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Generalized net model of telemedicine based on body temperature sensors

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Abstract: Generalized net (GN) model of telemedicine/telehealth based on body temperature sensors is proposed. In a previous paper, GN that describes the connection between sensors and remote server was proposed. In the present model, the focus is on the process of decision making in the telemedicine/telehealth center.
Keywords: Generalized net, telemedicine, Telehealth, Body temperature sensor.
AMS Classification: 68Q85.

1 Introduction

Disintegration of the domain organization of myelin nerve fibres, sometimes leading to an internodal dysfunction (demyelination), is a characteristic feature of hereditary, chronic and acquired peripheral nerve disorders such as Charcot-Marie-Tooth Disease (CMT) and Type 1A (CMT1A), Chronic Inflammatory Demyelinating Polyneuropathy (CIDP) and its Subtypes, Guillain-Barré Syndrome (GBS), Multifocal Motor Neuropathy (MMN), etc. Some cases of diabetic and carcinomatous neuropathies also belong to this category, although the most paraneoplastic syndromes show axonal degeneration than demyelination. Amyotrophic Lateral Sclerosis (ALS), also known in the USA as Lou Gehrig's disease, is the most common of the motor neuron diseases. It is a neurodegenerative and usually fatal disorder involving the neurons and the motor system pathways in the brain and spinal cord. ALS subtypes classified as Type 1, Type 2 and Type 3 are associated with progressively increased axonal potassium ion channel dysfunctions (see [10]), which are usually caused by genetic factors.

It is well known that an accurate diagnosis of a given disorder depends in part on the application of the appropriate electrodiagnostic technique and on electrophysiological studies. The nerve conduction study, which is part of the laboratory studies that include blood tests, muscle or nerve biopsy, genetic testing, etc. is still successfully realized. Recently, using a non-invasive threshold tracking technique (see [8, 9, 21]), the clinical investigations of the above mentioned diseases show that their axonal excitability parameters (such as threshold electrotonus, strength-duration time constant, rheobasic current, and recovery cycle) are abnormal at normal body temperature (see [12, 20, 26, 29, 30, 31, 49]). Using our models of the human motor nerve fibres (see [32, 34, 35, 48]), we have simulated the same disorders at normal (37°C) temperature (see [14,23,25,33,36–39,42–47]). And the mechanisms underlying the abnormalities in their axonal excitability parameters (such as action, electrotonic, extracellular potentials, strength-duration time constant, rheobasic current, and recovery cycle have also been summarized, compared and explained (see [41]). The results confirm that the changes obtained in the simulations replicate those recorded in vivo in control groups and in patients with corresponding diseases. The results also confirm that the axonal excitability properties are not identical and can be used as specific indicators for these disorders.

The effects of temperature on nerve conduction measurements have been studied a long time ago. It is well established that the conduction velocity increases by 5% per degree C (see [7, 15, 16, 17, 19, 28]), while the amplitudes and durations of compound motor action potentials decrease slightly (see [7, 11, 27]), when the temperature of nerve increases from $29°$ to $38°$C. It is also established that cooling (from 35 to $29°$C) increases slightly the strength-duration time constant, while the relative refractory period increases significantly, but the threshold electrotonus to subthreshold depolarizing and hyperpolarizing current stimuli is not affected significantly (see [21, 22]). In contrast, the effects of hypothermia ($25°$C) and hyperthermia ($40°$C) on the axonal excitability have been much less studied (see [18]). In this study the excitability parameters of both motor and sensory nerve axons are measured in healthy subjects during focal hyperthermia at $42°$C. Recently, we have also examined the effects of temperature on simulated nodal and internodal action, electrotonic potentials and their current kinetics of the human motor nerve axons in a range of $20-42°$C (see [13, 24, 40, 41]). The results provide evidence that electrotonic potentials and their current kinetics like action potentials and their current kinetics are more sensitive to hypothermia and are most sensitive to hyperthermia than at temperatures in the physiological range of $28-37°$C. Our results also indicate that the blockage of accommodation is increased gradually with the increase of temperature, and the block is achieved by hyperpolarizing current stimuli, which are stronger than -50, -35, -26 and -20$\%$ of threshold, at 42, 43, 44 and $45°$C, respectively. However, a block of accommodation cannot be realized by current stimuli which are even up to -100$\%$ of threshold during hyperthermia at $40°$C. The conduction block of the human motor action potential is achieved at $45°$C.

In healthy subjects, the symptoms of fatigue and exhaustion can result from elevations in body temperature. The slow skin temperature of the hand, the so called ”cold hands sign”, may be useful for distinguishing multiple system atrophy from Parkinson’s disease (see [2]). It is known that the elevation or slowing in body temperature may worse or improve the axonal excitability properties in patients with different disorders. However, comparable information on any excitability parameter during hypothermia or hyperthermia is not available for patients with demyelinating neuropathies such as CMT1A, CIDP, GBS, MMN and neuronopathies such as ALS, simulated by us. Consequently, it is important to establish which critical temperature levels for these diseases are. Such data are also essential for the interpretation of mechanisms of temperature dependent excitability parameter measures in control subjects and patients with demyelinating neuropathies and neuronopathies with symptoms of cooling, fatigue, exhaustion and fever, which can result from alterations in body temperature.

2 Generalized net model

We use the apparatus of generalized nets (GNs) (see [3, 4]) to model telemedicine/telehealth based on body temperature sensors. The model consists of four transitions:

- Z_1 represents the temperature sensors (for example bracelets).
- Z_2 represents the communication between the sensors and the telemedicine center.
- Z_3 represents the database with the patients' history.
- Z_4 represents the telemedicine/telehealth persons.

Four types of tokens are used:

- $\sigma_1, \sigma_2, \cdots, \sigma_n$ represent the body temperature sensors (for example bracelets).
- γ keeps as characteristic the type of communication between the sensors and the telemedicine center.
- α represents the database with the patients' history.
- δ represents the telemedicine/telehealth persons.

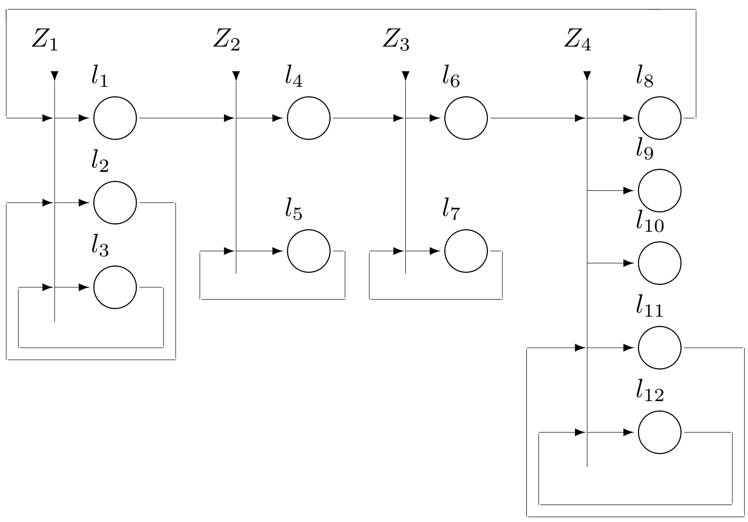

Figure 1. GN of telemedicine/telehealth based on body temperature sensors.

Initially, tokens stay in the following places:

- In place l_3 tokens $\sigma_1, \sigma_2 \cdots, \sigma_n$ with characteristic "type of sensor, name of the patient, coordinates".
- In place l_5 token γ with initial characteristic a list of all sensors and the type of communication between the sensor and the server.
- In place l_7 token α with characteristic "database with history of the patients".
- In place l_{12} token δ with characteristic "telemedicine/telehealth person, name, duration of the shift" .

What follows is a description of the transitions of the net.

$$Z_1 = \langle \{l_2, l_3, l_8\}, \{l_1, l_2, l_3\}, r_1, \vee(l_2, l_3, l_8) \rangle$$

where

$$r_1 = \begin{array}{c|ccc} & l_1 & l_2 & l_3 \\ \hline l_2 & W_{2,1} & W_{2,2} & false \\ l_3 & false & W_{3,2} & true \\ l_8 & false & true & false \end{array}$$

and

- $W_{2,1}$ = "the temperature of the current patient has been measured",
- $W_{2,2}$ = $\neg W_{2,1}$,
- $W_{3,2}$ = "the temperature of the current patient should be measured".

When the predicate $W_{2,1}$ has truth value "true" the σ token from place l_2 enters place l_1 with characteristic "measured temperature of the current patient".

$$Z_2 = \langle \{l_1, l_5\}, \{l_4, l_5\}, r_2, \wedge(l_1, l_5) \rangle,$$

where

$$r_2 = \begin{array}{c|cc} & l_4 & l_5 \\ \hline l_1 & true & false \\ l_5 & false & true \end{array}$$

In place l_4 the σ-token obtains the characteristic "type of the connection between the sensor and the server".

$$Z_3 = \langle \{l_4, l_7\}, \{l_6, l_7\}, r_3, \wedge(l_4, l_7) \rangle$$

where

$$r_3 = \begin{array}{c|cc} & l_6 & l_7 \\ \hline l_4 & true & false \\ l_7 & false & true \end{array}$$

In place l_6 the σ-token obtains the characteristic "history of the current patient".

$$Z_4 = \langle \{l_6, l_{11}, l_{12}\}, \{l_8, l_9, l_{10}, l_{11}, l_{12}\}, r_4, \wedge(\vee(l_6, l_{11}), l_{12})\rangle,$$

where

$$r_4 = \begin{array}{c|ccccc} & l_8 & l_9 & l_{10} & l_{11} & l_{12} \\ \hline l_6 & false & false & false & true & false \\ l_{11} & W_{11,8} & W_{11,9} & W_{11,10} & W_{11,11} & false \\ l_{12} & false & false & false & false & true \end{array}$$

and

- $W_{11,8}$ = "the temperature of the current patient should be measured again".
- $W_{11,9}$ = "the patient should be transported to hospital".
- $W_{11,10}$ = "medical doctor should visit the patient",
- $W_{11,11}$ = "decision is not taken yet".

When the truth value of the predicate $W_{11,8}$ is "true" the σ token in l_{11} enters place l_8 with characteristic "temperature should be measured again".

In place l_9 the σ token obtains the characteristic "the current patient should be transported to hospital". In place l_{10} the σ token obtains the characteristic "doctor should visit the patient, name of the doctor". In place l_{12} the δ token obtains the characteristic "telemedicine person, decision taken".

3 Generalized nets with characteristics of the places

The concept of Generalized Nets with Characteristics of the Places (GNCP) is introduced in [1]. GNCP is the ordered four tuple

$$E = \langle\langle A, \pi_A, \pi_L, c, f, \theta_1, \theta_2\rangle, \langle K, \pi_K, \theta_K\rangle, \langle T, t^0, t^*\rangle, \langle X, Y, \Phi, \Psi, b\rangle\rangle.$$

All other components except the characteristic functions Y and Ψ are the same as in the standard GNs.

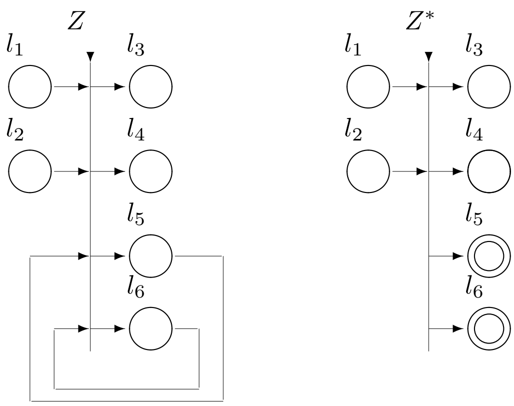

Figure 2.

The characteristic function Y assigns initial characteristics to the places of the net. The function Ψ assigns characteristics to some of the places when tokens enter them. These characteristics can be the number of tokens in the place, the moment of time when they arrive or other data which is related to the place.

GNCP can be used to simplify the graphical structure of the net. Often in a GN we have transitions for which a place is both input and output. If tokens loop in this place or other tokens from other input places can enter it but no tokens can be transferred from this place to other output places of the transition, then we can exclude this place from the set of the input places of the transition. The characteristics of the tokens that loop in this place can be assigned to the place instead. For the transition Z in Fig. 2 we have two such places - l_5 and l_6. If we use characteristics for these two places, the functioning of Z can be represented by the transition Z^*. The two circles denote the fact the place can obtain characteristics. GNCP can also be used for evaluation of the work of the places on the basis of their characteristics. For example let Δ_l denotes the set of all good characteristics that can be assigned to place l and Ξ_l denotes the set of all bad characteristics. Let $\chi^{l,t} = \langle \chi_1^l, \cdots, \chi_n^l \rangle$ be the n-tuple of the characteristics obtained by place l up to the time moment t. Let

$$I_\Delta^l(x_i^l) = \begin{cases} 1 & , \ \chi_i^l \in \Delta_l \\ 0 & , \ \chi_i^l \notin \Delta_l \end{cases}$$

$$I_\Xi^l(x_i^l) = \begin{cases} 1 & , \ \chi_i^l \in \Xi_l \\ 0 & , \ \chi_i^l \notin \Xi_l \end{cases}$$

Then the characteristic function Ψ can assign to place l the ordered couple $\langle \mu_l^t, \nu_l^t \rangle$ where

$$\mu_l^t = \frac{\sum\limits_{i=1}^{n} I_\Delta^l(\chi_i^l)}{n}$$

$$\nu_l^t = \frac{\sum\limits_{i=1}^{n} I_\Xi^l(\chi_i^l)}{n}$$

Obviously, μ_l^t, $\nu_l^t \in [0, 1]$ and $\mu_l^t + \nu_l^t = 1$. The ordered couple $\langle \mu_l^t, \nu_l^t \rangle$ is a fuzzy evaluation of place l at time t.

In the more general case, we also have characteristics that are neither good nor bad. Then for the couple $\langle \mu_l^t, \nu_l^t \rangle$ we have $\mu_l^t, \nu_l^t \in [0, 1]$ and $\mu_l^t + \nu_l^t \leq 1$. The number $\pi_l^t = 1 - \mu_l^t - \nu_l^t \leq 1$ corresponds to the degree of indeterminancy. In this case $\langle \mu_l^t, \nu_l^t \rangle$ is an intuitionistic fuzzy evaluation of the place. For fuzzy and intuitionistic fuzzy sets see [5].

4 GNCP model of telemedicine/telehealth based on body temperature sensors

To illustrate the concept of GNCP we propose a GNCP of telemedicine/telehealth based on body temperature sensors. The GNCP in Fig. 3 is based on GN model described in Section 2 (see Fig. 1). It has the same number of transitions and they have the same meaning as their corresponding transitions of the GN model. The characteristics of the places allow us to reduce the number of places and the types of tokens.

In the GNCP model we have only one type of tokens. In the initial time moment tokens $\sigma_1, \sigma_2, \cdots, \sigma_n$ stay in place l_2 with initial characteristic "type of sensor, name of the patient, coordinates".

Place l_1 has initial characteristic "database with information about the type of the connection between the sensors and the remote server". Place l_2 has initial characteristic "database with initial state of of the sensors". Place l_3 has initial characteristic "database with patients' history". Place l_4 has as initial characteristic a list of the telemedicine/telehealth persons and the duration of their shift in the form "telemedicine telehealth person, duration of the shift, previous decisions taken".

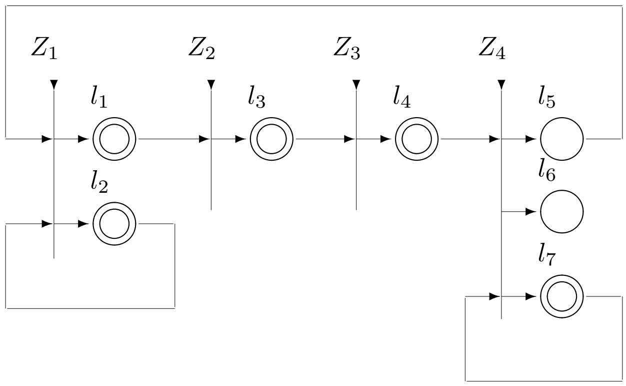

Figure 3.

$$Z_1 = \langle \{l_2, l_5\}, \{l_1, l_2\}, r_1, \vee(l_2, l_5) \rangle$$

where

$$r_1 = \begin{array}{c|cc} & l_1 & l_2 \\ \hline l_2 & W_{2,1} & true \\ l_5 & true & false \end{array}$$

and $W_{2,1}$ = "the temperature of the current patient should be measured".

When the truth value of predicate $W_{2,1}$ is "true" the σ token in l_2 splits into two tokens - the original that stays in l_2 and a new identical one that enters l_1 with characteristic "temperature, type of the connection between the sensor and the server".

Place l_2 obtains the characteristic "current state of the sensors".

$$Z_2 = \langle \{l_1\}, \{l_3\}, r_2 \rangle$$

where

$$r_2 = \begin{array}{c|c} & l_3 \\ \hline l_1 & true \end{array}$$

When σ token enters l_3 the place obtains the characteristic "measured temperature of the corresponding patient, time".

In place l_3 the σ token obtains the characteristic "history of the current patient".

$$Z_3 = \langle \{l_3\}, \{l_4\}, r_3 \rangle$$

where

$$r_3 = \begin{array}{c|c} & l_4 \\ \hline l_3 & true \end{array}$$

When σ token enters l_4 the place obtains the characteristic "telemedicine persons, decisions taken".

$$Z_4 = \langle \{l_4, l_7\}, \{l_5, l_6, l_7\}, r_4, \vee(l_4, l_7) \rangle$$

where

$$r_4 = \begin{array}{c|ccc} & l_5 & l_6 & l_7 \\ \hline l_4 & W_{4,5} & W_{4,6} & W_{4,7} \\ l_7 & false & W_{7,6} & true \end{array}$$

and

- $W_{4,5}$ = "the temperature of the current patient should be measured again".
- $W_{4,6}$ = "the patient must be transported to hospital or a medical doctor should visit the patient".
- $W_{4,7} = W_{4,5}$.
- $W_{7,6}$ = "confirmation of the signal has arrived in place l_4 and decision to either transport the patient to hospital or send a medical doctor is taken".

When the truth value of predicate $W_{4,5}$ is true the σ token in place l_4 splits into two tokens - the original that enters place l_7 without new characteristic and a new one σ' that enters place l_5 with characteristic "temperature should be measured again".

In place l_6 the σ token obtains the characteristic "decision taken by the telemedicine person for the current patient".

In place l_7 the σ token does not obtain new characteristic. Place l_7 obtains the characteristic "duration of the period of waiting for a confirmation signal".

When the truth value of the predicate $W_{7,6}$ is "true" the σ token in place l_7 enters place l_6 where it merges with the corresponding token σ'.

The method has shown potential for implementation into telemedicine/telehealth solutions.

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References

[1] Andonov V., K. Atanassov. Generalized nets with characteristics of the places, Compt. rend. Acad. bulg. Sci., 66, 2013, No 12, 1673-1680.

[2] Asahina M., DA. Low, CJ. Mathias, Y. Fujinuma, A. Katagiri, Y. Yamanaka, J. Shimada, A. Poudel, S. Kuwabara. Skin temperature of the hand in multiple system atrophy and Parkinson's disease. Parkinsonism and Related Disorders 19, 2013, 560-562.

[3] Atanassov K., Generalized Nets, World Scientific, Singapore, London, 1991.

[4] Atanassov K. On Generalized Nets Theory. Prof. M. Drinov Academic Publ. House, Sofia, 2007.

[5] Atanassov K. On Intuitionistic Fuzzy Sets Theory. Springer, Berlin, 2012

[6] Bolton CF., K. Carter, JJ. Koval. Temperature effects on conduction studies of normal and abnormal nerve. Muscle Nerve 5, 1982, 145-147.

[7] Bolton CF., Sawa GM., Carter K. The effect of temperature on human compound action potentials. J Neurol Neurosurg Psychiatry 44, 1981, 407-413.

[8] Bostock H., M. Baker.Evidence for two types of potassium channel in human motor axons in vivo. Brain Res. 462, 1988, 354-358.

[9] Bostock H., K. Cikurel, D. Burke. Threshold tracking techniques in the study the human peripheral nerve. Muscle Nerve 21, 1998, 137-158.

[10] Bostock H., M.K. Sharief, G. Reid, N.M.F. Murray. Axonal ion channel dysfunction in amyotrophic lateral sclerosis. Brain 118, 1995, 217-225.

[11] Buchthal F., A. Rosenfalck. Evoked action potentials and conduction velocity in human sensory nerves. Brain Res 1, 1966, 1-122.

[12] Cappelen-Smith C., S. Kuwabara, CS-Y. Lin, I. Mogyoros, D. Burke. Membrane properties in chronic inflammatory demyelinating polyneuropathy. Brain 124, 2001, 2439-2447.

[13] Daskalova M., S. Krustev, D. Stephanova. Temperature effects on simulated human nodal action potentials and their defining current kinetics. Scripta Scientifica Medica 45(3), 2013, 42-47.

[14] Daskalova M., D.I Stephanova. Strength-duration properties of human myelinated motor and sensory axons in normal case and in amyotrophic lateral Sclerosis. Acta Physiol. Pharmacol. Bulg. 26, 2001, 1-4.

[15] De Jesus PV., I. Hausmanowa-Petrusewicz, RI. Barchi. The effect of cold on nerve conduction of human slow and fast nerve fibres. Neurology 23, 1973, 1182-11829.

[16] Dioszeghy P., E. Stålberg. Changes in motor and sensory nerve conduction parameters with temperature in normal and diseased nerve. Electroencephalogr Clin Neurophysiol 85, 1992, 229-235.

[17] Geerlings AHC., K. Mechelse. Temperature and nerve conduction velocity, some practical problems. Electromyogr Clin Neurophysiol 25, 1985, 253-260.

[18] Howells J., Czesnik D., Trevillion L., Burke D. 2013. Excitability and the safety margin in human axons during hyperthermia. J Physiol 591:3063-3080.

[19] Johnson EW., KJ. Olsen. Clinical value of motor nerve conduction velocity determination. JAMA 172, 1960, 2030-2035.

[20] Kaji R. Physiology of conduction block in multifocal motor neuropathy and other demyelinating neuropathies. Muscle Nerve 27, 2003, 285-296.

[21] Kiernan M.C., D. Burke, K.V. Andersen, H. Bostock. Multiple measures of axonal excitability: a new approach in clinical testing. Muscle Nerve 23, 2000, 399-409.

[22] Kiernan MC., K. Cikurel, H. Bostock. Effects of temperature on the excitability properties of human motor axons. Brain 124, 2001, 816-825.

[23] Krustev S., M. Daskalova, D. Stephanova. Myelin sheath aqueous layers do not modulate membrane fibre properties of simulated cases of paranodal internodal systematic demyelinations. Compt. rend. Acad. bulg. Sci. 63(12), 2010, 1845-1852.

[24] Krustev M., M. Daskalova, D. Stephanova. Temperature effects on simulated human internodal action potentials and their defining current kinetics. Scripta Scientifica Medica 45(4), 2013, 36-40.

[25] Krustev S.M., N. Negrev, D.I. Stephanova. The strength-duration properties in simulated demyelinating neuropathies depend on the myelin sheath aqueous layers. Scripta Scientifica Medica 44(1), 2012, 117-123.

[26] Kuwabara S., K. Ogawara, J.Y. Sung, M. Mori, K. Kanai, T. Hattori, N. Yuki, C.S. Lin, D. Burke, H. Bostock. Differences in membrane properties of axonal and demyelinating Guillain-Barré syndromes. Ann. Neurol. 52, 2002, 180-187.

[27] Lang AH., A. Puusa. Dual influence of temperature on compound nerve action potential. J Neurol Sci 51, 1981, 81-88.

[28] Lowitzsch K., HC. Hopf, J. Galland. Changes of sensory conduction velocity and refractory periods with decreasing tissue temperature in man. J Neurol 216, 1977, 181-188.

[29] Nodera H., H. Bostock, S. Kuwabara, T. Sakamoto, K. Asanuma, J.Y. Sung, K. Ogawara, N. Hattori, M. Hirayama, G. Sobue, R. Kaji. Nerve excitability properties in Charcot-Marie-Tooth disease type 1A. Brain 127, 2004, 203-211.

[30] Nodera H., R. Kaji. Nerve excitability testing and its clinical application to neuromuscular diseases. Clin. Neuphysiol. 117, 2006, 1902-1916.

[31] Priori A., B. Bossi, G. Ardolino, L. Bertolasi, M. Carpo, E. Nobile-Orazio, S.Barbieri. Pathophysiological heterogeneity of conduction blocks in multifocal motor neuropathy. Brain 128, 2005, 1642-1648.

[32] Stephanova D.I. Myelin as longitudinal conductor: a multi-layered model of the myelinated human motor nerve fibre. Biol. Cybern. 84, 2001, 301-308

[33] Stephanova D.I., A.S. Alexandrov. Simulating mild systematic and focal demyelinating neuropathies: membrane property abnormalities. J. Integr. Neurosci. 5, 2006, 595-623.

[34] Stephanova D.I., H. Bostock. A distributed-parameter model of the myelinated human motor nerve fibre: temporal and spatial distributions of action potentials and ionic currents. Biol. Cybern. 73, 1995, 275-280.

[35] Stephanova D.I., H. Bostock. A distributed-parameter model of myelinated human motor nerve fibre: temporal and spatial distributions of electrotonic potentials and ionic currents. Biol. Cybern. 74, 1996, 543-547.

[36] Stephanova D.I., M. Daskalova. Extracellular potentials of human motor myelinated nerve fibres in normal case and in amyotrophic lateral sclerosis. Electromyogr. Clin. Neurophysiol. 42, 2002, 443-448.

[37] Stephanova D.I., M. Daskalova.. Differences in potentials and excitability properties in simulated cases of demyelinating neuropathies. Part II. Paranodal demyelination. Clin. Neurophysiol. 116, 2005a, 1159-1166.

[38] Stephanova D.I., M. Daskalova. Differences in potentials and excitability properties in simulated cases of demyelinating neuropathies. Part III. Paranodal internodal demyelination. Clin. Neurophysiol. 116, 2005b, 2334-2341.

[39] Stephanova D.I., M. Daskalova. Membrane property abnormalities in simulated cases of mild systematic and severe focal demyelinating neuropathies. Eur. Biophys. J. 37, 2008, 183-195.

[40] Stephanova D.I., M. Daskalova. Effects of temperature on simulated electrotonic potentials and their current kinetics of human motor axons at $20 - 42°C$. Clin. Neurophysiol, 2014. (in press)

[41] Stephanova DI., B. Dimitrov. Models and methods for investigation of the human motor nerve fibre. In: Stephanova DI, Dimitrov B, editors. Computational Neuroscience: Simulated Demyelinating Neuropathies and Neuronopathies. Boca Raton (USA), CRC Press, Taylor and Francis Group, 2013, 18-32.

[42] Stephanova D.I., M. Daskalova, A.S. Alexandrov. Differences in potentials and excitability properties in simulated cases of demyelinating neuropathies. Part I. Clin. Neurophysiol. 116, 2005, 1153-1158.

[43] Stephanova D.I., M. Daskalova, A.S. Alexandrov. Differences in membrane properties in simulated cases of demyelinating neuropathies. Internodal focal demyelination without conduction block. Journal of Biological Physics 32, 2006, 61-71.

[44] Stephanova D.I., M. Daskalova, A.S. Alexandrov. Differences in membrane properties in simulated cases of demyelinating neuropathies. Internodal focal demyelination with conduction block. Journal of Biological Physics 32, 2006b, 129-144.

[45] Stephanova D.I., M. Daskalova, A.S. Alexandrov. Channels, currents and mechanisms of accommodative processes in simulated cases of systematic demyelinating neuropathies. Brain Research 1171, 2007b, 138-151.

[46] Stephanova D.I., S.M. Krustev, M. Daskalova. The aqueous layers within the myelin sheath modulate the membrane properties of simulated hereditary demyelinating neuropathies, J. Integr. Neurosci., 10(1), 2011a, 89-103.

[47] Stephanova D.I., S.M. Krustev, N. Negrev, M. Daskalova. The myelin sheath aqueous layers improve the membrane properties of simulated chronic demyelinating neuropathies, J. Integr. Neurosci. 10(1), 2011b, 105-120.

[48] Stephanova D.I., N. Trayanova, A. Gydikov, A. Kossev. Extracellular potentials of a single myelinated nerve fiber in an unbounded volume conductor. Biol. Cybern. 61, 1989, 205-210.

[49] Sung J.Y., S. Kuwabara, R. Kaji, K. Ogawara, M. Mori, K. Kanai, H. Nodera, T. Hattori, H. Bostock. Threshold electrotonus in chronic inflammatory demyelinating polyneuropathy: correlation with clinical profiles. Muscle Nerve 29, 2004, 28-37.