line). To make clear to the musician the significance of the area of dispersion, the note values that correspond to the factors 1.125, 1.25, and 1.5 are given. In the right lower panels are depicted the dispersion of the individual values around the mean value, indicating—according to the same principle that applies in the left lower panel—how accurately the specified rhythm was executed. If the note values are not equal as in these exercises, the individual values are standardized. As more pronounced deviations are usually displayed in the analysis of the rhythm than in the analysis of the tempo, the scale of dispersion factors has been extended to 2.0 (to double the mean value).

The exercise, the performance of which has been assessed in Figures 6 and 7, consisted of three bars with continuous sixteenth notes and one bar's rest; this four-bar sequence was repeated twice. Figure 6 shows an almost equal performance level in all fingerings as far as the tempo deviations that occurred in playing with the fourth and fifth fingers of the left hand, to which very little practical significance can be attached. It is noticeable that although there is a slight increase in the dispersion of individual values in playing with the third and fourth or fourth and fifth fingers of the left hand, the tempo fluctuates just as little as it does with the other fingerings. This player is just on the point of taking his final diploma examination as a pianist. In Figure 7 it is particularly interesting that although the player in this case is right-handed, the values prove to be poorer in playing with the right hand than in playing with the left hand. The values also fluctuate considerably within a hand. It can be seen immediately at what points a correction is particularly necessary. The two lower panels also show that the ratios of tempo and rhythm by no means vary in the same direction. Such a system of dispersion diagrams can be extended and altered at will, of course. It should be a useful aid for the teacher in every case, because it enables him to choose technical

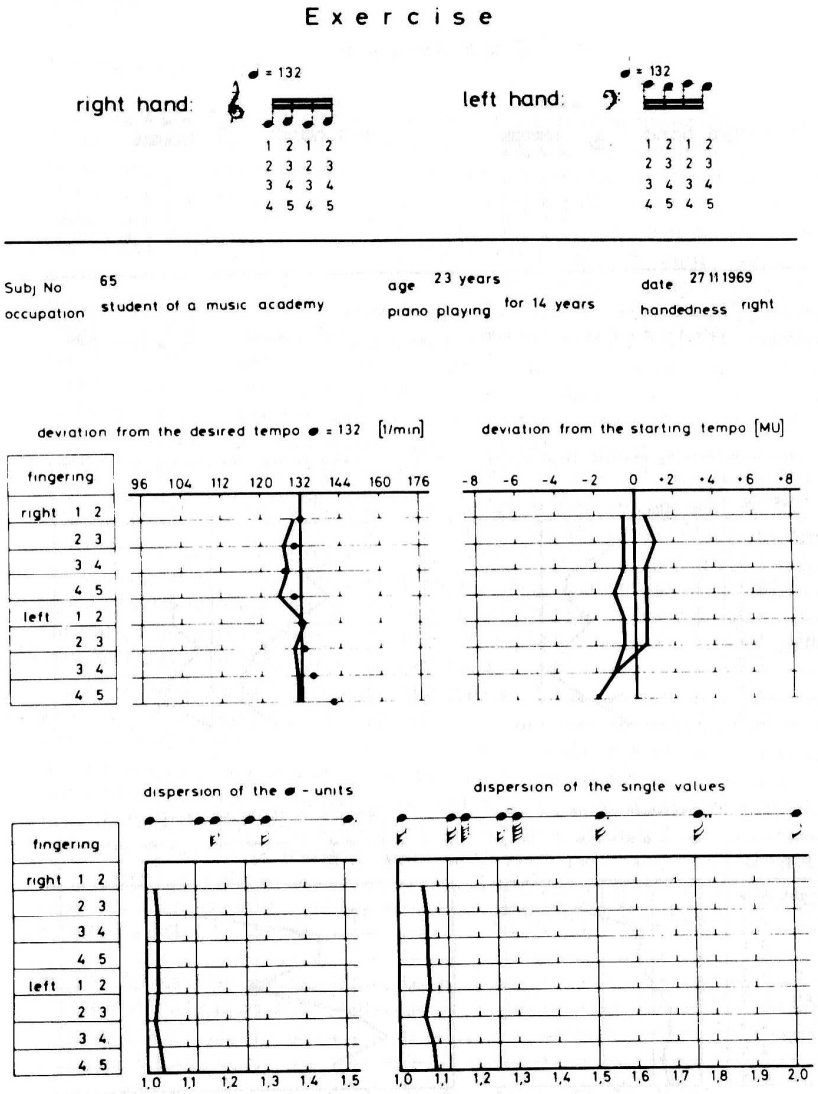


Figure 6. Deviation Diagrams for Assessment of Pianist's Musical and Technical Skills

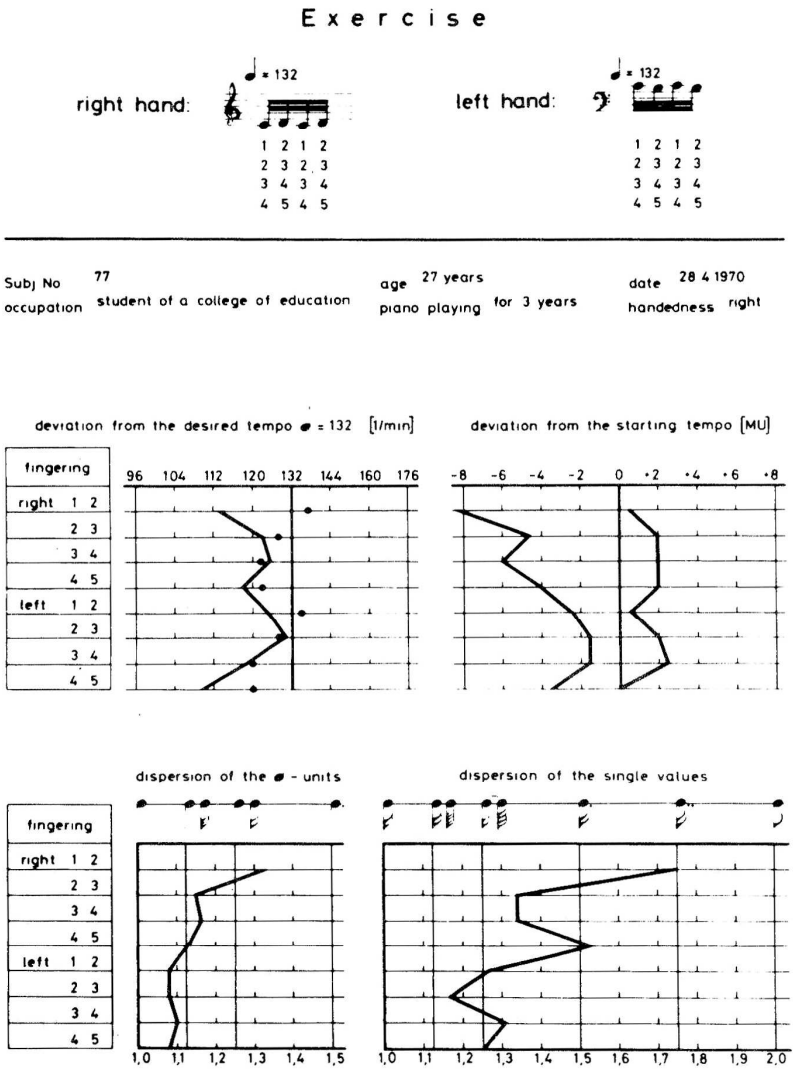


Figure 7. Deviation Diagrams for Assessment of Beginning Piano Player's Musical and Technical Skills

exercises and studies suited to the level of the pupil's skills at any particular time.

Future Research

As a number of new possibilities are open in a circumscribed area of piano instruction, it is a question of investigating which of them are most suited to the intensification and the shortening of the musical and the sensorimotor learning process. That generally cannot be decided until two problems are solved. The first problem concerns to what level the individual skills that are considered quantitatively should be developed. It is not wise, theoretically, to use the musical notation as a basis for stipulating requirements that cannot be fulfilled, even by outstanding musicians. Furthermore, it is not necessary to aim at a uniform level for all the technical aspects of performance. The only important piece of information concerns the specific tolerance limits. These limits are deduced for the separate elements of technique in their different applications when one makes an analysis of the performance of pianists who are able to cope with the representative works of musical literature. This information seems to be sufficient in the initial stages. When these tolerance limits are eventually recorded in the deviation diagrams, one is provided with a realistic basis for the assessment of a pupil's ability. Regarding the training required to become a professional pianist, it would be interesting and desirable to investigate at a later date the performances of pianists with international reputations, and thereby ascertain whether and how far standards vary.

The second problem concerns the means chosen to attain the desired goal. It is a question of first investigating the traditional types of exercise with regard to their effectiveness, to make use of the wealth of technical knowledge available. At the same time, those methods that are not really effective or are even harmful from this great mass of material must be extricated. This material is then newly arranged in accordance with the principles of learning theory and work physiology, and is tested in its entirety with regard to its practical success. It is not too difficult a problem then to find suitable forms of programed instruction for the selected material.

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