Contemporary models and preservation possibilities assessment in conceptual-production system of voluntary motor action

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Abstract

The aim of this paper is to describe the emergence of contemporary models of the voluntary motor action. This paper describes the best known models, and preservation assessment in conceptual-production system of voluntary motor action.

Paper is a review of available literature in the field of apraxia. Reviewing the literature we have found that the originator of modeling of conceptual -production system of voluntary motor action is Hugo Liepmann, that the dominant models of this system is Hailman's and Roy's models, and assessment instruments which are well known are Florida Apraxia Battery and Waterloo Apraxia Battery.

The impression is made that, for the future voluntary motor actions studies, it is needed to integrate comprehensive knowledge, derived from clinical studies, testing researches and improvement of conceptual-production systems models, movement researches in functional, practical and social context.

Key words: apraxia, disability, motor action

Introduction

Every human being exists and functions in different contexts. Just as physics claims that there is no body in nature free from the influence of external forces, there is no human liberated from its biological, psychological, cognitive, social, functional and other determinants used for changing and knowing the world around him.

The movement is one of the basic characteristics of humans. A child is by birth obtained with the systems needed for functioning. Most of these systems a child must master, in order to use them purposefully to establish contacts with world surrounding him. One of the basic systems that a child must master is the motor system. Combined with the cognitive and sensor system, as well as all other systems in human organism, the motor system presents the basis for creating a voluntary movement, which is determined by the overall development of man with all its determinants.

The origin and characteristics of the movement are the subject of human`s interest and research throughout history. The movements and the way of performing them are different for each individual, by which they picture his character and arouse interest of others. From observing the movement, measuring and comparing motor skills, trough movement as artistic expression, and scientific approach - a long way was journeyed.

The scientific approach to the movement research has been made in the mid of the last century. The initial primacy was given to the anatomy and mechanics of the joints. The latter studies have expanded the frames of anatomy and mechanics including more experimental model (physiology and neurophysiology) and human model (special education and rehabilitation, neuropsychology, cognitive psychology) (1). Emerging influence of natural science, contemporary technology and informatics on the medical and social sciences, has made the latest movement research more objective and more qualitative in the past decades, especially in the past few years.

Kinesiological approach describes in the best possible way the laws of movement performan-

ce in space, using the laws of physics (especially biomechanics) and medicine. Zec (2) states that the basic obstacle for rapid development of kinesiology is limited knowledge about processes occurring in central nervous system while initiating and controlling voluntary, automated and reflex actions. Hence, this area of research is still referred to as an unexplored area. The truth is that biomechanical component of human movements is today very well known, but it is only a small part of the problem needed to enlighten, the regularity needed to establish and conclusions needed to determine for understanding numerous uncertainties. That is why new studies have been orientated more towards the problems of coordinating the functions, which includes the roles of sensibility, physical activity and motor response in form of harmonious action of highly coordinated movements when changing the conditions of execution of motor tasks.

Recent studies of movement have been aimed at defining the cognitive aspects of motor behavior (planning, control and performance) in various degrees of impairment, as well as the possibilities of restitution of lost or altered movement (1) In this sense we can say that in frames of contemporary approach in studying movements the neuropsychological approach is dominant.

Apraxia as a cognitive aspect of motor functioning

Most researchers involved in studying voluntary movement from the human science aspect believe that the initiator of exploratory approach in examining conceptualization and production of voluntary motor activity is Liepmann. Liepmann explored this subject trough research of problems in praxic activity, that is trough apraxia research. Liepmann (3) stated that the term apraxia first appeared in the literature in 1871. This term had a much narrower meaning than today. More specific, it marked low recognition or inadequate use of objects by people with brain damage (3). It is believed that the creator of the term apraxia in its closest meaning it has today was Steinheil. He described apraxia as a phenomenon in which patients with brain damage occasionally lose a learned ability to perform actions (e.g. playing of a musical instrument, etc.). The meaning of the word apraxia defined by Steinheil partially coincides with the one defined by Liepmann in 1900.

The main difference is that Steinheil believes that the cause of impairment is inability to recognize the use and application of objects and tools, in other words - form of agnosia. It is not clear from his statement what is the basis of agnosia - is it impairment by nature motor, sensory or gnostic. On the other hand, Liepmann considers apraxia as a motor impairment (4).

Numerous scientists trough history have tried to define the way of making movements and to establish the problems in planning and movement performance. Wernicke uses the term "loss of the ideas of movement" and considers that there is a memory of kinesthetic sensations which are remembered by repetition and stored in the specific parts of the cortex. Nothnagel considers that "memorized images" are in the basis of the movements, and defines the "mental paralysis" as impairment in the level of "memorized images". Meynert introduces the concept of "innervation image" as a basis for creating a movement, and "motor asymbolia" as a problem that occurs at the level of movement planning. All these concepts are actually in a specific way and in a certain degree consistent with the theory of the movement patterns and motor action whose initiator was Liepmann (3).

Liepmann describes in details the case of apraxia in 48-years old patient in Berlin hospital received under the diagnosis of mix aphasia and post infarct dementia, which is to today the example of neuropsychological and neurophysiologic interpretations of these impairments. Liepmann and Mass believe that in the left hemisphere, besides the language engrams, lay also the movement patterns (Bewegungsforme in German) (5). In the literature of English-speaking areas this term is usually translated as "movement formulae". Movement patterns contain time-space images for controlling purposeful motor activity and learned motor skills. In the light of modern terminology, this term is the closest to the Heilman`s term of "visuokinaesthetic motor engrams" (6). Learning of motor skills is based on the adoption of the movement patterns and innervation schemes, through which data of movement patters are transmitted to the primary motor cortical regions. Accor-

ding to the Leipmann`s model, the performance of complex motor skills depends on the plan of motor action which defines and controls spatial-temporal sequence and combination of individual movements in complex forms of motor action (7). Motor formula, that is the pattern of movements, contains images of movement in space and time, or spatial-temporal sequences. These images, that is sequences, actually represent general knowledge of the action plan which is to be performed. This knowledge is by nature sensory, most often visual but it can be presented in other sensory modalities when it is necessary for the specific action. Leipmann claims that innervation schemes are established trough exercise and provide efficiency in transformation of motor formula, that is movement pattern, fully and precisely in innervation which enables proper limbs positioning in accordance with the idea of the movement performance direction. Another significant factor is kinetic memory that includes a functional link between the innervation acting via "shortcuts" without innervation of visual images and orientation (8).

When a person with a form of brain impairment cannot perform movements as an adequate response to verbal instruction, causes may be different (8), specifically: palsy or paresis (part of the body that a person should use for a movement performance may be paralyzed or to some extent paretic that the movement is impossible to perform); ataxia (part of the body is strong enough to perform a movement, but the ataxia as a consequence of losing sensory determinants needed for movement coordination makes the movement impossible. The person misses target, or violent, uneconomical, uncontrolled movements occur. The person often drops the objects out of the hands, which is a consequence of uneven force deployment during the movement performance, as well as the insufficient muscle and muscle group cooperation included in motion (dysmetria, asynergia). Cooperation amongst muscles (synergy, which mainly occurs at the unconscious level, in this case is absent); tremor, chorea, athetosis and similar disorders (may be disturbing factors in the movement performance); word deafness (presents the agnosia in the acustics. For example, because of the misunderstanding of the language (sensory aphasia), a person cannot understand the order and therefore performs a particular aspect or aspects of the movement incorrectly); optical or tactical agnosia (when a person cannot recognize objects or tools and uses them in a wrong manner. For example, a person uses scissors like a pen, because he/she cannot recognize the object due to so-called "physical blindness", which is often paired with tactile amnesia - inability to recognize by touch); mental processes vulnerability (a large decrease of all mental processes can be noticed (dementia), meaning that abilities to observe, differentiate, understand and mentally process are decreased, which leads to reduction of motor skills. The role of mental processes in movement performance is often ignored).

It is more than often that persons with brain impairments show none of the mentioned symptoms, yet a possibility of adequate movement performance is decreased or disabled. There could be some presence of the symptoms, but not enough to explain inadequate movement performance. For example, a person with ataxia uses spoon as a cigarette. Inadequate use of objects cannot be attributed to ataxia; in this case apraxia is present.

In movement impairments such as palsy, paresis, ataxia or tremor, athetosis and other, the basis are impairments within the systems which humans are born with, like - above others - central nervous system. The functions affected are, e.g. equilibrium in the locomotor system while walking or standing. Praxia, on the other hand, involves actions that are learned from experience and by exercising.

The fact is that a child in certain way learns to keep coordination and balance while walking, but this type of learning is in many ways different than learning a language or a meaningful movement. Maturation of the medulla after the birth plays a significant role in acquiring these skills. In adopting basic motor skills the important process is taking over control of the functions given by birth. Coordination of existing functions is established by trials, and in time it becomes incorporated in the movement by which it becomes fully developed. In this way the developed movement takes nothing from the social environment. It implies learning proper use of centrifugal impulses on its own centripetal impressions, according to the principle of least effort, that is, it presents control of its own motor skills (8).

On the other hand, learning of meaningful movement in order to achieve person`s needs and to

establish social contact, which includes the manipulation of objects, using words, gestures, is in the domain of praxic activities.

Apraxia is defined as an impairment of learned movements, which is not caused by muscle and/or neurological factors (e.g, weakness, akinesia, aphasia, cognitive decline resources, vision problems, etc.) (9, 10, 11).

According to the International Classification of Functioning, Disability and Health (ICF), World Health Organization (WHO), apraxia is classified as b176 Category. This category is named "Mental function of sequencing complex movements" and includes ideational, ideomotor, oculomotor apraxia, dressing apraxia and apraxia of speech, and excludes categories of impairments of psychomotor functions (b147), higher cognitive functions (b164), and whole 7th chapter in ICF in which neuromuscular impairments, skeletal function related to movement performance are categorized (12)

Within this classification different categories of apraxia are listed, which are defined in detail in numerous and various researches. One of the most common approaches in assessing apraxia trough history is assessing the quality of pantomime or imitation of gestures. The quality of pantomime is usually assessed by giving an order to the respondent such as: "Show me how to..." The respondent would perform the movement, after which the examiner would assess the quality of the motion. For assessment of the imitation of gestures, the examiner would use the order: "Do this…" after which the examiner would perform the movement that the responded needs to imitate (13). Studies that have used this method of assessment of apraxia, according to Benke (14), led to defining two different forms of apraxia: ideomotor and ideational apraxia. These two forms of apraxia in fact differ in patterns of errors that occur during the movement imitation and pantomime (15). For ideomotor apraxia it is typical that spatial orientation, selection and movement sequencing is damaged, in the imitation of movement and in pantomime as well (13). These errors are according to Benke (14) the most evident in imitation of purposeless movements. Ideomotor apraxia is caused by impairments in selection and combination of individual, natural movements from which the complex motor activity is organized. The movement is clumsily performed, with individual movements that are placed in space and time in a wrong manner (e.g. while performing military salute the hand is placed behind the ear). The patient is aware of his mistake and tries to correct it, which testifies that the representation of the gesture is preserved but it is clumsily performed, and one of its components is wrongly selected or placed in spatial and/or temporal terms (7). On the other hand, ideational apraxia is in its basis conceptual and related to the use of tools and objects. In this type of apraxia the movement imitation is intact, while pantomime is performed with errors, which means that the semantic component of the movement is compromised. Ocic (7) states that the ideational apraxia represents the impairment in recalling the general scheme of movements caused by loss of motor engrams or their difficult access to semantic memory in which information about basic features of objects and their usage are stored.

Contemporary models of conceptual-production system of voluntary motor action

These researches have not only recognized and defined different forms of apraxia, but have also established general attitude of scientist that in the basis of voluntary motor actions lays complex system. When impairment occurs in some element or more elements of this system, different clinical features could be made. Also, there are certain differences in defining same forms of apraxia by different researchers. Therefore, the contemporary researches are more and more based on defining elements and creating adequate models of conceptual-production system of voluntary motor action.

Coltheart (16) states that simultaneous explanation of normal and neuropsychological abnormal processing of information is not of recent date. This approach is typical for work of recognized neurologists from the late nineteenth and early twentieth century like Wernicke, Lichtheim and Leipmann, that Head (17) depicted as the "diagram makers." Designing diagrams refers to the creation of the first movement's scheme theories and a motor action plan, as well as a model of praxic activity.

We have previously mentioned Leipmann`s model of praxic activities which was a starting point for creation of contemporary models of conceptual-production system of voluntary mo-

tor action. In foreign literature the two models are defined as dominant in contemporary researches: Heilman`s and Roy`s. Both models are composed of similar components, but their modeling by levels is different in many ways. Rothi, Ochipa and Heilman have developed a model with the aim of better understanding praxia and apraxia which is today known as Heilman`s model. This model is based on the belief that motor impairments such as apraxia are similar to those which develop in speech-language system after specific brain injuries. It is assumed that a certain pattern of dysfunctions developed in persons with apraxia could occur exclusively as a result of impairments in more than one system, and that these impairments patterns are conceptually similar to those which develop in the speech-language sphere (18, 19).

Heilman`s model (Figure 1.) includes an analysis of sensory information (auditory and visual analysis), the existence of internal knowledge (object recognition, phonological, vocabulary and verbal actions, which are all connected and operated through the semantic and action system) and the generation and control of gestures (interval schemes and motor systems) (13). It is important to emphasize that Heilman`s group defines lexicon as "the memory of movement or visuokinaesthetic motor engrams", and semantics as the "conceptual knowledge" (20).

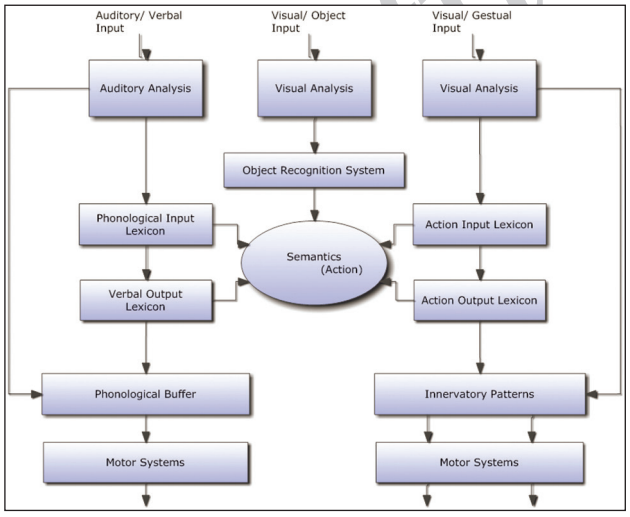

Figure 1. Rothi, Ochipa and Hailman's 1991 version of a cognitive neuropsychological model of limb praxis

The second dominant model in contemporary researches is the one developed by Roy and Square (11), based on the impairment analysis in motor action sphere, enabling a comprehensive approach to this topic. The authors believe that the impairments in the motor action sphere are multimodal. The Roy`s model (Figure 2.) includes sensory and motor skills brain impairments, but also impairments of some cognitive systems, like working memory. Unlike Heilman`s model, Roy`s clearly identifies sensory / perceptual system, a conceptual system and a production system. The assessment of preservation of these systems is based on the pantomime, imitation and postponed imitation of movement analysis. Sensory and conceptual systems are also assessed. Relating to the ability assessment, Roy defines eight patterns of performances. When a person is unable to perform gesture recognition, tools and objects and inadequately performs pantomime, while imitation and postponed imitation of movement are preserved, this pattern is attributed to impairment of the conceptual system. When it comes to the impairment of the production system, the ability of gesture, tools and objects recognition is preserved, while a person achieves poor results performing pantomime and/or imitation and/or postponed imitation (21). There is a possibility that both conceptual and production system may be damaged, which means that a person shows inadequate results performing all tasks. From eight error patterns, one defines impairment of the conceptual system; six define impairments in the production system, while one defines impairment of both systems.

Preservation assessment possibilities in conceptual-production system of voluntary motor action

Both models estimate the errors in performing different tasks; however Roy`s and Heilman`s model differ in many ways, both in components examined, and in constructed instruments for assessing performances. Both groups have developed instruments for assessing performances. Heilman`s group had designed (22) Florida Apraxia Battery (FAB), while Roy`s group had constructed Waterloo Apraxia Battery (WatAB). Scott (13) provided a parallel review of these two batteries of tests and concluded that the battery designed by Roy`s group contained more elements and examined more different types of movements.

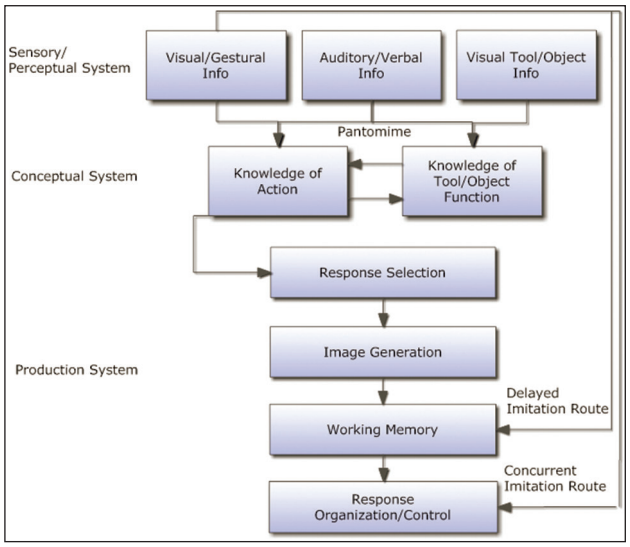

Figure 2. The Conceptual Production Model of Apraxia Roy (1996)

Speaking of performance assessment, both batteries similarly assess the achievements in sensory/perceptual tasks, as well as conceptual system, that is internal knowledge about tools, objects, gestures recognition and similar. When it comes to movement performance, the assessment instruments are different. Heilman`s group estimates movement in more descriptive manner. The authors define five categories of errors, namely: content errors (perseveration, relational, non-relational, errors while using hands), temporal (sequencing, timing, appearance), spatial (amplitude, internal configuration, using body parts as objects, external configuration, spatial movements), other (concretization, response impossibility, unrecognizable response). Each of these errors contains a description of the error (23, 24). In local author`s research (1, 25, 26, 27, 28) errors are defined in a similar manner.

On the other hand, Roy`s group describes errors using kinesiological knowledge. When performing a movement, the presence of location errors is estimated, as well as hand posture, action, movement plane, orientation. Kinesiological findings in the evaluation are applied in a descriptive manner.

The theoretical and practical importance of praxia assessment is under question. Researches in this field have great clinical importance. Clinical-anatomical studies, which are in the same time the most present, speak in favor of apraxia as a cognitive-motor syndrome which influences both body parts and is mostly developed in left parieto-frontal impairments. It often develops as a consequence of stroke, with the damage in left hemisphere or in neurodegenerative disorders with the impairments in parietal lobe (Alzheimer's disease, corticobasal degeneration). Studies in other populations are almost nonexistent. Apraxia is a major cause of disability in patients with brain damage after stroke, and significantly affects daily lives of people, predicting the dependence on someone else's care. Clinical studies have enormous significance for Restorative Neurology (29).

Schwartz & Buxbaum (30) suggest that development of impairments in gesture performance and movement imitation does not mean that the problems in everyday life will occur. Because of the reasons described, the authors recommend that the praxia assessment is conducted through natural action (Naturalistic Action), using real objects and tools. Rare are the studies that examine the impact of quality of praxic activities on everyday life. Research results of some authors (31), which were conducted on a sample of 33 patients after a stroke in the left hemisphere, speak in favor of the importance of rehabilitation in limb apraxia and its impact on improvement of daily patient`s activities. In this research authors do not emphasize the importance of the apraxia assessment instruments description, nor describe in detail the elements of the treatment itself. Although it is quite clear that this research does not provide enough information, it is rear in this type of researches and opens new issues in terms of praxia relation to everyday life activities.

Buksbaum et al. (32) provide an overview of current apraxia treatments, indicating that development of apraxia treatments is in the early stage, and that most researches are based solely on case studies. Further development of a clear approach and treatments paradigm are necessary.

Other current researches are based on the development of new assessment methods (33, 34), as well as on the testing of the conceptual-production system models (35, 36) in voluntary motor actions, analyzing praxic abilities from kinematic aspect (37, 38).

Conclusion

The impression is made that, for the future voluntary motor action studies, it is needed to integrate comprehensive knowledge, derived from clinical studies, testing researches and improvement of conceptual-production system models, movement researches in functional, practical and social context. Overview of the most important concepts and review of the research praxic activities, as well as the integration of these findings will provide a basis for the quality research design.

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References

1. *Nedović G. Struktura motornih programa kod osoba sa zatvorenom povredom mozga. Beograd.: Univerzitet u Beogradu; 2000.*
2. *Zec Ž. Osnovi kineziologije. Beograd: Viša medicinska škola; 1984.*
3. *Liepmann H. Apraxia. In: Brown J, editor. Agnosia and apraxia : selected papers of Liepmann, Lange, and Pötzl Hillsdale. N.J.: L. Erlbaum Associates; 1988.*
4. *Rothi L, Heilman KM. Apraxia : the neuropsychology of action. London: Psychology Press; 1997.*
5. *Liepmann H, Maas O. Fall von linksseitiger agraphie und apraxis bei rechtsseitiger lahmung. Journal Fur Psychologie Und Neurologie. 1907;10:214-27.*
6. *Heilman KM. Apraxia. In: Heilman KM, Valenstein E, editors. Clinical Neuropsychology. New York: Oxford University Press; 1979. p. 159-85.*
7. *Ocić G. Klinička neuropsihologija. Beograd: Zavod za udžbenike i nastavna sredstva; 1998.*
8. *Liepmann H. The left hemisphere and action. In: Kimura D, editor. Translations of Liepmann's essays on apraxia. London: DK Consultants; 1980. p. 17-50.*
9. *Poeck K. The clinical examination for motor apraxia. Neuropsychologia. 1986;24(1):129-34.*
10. *Roy EA, Square PA. Common considerations in the study of limb, verbal and oral apraxia. In: Roy E, editor. Advances in Psychology: Neuropsychological studies of apraxia and related disorders. Amsterdam: Elsevier Science Publishers; 1985. p. 111-61.*
11. *Roy EA, Square PA. Neuropsychology of movement sequencing disorders and apraxia. In: Zaidel D, editor. Handbook of Perception and Cognition: Neuropsychology. New York: Erlbaum; 1994. p. 185-218.*
12. *WHO. International classification of functioning, disability and health : ICF. Geneva: WHO; 2001.*
13. *Scott L. Analysis of Apraxia in Alzheimer's Disease: University of Waterloo; 2000.*
14. *Benke T. Two forms of apraxia in Alzheimer's disease. Cortex; a journal devoted to the study of the nervous system and behavior. 1993;29(4):715-25.*
15. *Roy EA, Square-Storer P, Hogg S, Adams S. Analysis of task demands in apraxia. Int J Neurosci. 1991;56(1-4):177-86.*
16. *Coltheart M. Editorial. Cognitive neuropsychology. 1984; 1(1-8).*
17. *Head H. Studies in neurology. 1920. Aphasia and kindred disorders of speech. 1926. Neurosurgery. 1998;42(4):944-8. Epub 1998/05/09. PubMed PMID: 9574664.*
18. *Rothi L, Ochipa C, Heilman K. A cognitive neuropsychological model of limb praxis. Cognitive neuropsychology. 1991;8:443-58.*
19. *Rothi L, Ochipa C, Heilman K. A cognitive neuropsychological model of limb praxis and apraxia. In: Rothi L, Heilman K, editors. Apraxia: the neuropsychology of action. London: Psychology Press; 1997.*
20. *Rothi L, Heilman K. Apraxia : the neuropsychology of action. London: Psychology Press; 1997.*
21. *Stamenova V. A Model-Based Approach to Limb Apraxia: Evidence From Stroke and Corticobasal Syndrome. Toronto: University of Toronto; 2010.*
22. *Power E, Code C, Croot K, Sheard C, Gonzalez Rothi LJ. Florida Apraxia Battery-Extended and revised Sydney (FABERS): design, description, and a healthy control sample. Journal of clinical and experimental neuropsychology. 2010;32(1):1-18. Epub 2009/04/10. doi: 10.1080/13803390902791646. PubMed PMID: 19358011.*
23. *Brown JW. Aphasia, apraxia, and agnosia; clinical and theoretical aspects. Springfield: C. C. Thomas; 1972.*

24. *Gonzalez L, Rothi L, Reymer A, Heilman K. Limb Praxis Assessment. In: Rothi L, Heilman K, editors. Apraxia: the neuropsychology of action London: Psychology Press; 1997. p. 7-18.*

25. *Rapaić DI, Ivanuš J, Nedović G. Izvođenje pokreta kod mentalno retardiranih. Beogradska defektološka škola. 1996;1:105-16.*

26. *Rapaić D, Nedović G. Metodološki pristup u dijagnostici i rehabilitaciji osoba sa oštećenjem centralnog nervnog sistema. Beogradska defektološka škola. 1995;1:33-40.*

27. *Rapaić D, Nedović G, Jablan B. Vrste grešaka u izvođenju pokreta kod slepih. Beogradska defektološka škola. 1995;2:101-8.*

28. *Jablan B, Rapaić D, Nedović G. Istraživanje praksičkih sposobnosti kod slepih lica. Beogradska defektološka škola. 1997;2:69-74.*

29. *Bohlhalter S. Limb apraxia: a paradigmatic cognitive - (psycho?) motor disorder. Schweizer archive für neurologie und psychiatrie. 2009;160(8):341-6.*

30. *Schwartz M, Buxbaum L. Naturalistic Action. In: Rothi L, Heilman K, editors. Apraxia: the neuropsychology of action. London: Psychology Press; 1997. p. 269-89.*

31. *Smania N, Aglioti SM, Girardi F, Tinazzi M, Fiaschi A, Cosentino A, et al. Rehabilitation of limb apraxia improves daily life activities in patients with stroke. Neurology. 2006;67(11):2050-2. Epub 2006/12/13. doi: 10.1212/01.wnl.0000247279.63483.1f. PubMed PMID: 17159119.*

32. *Buxbaum LJ, Haaland KY, Hallett M, Wheaton L, Heilman KM, Rodriguez A, et al. Treatment of limb apraxia: moving forward to improved action. American journal of physical medicine & rehabilitation / Association of Academic Physiatrists. 2008; 87(2): 149-61. Epub 2008/01/23. doi: 10.1097/PHM.0b013e31815e6727. PubMed PMID: 18209511.*

33. *Vanbellingen T, Kersten B, Van Hemelrijk B, Van de Winckel A, Bertschi M, Muri R, et al. Comprehensive assessment of gesture production: a new test of upper limb apraxia (TULIA). European journal of neurology : the official journal of the European Federation of Neurological Societies. 2010; 17(1): 59-66. Epub 2009/07/21. doi: 10.1111/j.1468-1331.2009.02741.x. PubMed PMID: 19614961.*

34. *May-Benson TA, Cermak SA. Development of an assessment for ideational praxis. The American journal of occupational therapy : official publication of the American Occupational Therapy Association. 2007;61(2):148-53. Epub 2007/04/18. PubMed PMID: 17436836.*

35. *King L. A Model Based Approach to Apraxia in Parkinson's Disease. Waterloo: University of Waterloo; 2010.*

36. *Cubelli R, Marchetti C, Boscolo G, Della Sala S. Cognition in action: testing a model of limb apraxia. Brain and cognition. 2000;44(2):144-65. Epub 2000/10/24. doi: 10.1006/brcg.2000.1226. PubMed PMID: 11041987.*

37. *Haaland KY, Harrington DL, Knight RT. Spatial deficits in ideomotor limb apraxia. A kinematic analysis of aiming movements. Brain : a journal of neurology. 1999;122 (Pt 6):1169-82. Epub 1999/06/04. PubMed PMID: 10356068.*

38. *Caselli RJ, Stelmach GE, Caviness JN, Timmann D, Royer T, Boeve BF, et al. A kinematic study of progressive apraxia with and without dementia. Movement disorders : official journal of the Movement Disorder Society. 1999;14(2):276-87. Epub 1999/03/26. PubMed PMID: 10091622.*

39. *Arsic S, Eminovic F, Stankovic I, Jankovic S, Despotovic M. The Role of Executive Functions at Dyscalculia. HealthMed Journal. 2011; 6 (1): 314-318.*

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