THE MECHANISM OF CONTROL AND CORRECTION OF SPORTSMEN'S MOVEMENT

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The segmental apparatus of the spinal cord takes an active participation in the realization of motor acts and the sportsmen's capacity for work considerably depends on the stability of the spinal mechanism. The regulator apparatuses of the spinal cord play an important part in co-ordination of the sportsmen's motor activity. Before the movement starts, not only the excitability of the motoneurones change but also changes the interneuronal apparatus state of the spinal cord. The remake and transformation of the control commands entering the skeletal muscle is performed under the action of the complicated regulator mechanisms.

The mechanism of the presynaptic inhibition is the most effective and widely outstretched control mechanism. The limitation of transynaptic excitability occurs due to activation of the two-stage contour of negative feedback, formed by the pyramidal and gelatinosa neurones. The mechanism action is based on the long action of depolarization, increasing on exponent to 20 ms, and decreasing on exponent to 300 ms. Depolarization development display in a few millisecond and is connected with the synaptic delays availability in the negative feedback channel. The limitation of the excess information lowers the unfavourable influence of the excessive control signal on the muscles, protects the motor apparatus from overload and promotes the fluent and precision movement (Fig. 1).

The mechanism of the postsynaptic inhibition with Renshov neurones participation provides an additional control act in the motor zone. Mechanism action also realizes according to the principle of the negative feedback. The joint action of the presynaptic and postsynaptic inhibition mechanism allows to realize the reliable control of the sportsmen skeletal muscle (Fig.1).

The stability of the control mechanisms of the spinal cord segmental apparatus considerably influences on the sportsmen capacity for work. The considerable stability decrease of the control mechanisms occurs under tiredness influence during execution of the intensive physical loads. However, there are a number of links in the structure of the spinal cord segmental apparatus which allow to increase the spinal mechanism stability and respectively increase the sportsmen organism capacity for work. The availability of the considerable synaptic delay in the negative feedback channel of the presynaptic and postsynaptic inhibition mechanism is one of these factors. The synaptic delays of the Rolandi gelatinosa substantia neurones in the sensory zone and Renshow neurones in the motor zone influence in favourable, stabilizing way on the stability of the complicated spinal cord control mechanisms.

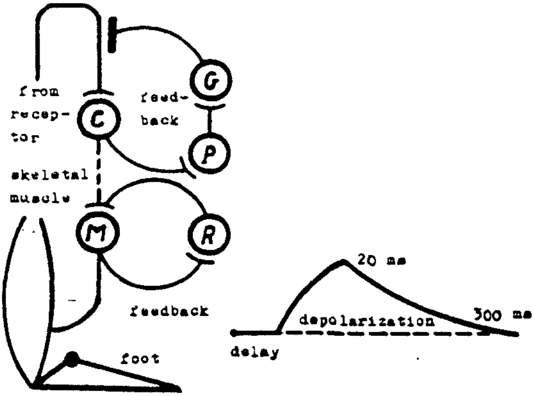

Figure 1: The automatic control scheme of the skeletal muscle. P-pyramidal neurones, G-gelatinose neurones, S-Renshov neurones, M-motoneurones.

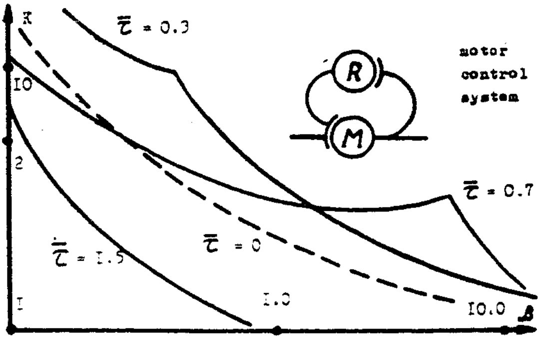

Figure 2: Dependence of control motor system from relative delay τ size.

Let's consider the influence of the synaptic delays value, just the delay, on the increase of the sportsmen segmental apparatus stability. The transmission function of the impulse system with rectangular impulses in the interimpulse intervals is as follows:

$$K^{*}(q,\epsilon) = \sum_{\nu=0}^{s} \sum_{\mu=0}^{\gamma_{s-1}} \frac{C_{\nu\mu}}{\mu!} \frac{d\mu}{dq_{\nu}^{\mu}} \left[\frac{e^{q}\,(e^{q_{\nu}^{\gamma}}-1)}{e^{q}-e^{q_{\nu}}} \, e^{q_{\nu}}\,(\varepsilon-\gamma) \right\} \qquad (1)$$

The system being considered has not divisible and zero poles. The transmission function is as follows

$$K^{*}(q,\epsilon) = \sum_{\nu=1}^{\gamma} C \; \frac{e^{q}(e^{q_{\nu}^{\gamma}}-1)}{e^{q}-e^{q_{\nu}}} \, e^{q(\varepsilon-\gamma)} \qquad (2)$$

Let's consider the influence of the Renshow neurones population delay (Fig.1) on the stability. The transmission function of the continuous system is

$$\tilde{K}_{H}(q) = \frac{P_{H}\,(q)}{Q_{H}\,(q)} \qquad (3)$$

On the basis of the displacement theorem, taking into account the delays in the negative feedback channel, with Renshow neurones participation is

$$K_{H}^{*}(q) = K \, \frac{\beta}{q+\beta} \, e^{-q\bar{\tau}} \qquad (4)$$

The coefficient values in the formula (2) are as follows:

$$q = -\beta,\ C_{00} = K,\ C_{10} = -K \tag{5}$$

After substitution of the coefficients to formula (2) at $\gamma = 1$ it will be

$$\overset{*}{K}(q,\epsilon) = K\ [1 - \frac{e^q - 1}{e^q - e^{-\beta}}\, e^{-\beta\epsilon}] \tag{6}$$

With regard to synaptic delay of the Renshow neurones and with regard to that

$$K^*(q,\epsilon) = e^{-q}\, \overset{*}{K}_0\ (q,\ 1+\epsilon-\bar{\tau}) \tag{7}$$

the formula (6) will be (at $\epsilon = 1 - \bar{\tau}$)

$$K^*(q,\epsilon) = K\ [\ \frac{1-e^{-\beta(1-\bar{\tau})}\ e^q + (e^{\beta\bar{\tau}} - 1)e^{-\beta}}{e^q(e^q - e^{-\beta})}] \tag{8}$$

Let's examine the neuronous control system at different relative delays of the Renshow neurons $\bar{\tau}$, by algebraic criteria. The characteristic polynomial is obtained by addition of the numerator and denominator of the formula (8)

$$\bar{G}^*(q) = e^{2q} + [\ K(1 - e^{-\beta(1-\bar{\tau})}) - e^{-}\ ]\ e^q + K(e^{\beta\bar{\tau}} - 1)e^{-\beta} \tag{9}$$

Polynomial coefficients

$$\bar{G}^*(q) = a_2\, e^{2q} + a_1 e^q + a_0 \tag{10}$$

have the following value

$$a_2 = 1,\ a_1 = K(1 - e^{-\beta(1-\bar{\tau})})e^{-\beta},\ a_0 = K(e^{\beta\bar{\tau}} - 1)\ e^{-\beta} \tag{11}$$

Stability condition is

$$\begin{aligned} a_2 + a_1 + a_0 &> 0 \\ a_2 - a_1 + a_0 &> 0 \\ a_2 - a_0 &> 0 \end{aligned} \tag{12}$$

Two last inequalities

$$a_2 - a_1 + a_0 = [\ 1 - K](1 - e^{-\beta}) + 2Ke^{-\beta(1-\bar{\tau})} > 0 \tag{13}$$

$$a_2 - a_0 = 1 - K\ (e^{\beta\bar{\tau}} - 1)\ e^{-\beta} > 0$$

are of great interest, determining stability limits as

$$K_{\Gamma p1} = \frac{e^{\beta}}{e^{\beta\bar{\tau}} - 1},\quad K_{r\,p2} = \frac{1 - e^{-\beta}}{1 - e^{-\beta} - 2e^{-\beta(1-\bar{\tau})}} \tag{14}$$

Depending on relative $\bar{\tau}$ delay the degree stability of the neuronal system control is changed in rather wide limits (Fig.2). From Figure 2 it is seen that with small synaptic delay of $\bar{\tau} = 0.3$ the stability of the system is maximal through all the frequency band and even excels the stability of control system with zero synaptic delay ($\bar{\tau} = 0$, dotted line). When increasing the relative synaptic delay stability at hight frequences (lowβ) decreases. Stability decrease at high frequences, however, is followed by stability increase at low frequences (hight β value). With higher values of relative synaptic delay ($\bar{\tau} = 1$) stability decreases both at high and low frequences. Starting from relative synaptic delay $\bar{\tau} = 1.5$ the system becomes unsteady at low frequences and at $\bar{\tau} > 1.5$ non-stability is transfered to high frequences. With so high values of relative synaptic $\bar{\tau}$ delay "excitement" of neuronal automatic system can occur.

Value of relative synaptic $\bar{\tau}$ delay fluctuates widely in neuronal automatic control system under study. At 150 Hz frequency the relative synaptic delay is of

$$\bar{\tau}_B = \tau : T_B = 5_{MS} : 7_{MS} \cong 0.7 \qquad (15)$$

Value and at low frequences the relative synaptic delay makes up

$$\bar{\tau}_H = \tau : T_H = 5_{MS} : 2000_{MS} = 0.0025 \qquad (16)$$

where τ is the minimal time delay of the signal in feedback loop made by Renshow neurones population.

Therefore, the neurones system is stable of the most high values of relative delay equal to $\bar{\tau}_B$ = I.Mean and low values of relative synaptic delay increase neurones system stability at low and high frequences respectively.

Let us consider the processes which occur in sensory zone providing the participation of Rolando gelatinosa substantia neurones. In negative feedback contour depolarization wave with exponent increase to 20 ms and similar attenuation to 300 ms is formed.

The transmission function of the forming wave may be presented as

$$K_T(P) = \frac{1}{T'_1 T'_2 P^2 + (T'_1 + T'_2)P + 1} \qquad (17)$$

T'_1 and T'_2 time constants are defined considering time constants of depolarization forming wave as

$$\frac{1}{T'_{12}} = \frac{T_H + T_Y + T}{2T_H T_Y} \pm \sqrt{\frac{(T_H + T_Y + T)^2 - 4T_H T_Y}{4T_H T_Y}} \qquad (18)$$

It is formula T_H and T_Y are the time constant of mediator increase and attenuation in forming wave of the primary afferent depolarization.

On the basis of the well-known formula of disconnected automatic pulse system transmission function

$$K^*(q,0) = \sum_{\nu=1}^{1} C_{\nu 0} (1 - e^{-q_\nu}) \frac{e^q}{e^q - e^{q_\nu}} \qquad (19)$$

determines neurones control system transmission function acting in high floor cord as

$$K^*(q,0) = \frac{1}{\beta_2 - \beta_1} \left[\beta_2 e^{\beta_1 \bar{\tau}} \frac{1 - e^{-\beta_1}}{e^q - e^{-\beta_1}} - \beta_1 e^{\beta_2 \bar{\tau}} \frac{1 - e^{-\beta_2}}{e^q - e^{-\beta_2}} \right] \qquad (20)$$

where β_1 and β_2 are the poles of neurones control system.

On the basis of Nyquist criteria, after q substitation for $j\omega$ and transformation obtain the formula for determining stability range as

$$K_{FP1} = \frac{(\alpha - 1)(1 - e^{-\beta 1(1-\alpha)})}{(1 - e^{-\alpha\beta_1})e^{-\beta_1}\, e^{-\beta_1\bar{\tau}} - \alpha\,(1 - e^{-\beta_1})e^{-\alpha\beta_1}\, e^{-\alpha\beta_1\bar{\tau}}} \tag{21}$$

$$K_{FP2} = \frac{\alpha - 1}{\alpha \mathrm{th}\, \beta_1/2e^{\beta_1\bar{\tau}} - \mathrm{th}^{\alpha\beta_1}/2\, e^{\alpha\beta_1\bar{\tau}}} \tag{22}$$

Dependence diagram of neurones control system stability from synaptic delays of pyramidal neurones Rolando gelatinosa substantia neurones population and ratio of time parameters of depolarization wave increase and attenuation are shown in Figure 3. From the Figure it is seen that synaptic delay of pyramidal and

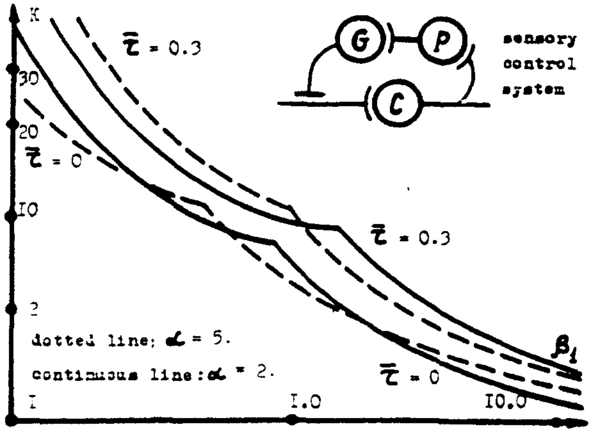

Figure 3: Dependence of control sensory system from relative delay $\bar{\tau}$ size.

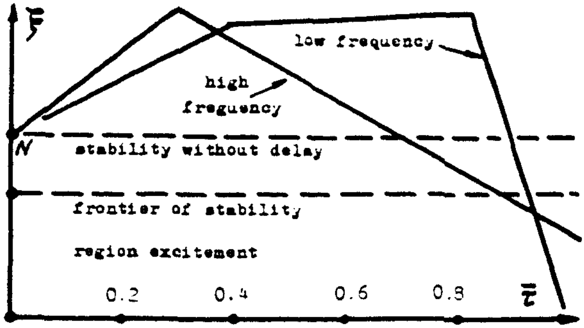

Figure 4: Dependence of control neurone automatic system from relative delay $\bar{\tau}$ size.

gelatinoza neurones population increases stability both in high and low frequencies area whatever the value of dimensionless parameter β_1 is. β_1 increase leads to a small decrease of stability through all the frequency band. The relative synaptic delay increases sharply the stability at high and low frequencies in a certain delay range.

Stability analysis of neurones control system, providing the synaptic delay value is in the range from 0 up to 0.7 $\bar{\tau}$, proves the increased stability of neurones systems under the given relative synaptic delays. The observed automatic control system operates just in the specified 0 - 0.7 $\bar{\tau}$ range. Working frequency range of the system is in the range of 0.5 Hz up to 150 Hz. Optimal range of the relative synaptic delays correspond to the given frequency range. So, $\bar{\tau}$ = 0.0025 synaptic delay corresponds to 5 Hz frequency and the relative synaptic delay of $\bar{\tau}$ = 0.7 corresponds to 150 Hz frequency (Fig.4).

Thus, automatic control neurones system operates in a favourable duty using the synaptic delays of negative feedback channel to increase stability of sportsmen motor apparatus.