Theoretical Prerequisites for the Creation of Handwriting Research in Criminalistics

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Abstract: Handwriting expertise is the most difficult one in criminalistics. Despite the significant recent development of information technology and technical means, handwriting research is still a difficult task. The available computer programs do not allow to make decisions automatically. This is largely explained by the fact that the field of researches of handwriting movements remains not fully studied. This article is devoted to theoretical issues of the physiology of handwriting movements, which can be used as the basis for modelling automated handwriting recognition systems.

1 INTRODUCTION

The problem of researching handwritten notes, for example, in the investigation of economic crimes, remains relevant (Shvets et al., 2018). Currently, various attempts are being made to automate handwriting research, but the theoretical foundations of handwriting movements are still insufficiently explored (Dziechciaruk, 2023). This article considers modern views on the problem of motion control in the implementation of the act of writing as the basis for digital handwriting research.

As is known, both the theory of forensic handwriting expertise and modern dissertation researches in the field of handwriting are based on the level theory of movement construction by N.A. Bernstein. However, professor Bernstein created his theory in the middle of the 20th century, so it makes sense to consider issues related to motion control from the point of view of modern scientific researches, since what has been discovered in physiology can expand our knowledge in the field of handwriting-forming movements and, accordingly, contribute to the development of forensic handwriting examination.

The fundamental principles of N.A. Bernstein's theory can be formulated as follows (Bernstein, 1947):

1. The system that controls the movements of a biological being is a hierarchical structure consisting of different levels.
2. There is feedback between the "lower" and "upper" levels of the system, which allows you to adjust the executed command.
3. The inevitable loss of time during the transmission of information in feedback systems indicates that motion control, along with feedback systems, should be built using proactive correction systems.
4. The number of degrees of freedom of biological systems is always excessive, and the process of motion control should be considered as overcoming the uncertainty of solving a motor problem caused by an excessive number of degrees of freedom.

N.A. Bernstein built his theory based on the concept of a "black box", i.e. a certain system, the structure of which is unknown, but the functioning of which can be studied by sending a signal to the input of the system and fixing the result at the output. For the purposes of our research, we will take as a basis the three–level scheme for the implementation of arbitrary movements by M.L. Latash, also based on the concept of a "black box". This scheme can be represented as "Making of decision - construction of movement – implementation of movement " (Latash, 1993).

The above scheme is useful because it does not reflect the organization of the central nervous system

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that controls arbitrary movements, but allows us to discuss issues related to the organization of movement of biological beings as a whole.

The content of the "making of decision" level of this scheme still remains a mystery to modern science, and although numerous studies have been conducted by various scientists concerning the role of certain brain structures in organizing of movement, the thought process associated with the adoption of certain volitional commands has not yet been fully completed studied.

The content of the level of "realization of movement " of the above scheme is determined by the physiological and biomechanical parameters of the system. The biomechanical parameters of the implementation of handwriting movements are considered in sufficient details in the forensic literature (Mantsvetova, 1997).

2 MATERIALS AND METHODS

In the meantime, we will focus on the second level of M.L. Latash's scheme. This level can be represented as a kind of device for transcoding the decision to perform a movement into some control signals for the lower level. A model of such coding, a kind of motion control language, was proposed back in the 60s of the last century by A.G. Feldman (1966). This model, known as the equilibrium point hypothesis or λ-model, is based on the idea of central control of only one variable for each muscle (λ is a threshold value of reflex tonic tension).

A.G. Feldman suggested that the control of the movements of a kinematic link with a single-articular joint can be described with the help of two variables: r and c. These variables have a direct correspondence to known physiological concepts: mutual reverse activation and coactivation. These variables can also be correlated with the characteristics of the joint: position (r) and angle of placement (c).

Since any movement takes place both in space and in time, it makes sense to consider the change in the values of the variables r and c in time, i.e. to consider the functions of time r(t) and c(t). And since, by definition, the variable r is the central control signal, the motion itself can be described as:

$$r(t)=r_0+ \omega t, \tag{1}$$

where r_0 is the initial value of r at time t=0, and ω is a constant.

The position of the kinematic link in space changes over a period of time Δt, and the variable r takes on a new value. If, during the movement of the distal part of the kinematic link, some external force is applied to it ($r(t)=r_1$), then

$$r_2=r_1+\omega \Delta t. \tag{2}$$

Thus, we come to the concept of a "virtual trajectory".

The assumption that there is some kind of an ideal concept characterizing arbitrary movement appeared in physiology quite a long time ago. It is worth mentioning the "engram of action" by N.A. Bernstein or the "virtual trajectory" by N. Hogan (1984). These two concepts reflect two approaches to the theory of control of arbitrary movements. An engram of action is a pre–planned sequence of complex motor acts, a virtual trajectory is a kind of proactive movement "plotting a course" right at the moment of movement. But in both cases, the change in the trajectory of motion under external influence is associated with a change in the value of the control variable in time (i.e., a change in r(t)). Hence, the virtual trajectory is an ideal curve of motion along which the distal end of the kinematic link would be moved without external influence.

Movement during the act of writing always occurs under the influence of external forces, and, above all, this act is associated with overcoming the friction force within two systems: “writing device – paper” and “hand – paper”.

3 RESULTS

The conducted research has established that the virtual trajectory is predominantly forms an N-shaped curve (Gottlieb, 2010). When the real and virtual trajectories are applied to the same coordinate plane, the following picture appears. In the initial phase of movement, the virtual trajectory is ahead of the real trajectory, since the movement of the limb is forced to overcome the forces of acceleration resistance. As soon as the moving limb gains a certain speed, the virtual trajectory changes its direction to the opposite, lagging behind the movement of the real trajectory. And finally, at the end of the movement, both trajectories meet again.

Since the nature of the trajectory of movement is determined by the physical characteristics of a particular biological object, the amount of deviation of the actual trajectory of movement from the virtual trajectory is individual. This value (and in fact these are several values characterizing the movement of the distal end of the kinematic link such as amplitude, trajectory shape and phase shift) could be used in forensic handwriting studies as another parameter characterizing the performer's motor system.

As is known, in modern criminalistics, the definition of a motor system that implements handwriting movements is inextricably linked to the concept of an individual and dynamically stable writing program. In our opinion, the very concept of "program" in relation to the organization of the movement requires clarification. On the one hand, a program is a certain sequence of control signals that arises or already exists in certain structures of the human brain, thanks to which the implementation of a particular movement is carried out.

On the other hand, the very concept of a " program of movement " is currently not as unambiguous in physiology as it was commonly believed half a century ago.

It is necessary to recall that the term "program" in relation to the implementation of movements was proposed by Professor N.A. Bernstein and is associated with the concepts of "synergy" and "engram" that were proposed by him as well.

According to Bernstein, synergy is a temporary sequence of control signals transmitted to muscle groups, as a result of which simple coordinated motor acts are possible. These motor acts are a kind of elementary actions, the combination of which allows to build more complex movements. An engram is a kind of abstract model of movements, the sequence of which can be represented as a program for the implementation of motor acts. According to Bernstein, there are basic engrams corresponding to certain synergies. Higher-level engrams are built on the basis of basic engrams.

However, there is still no clear answer to how engrams are formed. Attempts have been made to associate the engram with a model of muscle activation, i.e. to represent the engram as a sequence of different values of muscle tension. Initially, this interpretation of motion programming was criticized, because with such an approach, the engram of motion should consist of an infinite number of options, since motion is built and carried out under the influence of various external factors.

Even N.A. Bernstein, conducting research on movements when performing highly automated motor acts (cutting metal with a chisel), found out that, despite the fact that the trajectories of movement of the impact part of the object (hammer) approximately coincide, the trajectories of movement of the joints of the hand performing the impact movement differ significantly. Therefore, it is not the repetition of the same movement (the execution of the same engram), but the execution of the movement taking into account different external conditions.

At the end of the last century, a new approach to this problem arose in the physiology of movements (the idea of dynamic construction of a motion model) (Kelso, 1984). It has been suggested that motion control is based on the laws of dynamics of nonequilibrium systems. With this approach, movement is a self–organizing process that manifests itself as a coordination-stable structure with repetitive characteristics. The construction of movement depends not only on the task of the motor act, but also on the initial state of the system implementing the movement. The transition of a system from one equilibrium state to another equilibrium state is possible along an infinite number of trajectories.

When performing the same motor task repeatedly, while maintaining the initial conditions, the variation in the trajectories of movement of both joints and the working point of the limb remains significant. Within the framework of the theory of "programs" of movement, such a variety of implementations seems meaningless, indeed, why use different sequences of joint movements each time when repeating the same movement, if there is already a program that ensures the performance of a specific task?

From the point of view of the theory of dynamic motion construction, the answer to this question is as follows: the motion control system is in a non-equilibrium state, i.e. in a state of constant fluctuation (Shoner, 2011). Thus, even if the initial conditions of the system are reproduced with perfect accuracy with multiple repetitions of motion, then the trajectories of the realization of this motion will still differ, since the system itself is in a non-equilibrium state and, therefore, by definition it is impossible to reproduce the initially identical conditions.

All of the above applies to handwriting movements. Since the conditions for performing writing movements (the so-called "usual conditions") differ a little from each other, and every time the task of performing a handwriting object is solved anew, it is realized in approximately the same way, which creates the illusion of reflexivity of performing letters and their elements. Although any individual who does not have knowledge of handwriting analyses knows that it is impossible to reproduce letters and their elements in exactly the same way. The variability of handwriting from the standpoint of the dynamic construction of movements can also be explained by the nonequilibrium of the handwriting-forming system. The non-reproducibility of the absolute sameness of the handwriting object is a characteristic of the handwriting-forming system itself. In addition, the absolute coincidence of the geometric shape of a handwritten object (for example, a signature) is a sign indicating its forgery.

4 DISCUSSION

Among other things, speaking about the variation of handwriting, one more interesting aspect should be mentioned. Variation of handwriting is understood, first of all, as modifications of handwriting features, i.e. changes in the attributes of letters. But a handwritten letter is a trace of movement of the colorising element of the writing device fixed on the paper. But, as it is known from the course of physics, motion is characterized by the values of velocity (v), time (t) and distance (s). Consequently, modifications in the writing of the letter can be expressed by changes in the parameters of speed, time and distance. And since these quantities are interrelated, only two of them can change independently, while the third quantity is the result of the interaction of two other quantities and is determined mathematically. Thus, the variation of handwriting can be described through a change in two physical characteristics of movement. In this case, the following 3 options are possible.

1. The change in the values of v and t with unchanged s. In this case, an increase in speed (the new value is v_1) will lead to a decrease in time (the new value is t_1) spent on executing the same letter, and the ratio is true:

$$v/v_1=t_1/t=\alpha, \quad (3)$$

where α is a constant, and $\alpha < 1$.

The nonequilibrium state of the system of handwriting movements obviously ensures the reproduction of the trajectory with some (greater or lesser) deviations. The error of such deviation (Δs) is the sum of errors in the control of speed (dv) and time (dt) characteristics:

$$\Delta s=dv+dt, \quad (4)$$

and, accordingly:

$$\Delta s_1=dv_1+dt_1=dv/\alpha+d\alpha t. \quad (5)$$

As we noted, as the speed increases, the error of reproducing the trajectory increases with the increasing of speed. As the speed decreases, the trajectory playback error decreases.

Similarly, it can be shown that with an increase in the time spent on writing a letter, the reproduction error decreases, with a decrease in time, the reproduction error increases.

Thus, we have obtained a mathematical expression of the regularity of increasing the variation of handwriting with increasing writing speed (decreasing the execution time of the graphic element), and reducing the variation of handwriting with decreasing writing speed (increasing the execution time of the graphic element).

2. The change in the values of s and v at constant t.

3. The change in the values of s and t with v unchanged.

Variants 2 and 3 represent a special case of a manuscript execution – in the absence of visual control, when the trajectory of movements during the execution of letters is subject to significant changes. Under such writing conditions, the handwriting situation itself contributes to an increase in handwriting variation. However, in this case it is not a variation as such, but the effect of confounding factors on handwriting movements, which should include the biomechanical properties of the executive system itself.

In this regard, it is necessary to pay attention to the work of physiologist T. Flash (1987), who tried to experimentally find out why, when trying to perform a rectilinear movement in space with his hand, the working end of this kinematic chain (arm) moves from the starting point to the end point along a trajectory that is not an absolute straight line. It is always inevitable that deviations from a straight trajectory occur in the course of movements. According to Flash, such deviation can be explained by the fact that the kinematic links forming the human arm have different mechanical properties at different points of the trajectory, i.e. different inertial characteristics that depend not only on the design of the executive system, but also on the position of the elements of this system relative to each other and on the position of the system itself in space.

Conducting researches on the movement of a human hand in a horizontal plane caused by the influence of an external force, Flash found that the working end of such a kinematic chain easily shifts in one direction, but moves very slightly in the other direction. When changing the initial coordinates of the placement of the working end of the kinematic chain of the arm, there is also a change in the ratio of force and direction of displacement.

As a result of the experiments, Flash identified the so–called "ellipses of inflexibility " (or in terms of mechanics - "ellipses of rigidity"), showing a significant difference in the inertial characteristics of a human hand when it moves in different directions.

4 CONCLUSIONS

Thus, from the modern point of view of studies of movements of multi-link kinematic chains, the implementation of handwriting movements occurs as follows: the central nervous system sets the coordinates of the end point of movement of the working part of the kinematic chain, the executive system moves the working part to a given coordinate with some delay in relation to the formed initial image, at the same time the biomechanical, anatomical properties of the executive system itself prevent rectilinear movement. The movement of the working part takes place in a given direction, but along an elliptical trajectory determined by the rigidity dependence of the system.

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