JOURNAL OF MEDICAL INFORMATICS & TECHNOLOGIES Vol.3/2002, ISSN 1642-6037

psychological test, psychomotorics,
psychoacoustics, reaction time,
data mining, computer system

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A COMPUTER-BASED SYSTEM FOR OBJECTIVE STUDIES OF HUMAN PSYCHOMOTORICS

Firstly the idea of objective psychological tests and their characteristics related to various features of human psychophysiology are introduced. Examples of objective tests are given. Next application of data mining algorithms to analyse data obtained from different tests are outlined. The general concept of a computer system for objective psychological studies of psychomotoric processes in humans is then described. Finally the possibility of implementation of the system in medical and psychoacoustical studies is pointed out.

1. INTRODUCTION

Human psychomotorics as a complex of perception → conscious analysis → reaction processes initiated by different visual and/or auditory stimuli determine effectiveness of human skills to perform manual and conceptual tasks. Such abilities are crucial in many practical situations (working, manual manipulations, solving conceptual tasks, driving etc.) and determine their performance quality and/or safety. That is why objective measurement or estimation of such psychological and psycho-physiological features of a given group of people is an important problem both from a scientific and a practical point of view. However, it is not easy to distinguish useful characteristic features of human psychophysiology, perform objective measurements in a given case and provide quantitative final results [1-6].

In this work a general concept of objective psychological (psycho-motor) tests is introduced. Basic requirements for such tests are formulated. The usefulness of computer-based tests to perform objective and repeatable experiments is pointed out. Six characteristic features of human psychomotorics especially useful for computer-based tests have been distinguished. Examples of such tests realised as independent software applications are described and results of practical experiments have been presented. It has been shown that due to high level of statistical dispersion many test repetitions are required in order to obtain valuable results. Therefore a test performance should be expressed in terms of certain statistical quantities.

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The statistical approach to psychological measurements enabled the discovery of certain interesting, subtle features of human psychophysiology that cannot be observed in classical psychological experiments. Therefore, the described tests can be implemented in special medical or psychoacoustical studies aimed to determine the influence of certain external factors (such as drugs, infections, anatomic disorders or sound and noise) on human beings.

In practical situations we usually want to determine the influence of a given external factor on selected features of human psychophysiology. However, there are no "pure" psychomotoric tests that could be applied to estimate a single feature. Psychological tests usually engage different aspects of human psychophysiology. In such a situation simultaneous application of several tests is necessary and the contribution of each psychophysiological feature to the final result of each test should be estimated independently. Then, appropriate methods of data analysis enable us to determine the influence of the external factor on each psychophysiological feature. To solve the above problem a computer-based system for psychomotoric testing has been proposed.

2. OBJECTIVE PSYCHOLOGICAL TESTS

2.1. THE PROBLEM OF OBJECTIVE MEASUREMENTS IN PSYCHOLOGY

Psychological features of people are rather difficult to measure directly and objectively. Therefore psychological research usually consists of direct observation of a group of subjects (patients) and/or analysis of the results obtained from questionnaires which are subjective in principle. Therefore this research methodology is not adequate in cases when the aim of the studies performed is obvious for the tested persons. Then the results can be dependent not only on the questionnaire applied but also on the individual attitude to the aim of the studies. In particular, in psychoacoustical studies it is not a good idea to ask subjects directly about annoyance of a given noise for example at a given workplace.

There are however some simple psycho-physiological or psychomotor aspects of human psychology (e.g. heart pulse, blood tension, reaction time, certain manual and conceptual skills, short-term memory and perception abilities) that can be measured directly and are independent of the human will. On this basis a methodology of exact and objective studies applicable in many practical situations can be formulated

2.2. THE IDEA OF OBJECTIVE PSYCHOLOGICAL TESTS

It is easy to formulate the following natural requirements/conditions concerning objective psychological tests [7]:

objectivity-	minimal influence of subjective factors on the test results
repeatability -	possibility to perform the test many times in different laboratories without the necessity of application of specialised instrumentation.
facility -	possibility to pass the test by any person independently of his/her intelligence, education, manual skills etc.
simplicity -	minimal number of aspects of human psychophysiology that should have essential influence on the test results.

Modern computation and multimedial techniques enables the realisation of computer-based tests satisfying the above requirements [8,9,10]. Personal computers are able to generate auditory and/or visual stimuli, react on mouse clicks and keyboard manipulations and store and analyse information, simultaneously. Therefore it is possible to realise psychomotoric tests as appropriate software applications that can be executed everywhere without specialised instruments.

2.3. CHARACTERISTIC ASPECTS OF HUMAN PSYCHO-MOTORICS

In order to describe psychological tests it is useful to distinguish certain characteristic aspects of human psychomotorics especially suited for computer-based tests. We assume that the following elementary psychomotor actions are essential in computer studies [7]

L- perception of a visual signal (light),
S - auditory perception of an acoustical signal (sound),
C - mouse click or keyboard manipulation (click),
M - recording a portion of information in short-term memory (memory),
A - analysis of stored information (analysis),
V - the use of voice (voice).

Subsequent repetition of a psychological test is usually a random process. Any realisation of such a process is a finite sequence of elementary psychomotor actions described above. The whole test can be represented by an oriented graph with nodes denoted by {L, S, C, M, A, V } and containing all possible realisations as pathways in the graph. Closed loops in the test graph indicate the possibility of repetitions of certain sequences in case of errors that always may occur during the test performance.

It is rather difficult to construct a test engaging only one of the above aspects. For this reason the essential point of any test is estimation of the relative contributions of the distinguished actions in final test results. The simplest measures of the contribution of elementary actions $E_j \in E = \{L, S, C, M, A, V\}$ in a given test T are the relative average numbers of their repetitions r_j , $j=1,...,6$ (within the execution of the test) multiplied by the average time τ_j of the corresponding actions or the number of errors. Thus the relative contribution of the elementary action E_j in a test $T_i \in T = \{T_1,..., T_n\}$ is given by the following formula

$$p_{ij} = p(T_i , E_j) = \tau_j \cdot r_j /(r_1 \tau_1 + ... + r_6 \tau_6). \qquad (1)$$

The collection of statistical quantities $p(T_i) = (p_{i1},..., p_{i6})$ that can be estimated from experimental data and the structure of the test graph determines completely experimental properties of the test and its usefulness.

2.4. TYPICAL TEST PERFORMANCE IN SESSIONS

The indeterminism of psychological processes causes the results of any psychomotor test to be random and an unavoidable statistical dispersion always occurs. Therefore, an appropriate number of test repetitions (in sessions) is necessary in order to obtain objective results with a sufficient level of statistical confidence. However, experimental studies proved that independently of details of a given test and particular features of a subject certain typical behaviour of averaged subsequent test results can be expected as is shown in Figure.1.

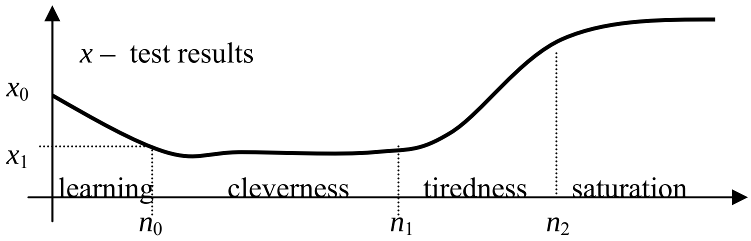

Fig.1. The typical phases of a test performance

At the beginning of any session worse test results may be achieved. This is due to learning and adaptation of the subject psychophysiology to perform the new task. Then (after n_0 test executions) begins the stage of cleverness in which good results are achieved with relatively small dispersion. After a number of test executions n_1 the subsequent test results are getting worse due to subjects' tiredness. Finally, the obtained test results tends to a certain saturation level which is guaranteed by the assumed test facility.

Similarly, the number of errors made in a given session should increase with subjects tiredness that is the slope of the corresponding curve should increases after a number of test executions n_3 as is shown in Figure.2.

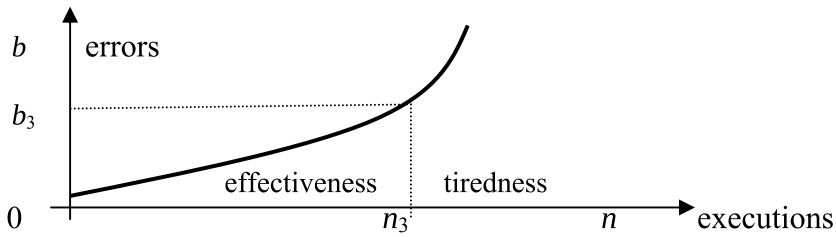

Fig.2. The typical dependence of errors on the number of test executions n

It is clear that the characteristic numbers n_2, n_3 should be correlated and dependent not only on the subjects abilities but also on the assumption concerning errors which can or cannot be tolerated during the test performance. Of course, any particular (non-averaged) realisation of the test is usually much more complex due to statistical dispersion.

2.5. QUALITY INDICES OF TEST PERFORMANCE

It follows from our considerations that any test session can be characterised by certain numbers such as n_1, n_2, n_3 , b_3 which are statistical values in principle. The statistical average $\langle x \rangle$ and dispersion $d(x)$ of any measured quantity x in a given test T can be determined for any session but estimation of averages $\langle n_1 \rangle$, $\langle n_2 \rangle$, $\langle n_3 \rangle$, $\langle b_3 \rangle$ requires data from many sessions.

It is clear that any quality index Q_T of the test performance should in general be a function $Q_T = Q_T(\langle x \rangle, d(x), \langle n_1 \rangle, \langle n_2 \rangle, \langle n_3 \rangle, \langle b_3 \rangle)$ [7]. In order to estimate the influence of a given external stimulus (pharmacological, acoustical etc.) on the test results a suitable statistical hypothesis has to be posed and tested on the basis of experimental data obtained from sessions with and without the stimulus.

3. EXAMPLES OF OBJECTIVE PSYCHOMOTORICAL TESTS

In this section we describe examples of computer-based psychomotoric tests that have been designed and implemented by the authors in psychological and psychoacoustical experiments [7]. Each test is an independent windows application with its own specialised data analyser and output.

3.1. TEST SQUARE

This test engaging a few psychomotor elementary actions can be realised in different versions. Any execution of the test Square means that the 3x3 square table with nine different random two digit numbers is displayed. A subject has to click some of the numbered fields as quickly as he can according to certain principles. Once the numbers are clicked properly the time of the test performance is measured and registered and the subsequent nine numbers are displayed.

In the test SquareMax only the maximal number has to be chosen. The test enables us to study human visual perception, conceptual abilities and manual skills. It is easily to see that the test SquareMax can be represented by the following graph

$$L \to A \to M \to L \to A \to M \to \ldots \to L \to A \to M \to C \to$$

where the closed loop symbolises the possibility of repetitions in case of errors. The test can be realised in the version SquareMaxBeep with an acoustical signal informing a subject about correctness of the choice.

The test SquareMaxMin is a more complex version of the previous test. In this case all the displayed numbers are to be clicked from the maximal to minimal ones in their natural order. The test can be in versions SquareMaxMinBeep, SquareMaxMinColour, SquareMaxMinBeepColour with beep and/or colouring of properly clicked numbers, respectively. The test versions differ in the contribution of short-term memory to the test performance. In particular, the test SquareMaxMin can be represented by the following graph.

$$L \to A \to M \to \ldots \to L \to A \to M \to C \to \ldots\ldots\ldots \to L \to A \to M \to \ldots \to L \to A \to M \to C \to$$

The graphs can be applied to determine the contribution of particular elementary psychomotor actions in the final results of the test.

3.2. TEST PIANO

The test Piano consists of instantaneous clicking of distinguished windows keys displayed in a horizontal line. The actually distinguished key is red while the remaining keys are white. A proper click means that a new key becomes distinguished. The number of improper clicks as well as the time necessary for the test performance for a fixed total number of clicks are registered. The test is oriented towards studies of visual perception of space separated objects, eye movements and manual abilities in humans. Since the two subsequent psychomotor actions L, C are performed during the test execution, the test can be represented by the following linear graph

$$L \to C \to \ldots \to L \to C.$$

Additional counting of improper mouse clicks enables the observation of certain subtle characteristics of the test performance determined by the subject psychology (temperament) and their dependence on the assumption whether mistakes are admissible or not.

3.3. TEST REFLEX

The test Reflex enables us to perform studies of human reaction time both for visual and auditory stimuli. Once the test is initialised, the random time generator is started. After a random time period the test software displays on the screen a visual signal and/or generates a beep and a subject has to click the mouse as quickly as possible. After the proper click the reaction time is registered and the random time generator restarts. The three versions of the test, namely ReflexColour, ReflexBeep and ReflexBeepColour can be applied for studying reaction time on visual, auditory or simultaneous visual and auditory stimuli, respectively. The described versions can be illustrated by the following linear graphs

ReflexColor: L → C →...→ L → C
ReflexBeep: S → C →...→ S → C
ReflexBeepColor: L → S → C →...→ L → S → C

3.4. TEST SHORTMEMORY

This test is intended to study the phenomenon of short-term memory in humans [7]. Each test execution starts an appropriate software displaying on the screen a finite set of random digits. Both the number of digits n displayed and the time of exposition τ can be adjusted before the test execution. A subject has to remember all the digits and print them in the appropriate order. If he succeeds the subsequent set of random digits is generated. However, in case of mistakes the subject has to restart the test to display the same combination and try to remember the digits again. During a session the number of repetitions (because of mistakes) is registered. The test ShortMemory with repetitions is represented by the following graph

$$L \to M \to V \to S \to M \to C \to$$

The test ShortMemory is simple and can be adjusted to psychomotor abilities of any subject by an appropriate choice of the test parameters (n, τ). It is also possible to apply different versions of the test with or without quiet/loud repetitions of combination of digits immediately after its visual perception. This is important for example in psychoacoustical studies of masking our internal voice by an external noise.

4. GENERAL CONCEPT OF A COMPUTERISED SYSTEM

In a particular practical situation usually selected aspects $E_j \in E$ of human psychomotorics are essential with certain importance factors $q_j \in <0,1>$. Therefore the psychological studies have to be performed according to the following order:

- determination of a collection of tests that are dependent on the assumed aspects,
- performing the selected tests in sessions with and/or without external stimuli,
- recording the tests results and the results of data analysis independently for each subject and averaged results for a selected group of subjects,
- data mining to estimate influence of the stimuli on the selected aspects and extract mutual relations.

It is obvious that a computer system should be applied in order to realise the above points. To explain the system concept let us assume that we have a set of tests $T = \{T_1,...,T_n\}$ and the corresponding collection of psychomotor actions $X_T = \{x_1 ,..., x_m\}$ that are necessary and sufficient to perform all the tests. In particular the set X_T can be equal to { L, S, C, M, A, V } i.e. we can confine considerations to the actions selected in Section 2. However new or more precise psychomotor actions can be added to the set of actions X_T in order to improve the description of psychomotoric tests. Similarly, the set of psychomotoric tests can be increased. There are however some limitations and basic requirements that are necessary for system completeness.

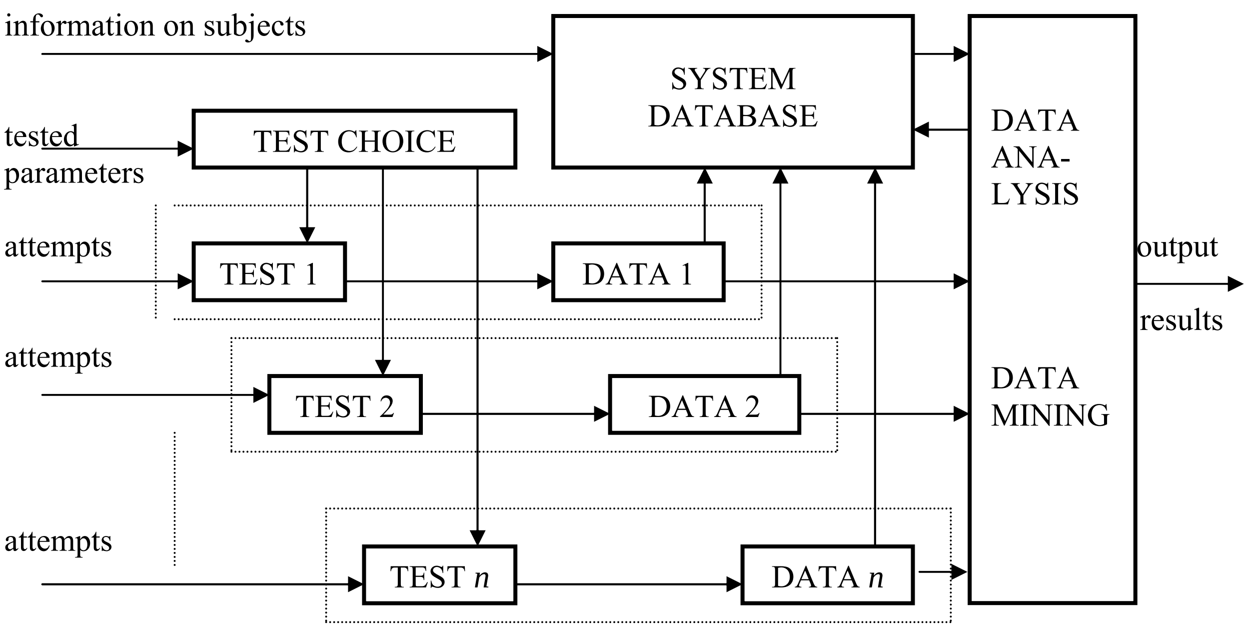

Fig.3. The block scheme of the computer-based system for studies of human psychomotorics

It is clear that each test T_i , i = 1,...,n is in some sense specific and can be associated with the corresponding graph and a set of psychomotoric actions $A_i \subset X_T$. Let us introduce the set of indices $I(A) = \{ i=1,...,n: A_i \cap A \neq \phi \}$ for any subset $A \subset X_T$. Then $T(A) = \{ T_i : i \in I(A) \} \subset T$ is the set of tests which are dependent on actions belonging to a given set $A \subset X_T$. Then the set of all psychomotoric actions essential for tests belonging to T(A) is equal to

$$X_{\mathbf{T}}(A) = \bigcup_{i \in I(A)} A_i . \qquad (2)$$

In a particular situation only selected psychomotor actions are of our interest. We denote by A the set of actions which are to be studied in psychological or psychoacoustical experiments. It is obvious that the influence of a given external factor on human psychomotorics can be determined independently for each action $x \in A$ if and only if the number of tests in T(A) is greater or equal to the number of actions in X_T (A). We say the subset $A \subset X_T$ is solvable with respect to the set of tests T if card(T(A))≥card(X_T (A)). It is clear that only solvable sets of psychomotor actions can be studied by the system utilising a given set of tests T. We say that the set of tests T is complete if card(T(A))≥card(X_T (A)) for any nonempty subset $A \subset X_T$. The universal system for psychomotoric studies should be based on a complete set of tests. To achieve this goal both the collection of tests T and elementary actions X_T should be carefully selected. Indeed, too many psychomotor actions applied require a large number of tests to ensure completeness. Then studies of human psychomotorics become more precise but also more complex, time consuming and expensive. On the other hand, too small a number of elementary actions defined makes the studies very imprecise.

The block scheme of the proposed computer-based system PSYCHOTEST is shown in Figure.3. When a set of psychomotor actions A together with importance factors q_j are put at the system input the block TEST CHOICE should provide the user with the appropriate set of tests T(A) to perform or inform the user that the set A is not solvable with respect to the set of available tests T.

Each test T_i i =1,...,n included into the system is a separate self-consistent software with the proper test generator in the block TEST i and local statistical data analyser/datastorage in the block DATA i . The local data and results of statistical calculations can be applied independently for any test and/or included into the block SYSTEM DATABASE for further analysis and data mining in the block of DATA ANALYSIS. Information on all patients/subjects is also stored in the system database. This is necessary to obtain final result of testing in individual cases as well as results averaged over selected (sub)groups of subjects.

Different quality indices Q can be applied to measure quantitatively the influence of given external stimuli on elementary psychomotor actions. The block DATA MINING is necessary to find mutual dependences and relations between the stimuli levels and human ability to perform selected psychomotor actions. In order to take into account the importnace factors q_j essential in a particular practical situations it is necessary to use a weighted quality factor of the form

$$Q = \lambda_1 Q_1 + ... + \lambda_n Q_n , \qquad (3)$$

where Q_i , i=1,…,n are quality indices of the corresponding tests $T_i \in T$ and the weights λ_i are chosen in such a way that satisfy the following system of linear equations

$$\sum_{i=1}^{n} p_{ij}\lambda_i = q_j . \quad (4)$$

If the collection of tests T is sufficiently rich equations (4) can be solved. Then index (3) is especially suitable for application in the practical situation under cosideration.

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