Artificial Intelligence in Medicine 29 (2003) 261–278

Artificial Intelligence in Medicine

www.elsevier.com/locate/artmed

A fuzzy cognitive map approach to differential diagnosis of specific language impairment

Voula C. Georgopoulos[a,*], Georgia A. Malandraki[a], Chrysostomos D. Stylios[b]

[a]Department of Speech Therapy, Technological Educational Institute of Patras, Koukouli, 26334 Patras, Greece
[b]Department of Computer Science, University of Ioannina, Ioannina, Greece

Received 11 December 2000; received in revised form 25 September 2001; accepted 10 October 2001

Abstract

This paper presents a computer-based model for differential diagnosis of specific language impairment (SLI), a language disorder that, in many cases, cannot be easily diagnosed. This difficulty necessitates the development of a methodology to assist the speech therapist in the diagnostic process. The methodology tool is based on fuzzy cognitive maps and constitutes a qualitative and quantitative computer model comprised of the experience and knowledge of specialists. The development of the model was based on knowledge from the literature and then it was successfully tested on four clinical cases. The results obtained point to its final integration in the future and to its valid contribution as a differential diagnosis model of SLI.

Keywords: Fuzzy cognitive maps; Differential diagnosis; Language disorders; Knowledge-based systems; Decision support systems; Soft computing

1. Introduction

Despite the numerous studies that have been conducted since the first half of the 19th century [25], Specific language impairment (SLI) remains a language disorder that cannot be easily diagnosed and discerned due to its similar characteristics to other disorders. Research has shown that almost 160 factors can be taken into account in the diagnosis of SLI [49] and that there is no widely accepted method of identifying children with SLI [23]. Therefore, it is necessary to develop a model of differential diagnosis of SLI, which will aid the specialist in the diagnosis by suggesting a possible diagnosis.

* Corresponding author. Tel.: +30-61-43-7362; fax: +30-61-43-7362.
E-mail addresses: voulag@otenet.gr (V.C. Georgopoulos), stylios@cs.uoi.gr (C.D. Stylios).

0933-3657/$ – see front matter
PII: S0933-3657(02)00076-3

Speech assessment is a procedure, which should include a complete history of each patient, diagnostic tests to examine all of the aspects of speech, language and communication in general, as well as a detailed observation of the patient over a long period of time. However, in many cases there are similar symptoms that correspond to a group of disorders. Thus, the differential diagnosis has to determine which is the most probable disorder and the goal of this study is to offer a model of differential diagnosis in order to facilitate this process.

In the first phase of this study, SLI and two other communication disorders were examined, dyslexia and autism. Findings in the literature have shown that both dyslexia and autism are disorders, whose diagnoses many times in the past have been confused with the diagnosis of SLI [2,18,25,43,56]. In particular, the data have initially lead to the assumption that SLI cases are confused either *with severe cases of dyslexia* or with *mild cases of autism*. This assumption was supported by the results of this study, as well.

The proposed method of differential diagnosis is based on fuzzy cognitive maps (FCMs). FCMs are a soft computing methodology that has been successfully used to model complex systems [5,7,46–48] and to support making decisions [29]. The differential diagnosis system can be considered a complex system. FCM theory uses a symbolic representation for the description and modeling of complex systems. It utilizes concepts to illustrate the different aspects of the model and behavior of the system while the concepts interact with each other showing the dynamics of the system [22]. FCM structures can be used to represent qualitative and quantitative data [28]. A FCM, due to the way it is constructed, integrates the accumulated experience and knowledge on the causal relationship between factors, characteristics and components of the system. In fact, it uses human experts that know the system and its behavior under different circumstances.

This paper presents some basic factors that appear in all three disorders (SLI, dyslexia and autism) with different frequency and severity in most cases. The considered factors are either causative factors or symptoms of the disorders. A detailed and in-depth analysis of the factors is not within the scope of this work. Instead, the development of an advanced system is discussed that is capable of contributing to the differential diagnosis of SLI from other disorders, taking into account the factors that are involved in each disorder. The factors considered in the model, are those that have been found to play an important role in the diagnosis of all three disorders. Some other factors (e.g. memory, auditory processing and orientation in space and time) will be included in the next phase of the study, because these factors need more investigation.

This paper contains five sections. Section 2 describes the disorders and their main causative factors and symptoms, which are taken into account in this differential diagnosis model. Section 3 describes FCMs, the method for developing the differential diagnosis. Section 4 discusses the results of the successful implementation of the model in four known clinical cases. Finally, Section 5 contains the conclusions and presents the future directions.

2. Disorders and factors

2.1. Definition of the disorders

SLI is a significant disorder of spoken language ability that is not accompanied by mental retardation, frank neurological damage or hearing impairment. Children with SLI face a wide variety of problems both on language and cognitive levels, although it is recognized that SLI children constitute a heterogeneous group [25]. SLI is congenital and it is not a result of some disease or a psychological trauma.

Dyslexia is a disorder of children that appears as a difficulty in the acquisition of reading ability, despite mental abilities, adequate school training or positive social environment [39]. It is a disorder of written and not of spoken language, although it is possible for a dyslexic child to have limitations in some aspects of spoken language as well [33]. Such a child is very likely to learn how to read with adequate training, but will always remain dyslexic. Dyslexics may also face problems concern writing and spelling, as well as other academic abilities [39].

Autism is a developmental disorder and pathologically it is defined as an interruption or a regression at a premature level of a person's development [55]. The main idea in autism is the impaired or limited relation that exists between the autistic person and its environment. It constitutes mostly a severe social weakness rather than a frank language disorder. The three basic terms that can give the picture, to a significant degree, of an autistic person are: social withdrawal, repetitiveness and lack of communication [12].

2.2. Basic factors of the disorders

Some basic factors that appear in all three disorders with different frequency and severity in most cases will be presented briefly. These factors are either causative factors or symptoms of these disorders. They are separated into two main categories: language factors (Table 1) and non-language factors (Table 2). Since only half or even less autistic children develop the ability to use language as a means of communication [12], the language factors used concern these cases of verbal autistic children.

The factors within each disorder were taken into consideration in a comparative way. For each factor, the degree of its importance as a diagnostic criterion (d.c.) in determining the corresponding disorder is provided in Table 1. The significance of each factor is defined with the following fuzzy variables: (a) very-very important d.c.; (b) very important d.c.; (c) important d.c.; (d) medium d.c.; (e) not very important d.c.; and (f) minimally important d.c. These criteria were converted to fuzzy weights for this FCM differential diagnosis model.

3. SLI differential diagnosis model

3.1. Fuzzy cognitive maps

Fuzzy cognitive maps are a soft computing tool that is a result of the synergy of fuzzy logic and neural network methodologies and is based on the exploitation of the integrated experience of expert scientists [7]. The graphical illustration of a FCM is a signed, weighted graph with feedback that consists of nodes and weighted arcs. Nodes of the graph are the *concepts* that correspond to variables, states, factors and other characteristics incorporated in the model, which describe the behavior of the system. Directed, signed and weighted *arcs*, which represent the causal relationships that exist between the concepts,

Table 1
Language factors

Lexical abilities	
SLI	Significant delay in the acquisition of first words and first word combinations [25]. School age: word-finding problem [24,41] and naming errors (both semantic and phonological) [34]. Very-very important d.c.
Dyslexia	Observations: word-finding problem, frequent naming errors [44]. Vocabulary: rather limited in most cases. Few sentences, short answers. Medium to important d.c.
Autism	Extremely limited. Excessively delayed language development (very few reach the two-word level). Limited vocabulary. Persistent naming of an object. Repetitive questions, not agreeing with the content of a conversation [12]. Very-very important d.c.
Syntax	
SLI	Simplified. Omissions: the most common mistakes. Use of the basic syntactic categories (subject–verb–object) [25]. Production of fewer sentences than normal children with the same MLU [16]. Types of questions indicative of younger normally developing children [25]. Very-very important d.c.
Dyslexia	Difficulties in construction of syntactically correct sentences [33]. Small, syntactically poor sentences. Incorrect intonation. Problems in both written and verbal language [11,32]. Medium to important d.c.
Autism	Significant weaknesses. Great delay in syntax acquisition compared both with younger normal children and mentally retarded children. The order of syntax development is qualitatively similar. Incorrect order of partial components of a sentence. Use of memorized pieces of speech [12]. Very important d.c.
Grammatical morphology	
SLI	Mainly: omissions, replacements or mistaken use of articles, plural of nouns (-s), pronouns, regular past (-ed), third person singular (-s), irregular past and copula, and auxiliary ‘‘be’’ forms and ‘‘do’’ forms [16]. Very-very important d.c.
Dyslexia	Inadequacy in the acquisition of grammar. Great difficulty in the conjugation of nouns and verbs and in distinguishing regular and irregular verbs especially in the past tense [32]. Medium to important d.c.
Autism	Great difficulties in the use of the language forms that express tense and person [12]. The order in which grammatical morphemes appear is the same in autistic, normal younger and children with Down syndrome [12]. Misuse of personal pronouns [17,12]. Very important d.c.
Phonological development	
SLI	Similar characteristics with the phonology of younger normally developing children. Acquisition of phonemes occurs with the same order as in normal children but at a slower rate [25]. Consonant cluster reduction, final consonant deletion and word-initial weak syllable deletion (processes frequently observed in two-year old normal children) [15,25]. Some unusual phonological errors. Important d.c.
Dyslexia	Difficulty in separating a written or spoken word in its phonological components [44]. Many errors in exercises concerning mixing sounds of language and relating a sound to its symbol [33]. Very-very important d.c.
Autism	During the premature language development, autistic children may have difficulties in formatting phonemes. Often confusion of words that are acoustically similar [12]. Medium d.c.
Pragmatics	
SLI	Reduced performance with respect to the acts of speech (requesting, naming, warning, thanking, questioning, etc.) which seem to reflect their problems in morphology and syntax [25]. Participation in conversations or initiation of conversations easier with peers than with adults [10,25]. Medium to important d.c.

Table 1 (*Continued*)

Dyslexia	–
Autism	Difficulties in the pragmatic use of language: one of the most important language characteristics of autism. Difficulty in beginning or even continuing a conversation [12,17]. Particular difficulties in: choosing topics, going from one topic to another, taking turns and preserving the cohesion of a conversation [12,42]. Incorrect use and understanding of prosody and metaphors [12,17]. Very-very important d.c.
Reading ability	
SLI	At high risk of limitations in reading ability at school age [21,36]. In some cases, reduced reading comprehension [50]. Confusion with severe cases of dyslexia. Medium to important d.c.
Dyslexia	Very serious problems. Difficulty in distinguishing words with the same letters and in reading uncommon words, mirror reading, mistaken pronunciation of vowels and replacement of words by others with similar meaning [39]. Slow, hesitant reading or even syllabicating [33]. Difficulties in reading comprehension [1]. Very-very important d.c.
Autism	A remarkable percentage of autistic children that are mental retarded learn how to read up to a very satisfying degree [12]. Autism and hyperlexia [40]. Important d.c.
Echolalia	
SLI	Appears only in severe cases of SLI [19]. Confusion with some cases of autism. Minimally important d.c.
Dyslexia	–
Autism	One of the main language characteristics of autism. Ability to repeat large or small pieces of language extremely accurately [12]. Very-very important d.c.
Comprehension of verbal language	
SLI	At a higher level than production. Limited, up to a point, compared with normal children of the same age [25]. Medium d.c.
Dyslexia	Comprehension of verbal language is affected but not to a very high degree. Confusion in the comprehension of compound commands [1]. Not very important d.c.
Autism	Quite impaired. Severe difficulties in understanding the meanings of words, the subtext and of non-verbal components of communication [12]. Very-very important d.c.
Other factors	
SLI	Mean length of utterance (MLU). The MLU of children with SLI approaches the MLU of at least one year younger normal children [25]
Dyslexia	Writing and spelling abilities. Severe problems, that are mainly connected with the problems in reading ability. Most common problems: many spelling errors, mirror writing, "untidiness" of written papers, use of capital letters among lower case, and omissions, transpositions, additions, and replacements of letters, syllables or even words [33,39]
Autism	–

interconnect the FCM concepts. An illustration of a simple FCM is depicted in Fig. 1. Each concept represents a characteristic, state or variable of the system; concepts stand for events, actions, goals, values and/or trends of the system being modeled as an FCM. Each concept is characterized by a numeric value that represents a quantitative measure of the concept's presence in the model. A high numeric value indicates the strong presence of a concept. The numeric value results from the transformation of the real value of the system's variable, for which this concept stands, to the interval [0, 1]. All the values in the graph are fuzzy, so weights of the arcs are described with linguist values that can be defuzzified and transformed to the interval [−1, 1]. Studying this graphical representation, one can

Table 2
Non-language factors

Verbal and non-verbal IQ	
SLI	A difference between verbal and non-verbal IQ, with the first being around 70 and the second being within normal limits [25]. Very-very important d.c.
Dyslexia	Steadily lower performance in verbal WISC test than normal readers, while the total IQ is within normal limits [1]. Very-very important d.c.
Autism	Scores in verbal subtests in contrast to non-verbal subtests are very low: three out of four autistic children are mentally retarded [12]. Medium to important d.c.
Heredity	
SLI	Plays an important role in many cases. Inconsistent percentages in studies: 20, 39 and 75% [35,51,57]. Medium to important d.c.
Dyslexia	Very important role. Percentages are reported on existence of positive family history: from 50 to 88% [6,39]. Very important d.c.
Autism	Significant role. Genetic predisposition for cognitive and language disorders [12]. Two percent of autistic siblings are also autistic. Important d.c.
Sociability	
SLI	Interaction with fewer peers. Selected as playmates in smaller percentages than normal children [14]. Medium to important d.c.
Dyslexia	Low self-esteem. Pathological fears and mood disorders in small percentages [26]. Difficulties in interacting with peers [4]. Medium d.c.
Autism	Characterizing element: impaired social behavior. Extreme difficulty or inability to develop social relationships. Weakness to understand social rules [12]. Indifferent to presence of others or shy, fearful, anxious, aggressive [42]. Very-very important d.c.
Mobility	
SLI	May be clumsier and have slower motor responses than normally developing children of the same age [3]. Medium d.c.
Dyslexia	Two cases: (1) clumsiness, hyperactivity, impulsiveness [26], difficulty writing [39]; (2) very good motor coordination [26]. Case dependent
Autism	Rather impaired. Stereotypical and constant movements of legs, hands, head, body etc., stereotypical jumping or shaking, difficulty in imitating complicated movements, walking on toes and in some cases deficient movements of articulators [12]. Exception: rather developed mobility [17]. Very-very important d.c.
Attention ability	
SLI	Limited attention and concentration abilities may be present [53]. Medium d.c.
Dyslexia	Reduced attention ability and great difficulty in concentrating on one task for a period of time [26,33]. Medium to important d.c.
Autism	Attention can be easily distracted. Non-steady eye contact. Reduced interest for many activities [12,42]. Very-very important d.c.
Arithmetic ability	
SLI	Pre-school age: difficulties remembering correct order of arithmetic words. School age: difficulty remembering very simple arithmetic operations or the correct order of numbers beyond 20 [9]. Reduced counting speed [8]. Medium to important d.c.
Dyslexia	Two cases: (1) frequent problems, memorization difficulties of multiplication tables or subtracting numbers [39], and confusion of visually similar arithmetic symbols and numbers [1]; (2) great performance in arithmetic [39]. Case dependent
Autism	Two cases: (1) very high abilities in math and in performing arithmetic operations [12]; (2) very low or mediocre abilities [42]. Case dependent
Symbolic play	
SLI	Less developed symbolic play. Same quality as that of younger children with the same MLU [25]. Medium d.c.
Dyslexia	–
Autism	The level of symbolic play is rarely reached and if so, its simplest form. Tendency to use objects and games without intention [12]. Very-very important d.c.

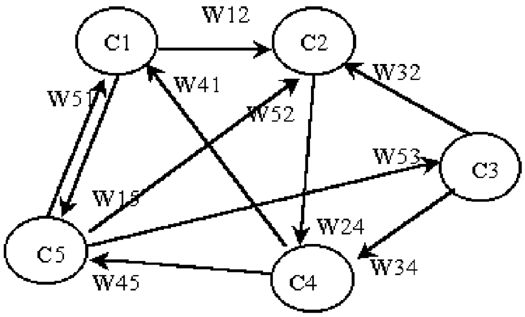

Fig. 1. Graphical representation of fuzzy cognitive map.

conclude which concept influences other concepts and what are the interconnections among them. This representation makes the updating of the structure of the graph easy, as new information becomes available or as more experts are asked. This can be done, for example, by the addition or deletion of an interconnection or a concept.

Between concepts, there are three possible types of causal relationships expressing the type of influence of one concept on another. The weight of an interconnection, W_{ij}, for the arc from concept C_i to concept C_j, can be positive ($W_{ij} > 0$), which means that an increase in the value of concept C_i leads to the increase of the value of concept C_j, and a decrease in the value of concept C_i leads to the decrease of the value of concept C_j. Or there is negative causality ($W_{ij} < 0$), which means that an increase in the value of concept C_i leads to the decrease of the value of concept C_j and vice versa. When there is no relationship from concept C_i to concept C_j, then ($W_{ij} = 0$) [22].

When the FCM starts to model the system, concepts take their initial values and then the system is simulated. At each step, the value of each concept is determined by the influence of the interconnected concepts on the corresponding weights:

$$A_i^{t+1} = f\left(\sum_{j=1, j\neq i}^{n} W_{ji} A_j\right) \tag{1}$$

where A_i^{t+1} is the value of concept C_i at step $t+1$, A_j the value of the interconnected concept C_j at step t, W_{ji} the weighted arc from C_j to C_i, and f a threshold function.

A FCM is a type of cognition network, which is developed by experts, using an interactive procedure of knowledge acquisition. An expert defines the main concepts that represent the model of the system, based on his knowledge and experience on the operation of the system. At first, the expert determines the concepts that best describe the system. He knows which factors are crucial for the modeling of the system and he represents each one by a concept. Moreover, he has observed which elements of the system influence other elements and for the corresponding concepts he determines the positive, negative or zero effect of one concept on the others. He describes each interconnection with a linguistic value that represents the fuzzy degree of causality between concepts.

For better results in the development of the FCM and in order to create an advanced FCM, a group of experts is used. All experts are polled together and they determine the relevant factors, the main characteristics of the system and thus, the number and kind of concepts, which should be contained in the FCM. Then, they determine the structure and the interconnections of the network using fuzzy conditional statements [20]. It is not necessary that all experts agree and assign exactly the same interconnections. FCMs can deal with multiple, perhaps even contradictory/conflicting data from experts, since explicit rules are not extracted as in rule-based expert systems. In order to deal with this, it is possible to assign credibility weights for each expert [46]. Thus, the FCM will represent the extraction of knowledge and experience of the more credible experts.

A major advantage of FCMs is that they can handle even incomplete or conflicting information. This is very important in the diagnosis of language/communication disorders because frequently important information may: (a) be missing (e.g. it may not be possible to conduct certain tests); (b) be unreliable (they may be a result of unreliable measurement techniques); (c) be vague or conflicting (there may be more than one logical ways to interpret them); or (d) be difficult to integrate with other information [13].

The development procedure of the FCM not only determines the number and kind of concepts making up the FCM, assigns linguistic weights from experts and combines them, but it continues a step further. The linguistic weights of the FCM are transformed into numerical weights using the methodology proposed in [48]. Then, an algorithm is proposed for adjusting the weights of the FCM in order to ensure that the FCM will always converge to a fixed desired region. Actually, the FCM could converge to a fixed point, limit cycle, or chaotic attractor [7], but when FCMs are used for the decision making process, it is desirable to converge to a region corresponding to the selection of one decision. This algorithm is used successfully in this research work here to strengthen some weight interconnections and weaken some others and it is presented in Section 3.2.

3.2. Description of the differential diagnosis model

The proposed FCM, depicted in Fig. 2, consists of two different types of concepts. The three central concepts (disorder concepts) correspond to the three disorders. The factors presented in Section 2 belong to the second type of concepts, factor concepts which are symptoms and cause factors to the disorder concepts, and they are considered as measurements that can determine the result of the diagnosis. The direction of interconnections between the concepts is shown in Fig. 2 by the arrowed arcs. This shows in a simple way which concept influences another concept. However, due to limited space and in order to make the figure simpler, the sign and weights of the connections are not illustrated in Fig. 2. These are extracted from Table 1 by assigning the qualitative (linguistic) values: very-very high, very-high, high, etc. to the importance of each diagnostic criterion, respectively. These connections may show a positive or negative dependence between factors and disorders. A positive connection (+) implies that the given factor increases the probability of diagnosis of the connected disorder. Lack of connection between a factor and a disorder suggests that no influence of that factor on the disorder has been found, yet. A negative (−) connection between the factor and the disorder (such as reading ability and autism in Table 1) implies that the existence of the given factor must lead to reduction of the probability of diagnosing the particular disorder.

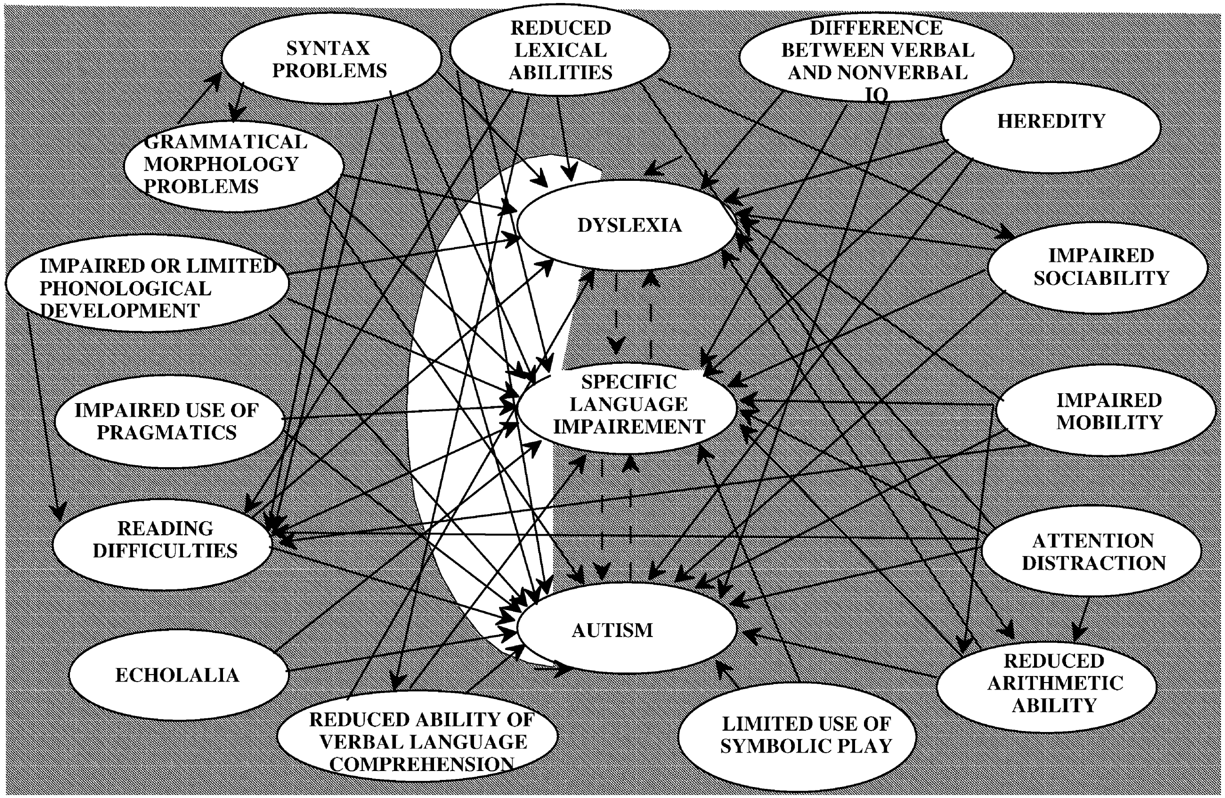

Fig. 2. FCM differential diagnosis model of SLI from dyslexia and autism.

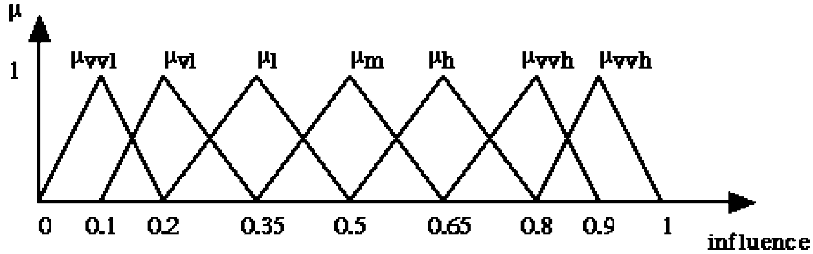

Fig. 3. Membership functions.

Apart from describing the direction of causality between two concepts and the sign of causality, the degree of cause and effect between two concepts must be determined, since we do not expect that all factors have the same weight for a given disorder, nor the same weight for each disorder. Each expert describes the degree of influence for each interconnection using a linguistic variable. Thus, each expert of the group of experts suggests a linguistic weight for each interconnection, so a set of linguistic weights for each interconnection is assigned. This set of weights for each interconnection is integrated, using a sum combination method and then the defuzzification method of center of area (CoA) [28,31] is used and a numerical weight for this interconnection is produced, which belongs to the interval $[-1, 1]$. In this first phase of the research, published research results have been used as "experts" and these were integrated using the procedure described above.

The allowable linguistic variables for this application may belong to the fuzzy sets described below. Each fuzzy set corresponds to a membership function shown in Fig. 3. Seven membership functions are suggested to describe the degree of influence, giving the possibility to the experts to describe in detail the influence of one concept to another:

- M(very-very low): the fuzzy set for influence around 10% with membership function μ_{vvl}.
- M(very low): the fuzzy set for influence around 20% with membership function μ_{vl}.
- M(low): the fuzzy set for influence around 35% with membership function μ_{l}.
- M(medium): the fuzzy set for influence around 50% with membership function μ_{m}.
- M(high): the fuzzy set for influence around 65% with membership function μ_{h}.
- M(very high): the fuzzy set for influence around 80% with membership function μ_{vh}.
- M(very-very high): the fuzzy set for influence around 90% with membership function μ_{vvh}.

The membership functions are not of the same size since it is desirable to have finer distinction between grades in the lower and higher end of the influence scale.

As an example, three experts have been asked to develop a FCM and they each propose different linguistic weights for the interconnection W_{ij} from concept C_i towards concept C_j: (a) positive and high; (b) positive and very high; and (c) positive and very-very high. The three suggested linguistic weights are summed and using the defuzzification method of CoA, the summed value is transformed into the numerical value of $W_{ij} = 0.7396$.

However, the real strength of FCMs is their ability to describe systems where there are feedback relationships and relationships between the factor concepts. Interrelations between factor concepts have also been found and are presented in Table 3. The linguistic weight of low is considered for all the connections.

The proposed FCM of Fig. 2 also has connections (arcs) between the disorder concepts. These are not cause–effect connections, but inhibitory connections. In this application where FCMs are used to establish a diagnosis, the disorder concepts are considered outputs. These output nodes must "compete" against each other in order for only one of them to dominate and be considered the correct diagnosis with the highest probability. Here a new idea is proposed for achieving this "competition" between concepts. The interaction of each of these nodes with the others should have a very high negative weight (even -1). This implies that the higher the value of a given node, this should lead to a lowering of the value of competing nodes, i.e. strong inhibition.

Another new consideration is that in the FCM in which there are nodes that do not accept feedback, it is important not to allow the values of those nodes to change. In order for this to be achieved, a check should be made of each node to examine if it accepts inputs from other nodes. If not, then a self-feedback value of the node should be set at 1 and the value of that node after each repetition should remain the same. Therefore, the algorithm is as follows.

- Set values A_i of nodes according to a patient's symptoms and causative factors. The symptoms' and causative factors' values are described using fuzzy degrees similar to the weights, i.e. none, very-very low, very low, low, medium, high, very high, and very-very high. These fuzzy degrees correspond to the crisp numerical weights 0, 10, 20, 35, 50, 65, 80 and 90%, respectively. The fuzzy values of the factor concepts that represent the estimate of the speech pathologist for each clinical case that is examined are defuzzified. The disorder concepts are given the initial value of 0 because there is no initial diagnosis.
- The fuzzy connection weights between the factor concepts and the disorder concepts are converted to initial values (between 0 and 1) using defuzzification. These are then placed in matrix $\boldsymbol{W}$. The values in the first column correspond to the weighted connections from all the concepts towards the SLI disorder concept, the values in the second column correspond to the weighted connections from all the concepts towards the dyslexia disorder concept, and the values in the third column correspond to the weighted connections from all the concepts towards the autism disorder concept. Also included in this matrix are the -1 weight values for competition between output disorder concepts, as described earlier. The values of the first three rows of the remaining columns are zero since there are no connections from disorder concepts towards factor concepts. The remaining submatrix of $\boldsymbol{W}$ and has its diagonal equal to 1. This ensures that the values of factor concept with no connections to other factor concepts remain unchanged. The matrix $\boldsymbol{W}$ (after defuzzification) for the values corresponding to the connections between concepts is shown in Fig. 4. The values of the diagonal weight elements sli_f, dys_f, and aut_f are a result of a logical majority rule operation. This means they are either 0 or 1 depending on whether the patient under investigation shows the majority of critical symptoms to a severe degree for the corresponding disorder. These critical symptoms are those that have the indication very-very high d.c. in Section 2.
- Use update rule: $A_{\text{new}} = A^{*}_{\text{old}}\boldsymbol{W}$.

Table 3
Relationships between factor concepts

Findings	Influencing factor	Influenced factors
Late talkers at high risk for developing reading difficulties [25]. Children with language delay may be at high risk for developing learning disabilities [37]. Strong relationship between vocabulary knowledge and reading comprehension [52]. Speech delay may have a significant impact on social as well as academic life of children [27]	Reduced lexical abilities	Reading difficulties, reduced arithmetic ability, reduced ability of verbal language comprehension, impaired sociability
Knowledge of morphology is critical for good reading abilities [52]	Problems in grammatical morphology	Reading difficulties
Children with poor motor coordination and hyperactivity may be at high risk for developing learning disabilities [37]	Impaired mobility	Reading difficulties, reduced arithmetic ability
Children with short attention span may be at high risk for developing learning disabilities [37]. Reading disability relatively common in children with inattention problems becoming even more frequent as the child [45]	Attention distraction	Reading difficulties, reduced arithmetic ability
The children who became poor readers were much weaker than other groups on the syntactic and phonological measures [45]. Abilities in syntax and grammatical morphology are closely related [25]	Problems in syntax	Reading difficulties, problems in grammatical morphology
	Impaired or limited phonological development	Reading difficulties
	Problems in grammatical morphology	Problems in syntax

W =

sli_f	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	dys_f	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	-1	aut_f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.9	0.58	0.9	1	0	0	0	0	0.2	0	0.2	0	0	0.2	0	0	0.2	0
0.9	0.58	0.8	0	1	0.2	0	0	0.2	0	0	0	0	0	0	0	0	0
0.9	0.58	0.8	0	0.2	1	0	0	0.2	0	0	0	0	0	0	0	0	0
0.65	0.9	0.8	0	0	0	1	0	0.2	0	0	0	0	0	0	0	0	0
0.58	0	0.9	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0.58	0.9	-0.65	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0.2	0	0.9	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0.8	0.35	0.9	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
0.9	0.9	0.58	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
0.58	0.70	0.65	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0.58	0.8	0.9	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
0.8	0	0.9	0	0	0	0	0	0.2	0	0	0	0	0	1	0	0.2	0
0.5	0.58	0.9	0	0	0	0	0	0.2	0	0	0	0	0	0	1	0.2	0
0.58	0.	0D	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0.5	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Fig. 4. Example of matrix ***W***.

- Pass the elements of A_{new}, where the first three elements correspond to the values of the disorder concepts, through a sigmoid non-linearity to ensure values of concepts between 0 and 1. The unipolar sigmoid is given by:

$$f(x) = \frac{1}{1 + e^{-\lambda x}} \tag{2}$$

where $\lambda \succ 0$ determines the steepness of the sigmoid.
- Since there is feedback between disorder concepts (the new value of a disorder concept is affected by the value of the others), there must be a number of repetitions of the above algorithm in order for the disorder concepts to reach their final values. When equilibrium has been reached and the values of the disorder concepts no longer change, the procedure stops and the final values of the disorder concepts are found, the maximum of which is the most probable diagnosis. It should be noted that these values do not represent probabilities per se.

In essence, a model was developed that is capable on its own to perform a comparison and lead to a diagnosis. The only things that were comparatively taken into consideration by the researchers in the development of the model were the weights of the factors for each disorder separately. For example, for SLI the problems in grammatical morphology have a weight of +very-very high, whereas the problems in phonology have a weight of +high. This means that the existence of problems in grammatical morphology in a case influences the diagnosis of SLI more than the existence of phonological problems. This does not imply that only one or the other type of problems exists. Rather it means that the first, according to the literature, is more prevalent than the second in a case. Of course, it would not be possible for the model to make such a comparison when the factors are taken into consideration on equal basis for all the disorders, because dissimilar things are being compared. For this reason, factors were chosen for each disorder that have the highest weights—which implies that these are more crucial in determining the diagnosis of each disorder—in order to constitute the key factors whose existence in a case is taken into consideration by the model more than the existence of other factors. This suggests that a sufficient model was developed which, under constraints (described above), processes the information about a case in such a way that out of three possible diagnoses we are lead to the diagnosis of the most probable disorder.

4. Confirmation of results of the model for four clinical cases

After the construction of the above differential diagnosis model, four case studies from the literature were investigated (two on SLI [54,56], one on dyslexia [38] and one on autism [30]), in order to confirm its effectiveness. The value of occurrence of each factor in each case study is denoted with similar qualitative degrees, as shown in Table 4. For the cases that the value of a concept factor is 0, it denotes that either there was no information supplied on the given factor or that the given symptom did not exist. The following initial vectors of concepts values are used for each one of the four cases; their values are produced

Table 4
Weight of each factor concept for each clinical case

Number	Factor concepts	Case 1	Case 2	Case 3	Case 4
1	Reduced lexical abilities	Very-very high	High	Medium to high	0
2	Problems in syntax	Very-very high	Very high	High	0
3	Problems in grammatical morphology	Very high	Very high	High	0
4	Impaired or limited phonological development	0	0	High	0
5	Impaired use of pragmatics	0	0	0	0
6	Reading difficulties	0	0	Very-very high	0
7	Echolalia	0	0	0	Very-very high
8	Reduced ability of verbal language comprehension	0	0	0	Very-very high
9	Difference between verbal and non-verbal IQ	High	High	High	0
10	Heredity	High	0	0	0
11	Impaired sociability	Medium	0	0	Very-very high
12	Impaired mobility	0	0	Medium	Very high
13	Attention distraction	0	0	0	Very high
14	Reduced arithmetic ability	0	0	Medium	0
15	Limited use of symbolic play	0	0	0	0

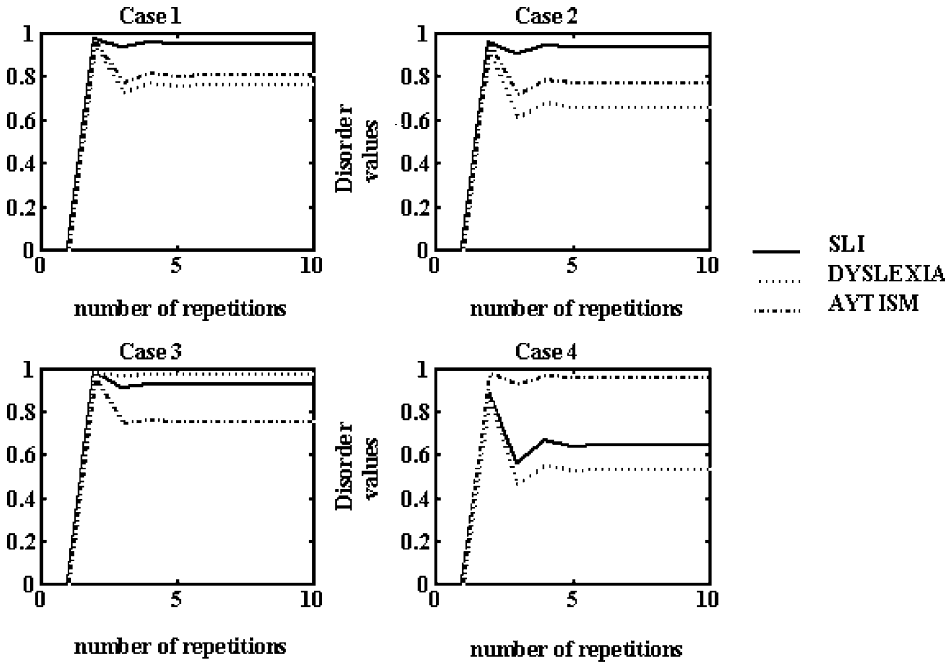

Fig. 5. Results of four clinical cases.

implementing using the defuzzification method of CoA on the linguistic values of Table 4, respectively:

$$A_0 = [0 \quad 0 \quad 0 \quad 0.9 \quad 0.9 \quad 0.8 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0.65 \quad 0.65 \quad 0.5 \quad 0 \quad 0 \quad 0 \quad 0]$$

$$A_0 = [0 \quad 0 \quad 0 \quad 0.8 \quad 0.9 \quad 0.9 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0.65 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$$

$$A_0 = [0 \quad 0 \quad 0 \quad 0.58 \quad 0.8 \quad 0.8 \quad 0.8 \quad 0 \quad 0.9 \quad 0 \quad 0 \quad 0.65 \quad 0 \quad 0 \quad 0.5 \quad 0 \quad 0.5 \quad 0]$$

$$A_0 = [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0.9 \quad 0.9 \quad 0 \quad 0 \quad 0.9 \quad 0.8 \quad 0.8 \quad 0 \quad 0]$$

Fig. 5 contains plots of the values of the output nodes, SLI, dyslexia and autism as a function of the number of repetitions for each case. Each node converges to a final value and the node with the maximum value is the most probable diagnosis based on the model. In all four cases, even though the information was incomplete, the result given by the model agreed with the published diagnosis. That is in all four cases, the correct diagnosis was concluded: SLI, SLI, dyslexia and autism, respectively (Fig. 5). Only in the case of dyslexia the maximum valued-final diagnosis, even though correct, differed by a relatively small amount from the second (which was SLI) for the reason that it is a severe case of dyslexia. As was originally hypothesized and is shown below, severe cases of dyslexia are often confused with SLI.

At this point, in order to confirm the initial hypothesis, i.e. that SLI is often confused with severe cases of dyslexia and mild cases of autism, the procedure was repeated 10,000 times with random values of factor concepts (this is equivalent to 10,000 different supposed cases with the given symptoms whether they existed or not). With this method, it was found that whenever the diagnosis was not SLI, in the very high majority of cases, the second most probable diagnosis was SLI, partially confirming the above hypothesis.

5. Conclusions and future directions

The major goal of this research was to describe a new approach to the differential diagnosis of SLI from dyslexia and autism based on FCMs, since it had been found that SLI cases were confused either with severe cases of dyslexia or with mild cases of autism. To a high degree this goal was achieved since the reported trials fully verified the effectiveness of the model.

In this first phase of the research, published results from the literature were used as "experts" and these were combined using the center of area method to design the differential diagnosis FCM. A questionnaire is under development, which will be sent to expert specialists along with the description of the current diagnostic model for the enrichment and improvement of the model. The reason FCMs were chosen as the design methodology is because they can be easily interpreted, since they clearly show the relationships between the different concepts and, at the same time, it is relatively easy to add or remove concepts, whenever necessary.

The ultimate goal of this effort is to develop a sufficient estimation model that can reliably be used complementary to other diagnostic methods to assist the speech pathologist in cases of language and communication disorders that are difficult to discern. Even though this effort is in its initial stage, we hope that when successfully completed it will contribute to the field of differential diagnosis in speech and language pathology.

References

[1] Anastasiou D. Dyslexia. Theoria kai ereyna—opsis praktikis [Dyslexia. Theory and research—practical views]. Athens: Atrapos; 1998 [in Greek].
[2] Bishop DVM. What is so special about Asperger's disorder? The need for further exploration of the borderlands of autism. In: Klin A, Volkmar F, Sparrow S, editors. Asperger syndrome. New York: Guilford Press; 2000.
[3] Bishop DVM. Handedness, clumsiness and developmental language disorders. Neuropsychologia 1990;28:681–90.
[4] Bradford J. What causes dyslexia? Dyslexia Online Magazine. http://members.aol.com/dddyslexia/mag24.html.
[5] Craiger JP, Goodman DF, Weiss RJ, Butler AB. Modeling organizational behavior with fuzzy cognitive maps. Int J Comput Intell Organ 1996;1:120–3.
[6] Critchley M. The dyslexic child. London: Heinemann; 1970.
[7] Dickerson JA, Kosko B. Virtual worlds in fuzzy cognitive maps. In: Kosko B, editor. Fuzzy engineering. Upper Saddle River, NJ: Prentice-Hall; 1997.
[8] Donlan C. The development of mathematical skills. Hove: Psychology Press; 1998.
[9] Fazio B. Arithmetic calculation, short-term memory and language performance in children with specific language impairment: a 5-year follow-up. J Speech Lang Hear Res 1999;42:420–31.
[10] Fey M, Leonard L. Partner age as a variable in conversational performance of specifically language-impaired children and normal-language children. J Speech Hear Res 1984;27:413–23.

[11] Fijalkow J. Mauvais lecteurs, pourquoi? Paris: Presses Universitaires de France; 1996.
[12] Frith U. Autism: explaining the enigma. Oxford: Blackwell; 1992.
[13] Georgopoulos VC, Malandraki GA, Stylios CD. A FCM approach to differential diagnosis of specific language impairment. In: Adlassnig K-P, editor. Fuzzy diagnostic and therapeutic decision support. Vienna: Osterreichische Computer Gesellschaft; 2000. p. 68–79.
[14] Gertner B, Rice M, Hadley P. The influence of communicative competence on peer preferences in a preschool classroom. J Speech Hear Res 1994;37:913–23.
[15] Ingram D. Procedures for the phonological analysis of children's language. Baltimore: University Park Press; 1981.
[16] Johnston J, Kamhi A. Syntactic and semantic aspects of the utterances of language-impaired children. The Same can be less. Merrill-Palmer Q 1984;30:65–85.
[17] Jordan R, Powell S. Understanding and teaching children with autism. New York: Wiley; 1995.
[18] Kamhi A, Catts H. Toward an understanding of developmental language and reading disorders. J Speech Hear Disord 1986;51:337–47.
[19] Karandanos G. Language development disorders and child psychiatric disorders: differential diagnosis and co-morbidity. In: Proceedings of the Eighth Conference of the Panhellenic Association of Logopedics. Athens: Ellinika Grammata; 2000. p. 75–83.
[20] Kim HS, Lee KC. Fuzzy implications of fuzzy cognitive map with emphasis on fuzzy causal relationship and fuzzy partially causal relationship. Fuzzy Sets Syst 1998;3:303–13.
[21] King R, Jones C, Lasky E. A 15-year follow-up report of speech–language-disordered children. Lang Speech Hear Serv Schools 1982;13:24–32.
[22] Kosko B. Neural networks and fuzzy systems. Englewood Cliffs: Prentice-Hall; 1991.
[23] Krasswski E, Plante E. IQ variability in children with SLI: implications for use of cognitive referencing in determining SLI. J Commun Disord 1997;30:1–9.
[24] Lahey M, Edwards J. Naming errors of children with specific language impairment. J Speech Lang Hear Res 1999;42:195–205.
[25] Leonard LB. Children with specific language impairment. Cambridge: MIT Press; 2000.
[26] Levinson Medical Center for Learning Disabilities. The dyslexic syndrome. http://www.levinsonmedical.com/information/syndrome.html; 2000.
[27] Leung AKC, Kao CP. Evaluation and management of the child with speech delay. Am Acad Fam Physicians 1999;59:3121–39.
[28] Lin CT, Lee CSG. Neural fuzzy systems: a neuro-fuzzy synergism to intelligent systems. Upper Saddle River, NJ: Prentice-Hall; 1996.
[29] Liu ZQ, Satur R. Contextual fuzzy cognitive map for decision support in geographic information systems. IEEE Trans Fuzzy Syst 1999;5:495–507.
[30] Lunt J. Steven: autism, 8-year-old boy. http://www.eegspectrum.com; 1997.
[31] Mamdani EH, Gaines BR, editors. Fuzzy reasoning and its applications. London: Academic Press; 1981.
[32] Markou NS. Dyslexia. Athens: Ellinika Grammata; 1994 [in Greek].
[33] Mavromati D. I katartisi enos programmatos antimetopisis tis dyslexias [Development of a program to overcome dyslexia]. Athens: Ellinika Grammata: 1995 [in Greek].
[34] McGregor K. Use of phonological Information in a word-finding treatment for children. J Speech Hear Res 1994;37:1381–93.
[35] Neils J, Aram D. Family history of children with developmental language disorders. Percept Mot Skills 1986;63:655–8.
[36] Padget S. Speech- and language-impaired 3 and 4 year olds: a 5-year follow-up study. In: Masland, Masland, editors. Pre-school prevention of reading failure. Timonium, MD: York Press; 1988.
[37] Pickering JS, Mcintyre CW. Montessori and multisensory structured language therapy applied to at-risk children. http://www.shelton.org/montessori/atrisk_paper.html; 1995.
[38] Plaza M, Guitton C. Working memory limitation, phonological deficit, sequential disorder and syntactic impairment in a child with a severe developmental dyslexia. Dyslexia 1997;3:93–108.
[39] Porpodas KD. Dyslexia. Patras: University of Patras; 1997 [in Greek].
[40] Quill KA. Teaching children with autism: strategies to enhance communication and socialization. New York: Delmar Publishing; 1995.

[41] Rapin I, Wilson B. Children with developmental language disability. In: Wyke M, editor. Developmental dysphasia. London: Academic Press; 1978.
[42] Rapin I. Autism. N Engl J Med 1997;337:97–104.
[43] Rice ML. Specific language impairments: in search of diagnostic markers and genetic contributions. Ment Retard Dev Disabil Res Rev 1997;3:350–7.
[44] Shaywitz SE. Dyslexia. Sci Am 1996;11:98–104.
[45] Snow CE, Burns MS, Griffin P, editors. Preventing reading difficulties in young children. Committee on the Prevention of Reading Difficulties in Young Children, National Research Council. Washington, DC: National Academy Press; 1998.
[46] Stylios CD, Georgopoulos VC, Groumpos PP. Introducing the theory of fuzzy cognitive maps in distributed systems. In: Proceedings of 12th IEEE International Symposium on Intelligent Control, Istanbul, Turkey, 1997. p. 55–60.
[47] Stylios CD, Georgopoulos VC, Groumpos PP. FCM modeling of supervisory large scale control systems. In: Proceedings of IFAC LSS'98, Patras, Greece, 1998. p. 73–8.
[48] Stylios CD, Groumpos PP, Georgopoulos VC. A fuzzy cognitive map approach to process control systems. J Adv Comput Intell 1999;3:1–9.
[49] Tallal P, Stark R, Mellitis E. Identification of language-impaired children on the basis of rapid perception and production skills. Brain Lang 1985;25:351–7.
[50] Tallal P, Curtiss S, Kaplan R. The San Diego longitudinal study. In: Gerber S, Mencher G, editors. International perspectives on communication disorders. Washington, DC: Gallaudet University Press; 1988.
[51] Tallal P, Ross R, Curtiss S. Familial aggregation in specific language impairment. J Speech Hear Disord 1989;54:167–73.
[52] Templeton S, Pikulski JJ. Building the foundations of literacy: the importance of vocabulary and spelling development. http://www.eduplace.com; 1999.
[53] Townsend J, Courchesne E, Covington J, Westerfield M, Harris NS, Lyden P, Lowry TP, Press GA. Spatial attention deficits in patients with acquired or developmental cerebellar abnormalities. J Neurosci 1999;19:5632–43.
[54] Tsimpli IM, Stavrakaki S. The effects of a morphosyntactic deficit in the determiner system: the case of a Greek SLI child. Lingua 1999;108:31–85.
[55] Tustin F. Autisme et psychose de l' enfant. Sevil: Editions de Sevil; 1977.
[56] Van der Lely KJH. Language and cognitive development in a grammatical SLI boy: modularity and innateness. J Neurolinguist 1997;10:75–107.
[57] Van der Lely KJH, Stollwerck L. A grammatical specific language impairment in children: An autosomal dominant inheritance? Brain Lang 1996;52:484–504.