Tourette Syndrome and Learning Disabilities: a focus on correlations in a neurodevelopmental perspective

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Abstract

People with Tourette Syndrome (TS) frequently show the presence of Learning Disabilities (LD) at school age. Literature investigating the correlation between TS and LD is limited: studies focus on the incidence of this correlation, the impact on school achievement and the number of fields affected by these difficulties, show neuropsychological diseases in comorbility and reveal a discrepancy between IQ scores and school results. The most important evidence shows that in some children the appearance of LD and tics coincide. In a neurodevelopmental approach, the origin of both symptoms, TS and LD, can be explained observing the nervous system's maturation process, through specific steps, which lead to the acquisition of visual, aural and tactile competence, and allow the development of mobility, language and manual ability. As they all develop along a continuum, neurodevelopmental levels that have not been completed always imply neuro-functional anomalies, which can be observed with brain-imaging techniques. Investigating this correlation in a neuropsychological perspective would be useful not only to better understand the underlying functional aspects, but also to properly plan good rehabilitation strategies to apply in everyday clinical practice.

Keywords: Tourette Syndrome; Learning Disabilities; Neurological organization

1. Tourette Syndrome and Learning Disabilities

The correlation between Tourette Syndrome (TS) and Learning Disabilities (LD) is frequently found in the clinical experience but little investigated by scientific literature. Several aspects of both clinical conditions lead to the same features of the underlying neurological functioning. The neurodevelopmental approach seems to be a crucial point of view to clearly explain and understand the causes of both TS and LD symptoms and to identify the common roots in the development of the nervous system during the first years of life.

1.1. Tourette Syndrome

TS is a neurodevelopmental disease characterized by the presence of multiple motor and vocal tics. Tics are sudden and repetitive, or slow and sustained, stereotyped movements (motor tics) and utterances (phonic tics) that involve specific muscle groups. Motor tics are movement-based tics, while phonic tics are involuntary sounds produced by moving air through the nose, mouth, or throat. Those tics can be simple, as winking, or complex, involving a major and more articulated number of muscle groups, and appear as winces with the face, shoulder shakings, hand torsion movements, rubbing or tapping on objects with fingers. Sometimes there is the tendency to exhibit "sensorial" behaviors, as sniffing or touching things or people. Vocal tics can be grunts, coughing, barks, or particular vocal sequences, or can appear as echolalies, with sentences formulated by repeating complete words or the final part of words spoken by others. Sometimes they show coprolalia, a complex vocal tic consisting in pronouncing obscene words continuously. Coprolalia can appear in three ways: as tic (an automatism while speaking), during colleric crisis (as an effective relief valve) and as compulsion (when people end saying exactly what they wouldn't). Only the first is completely automatic, then unaware. Tics vary in intensity during time and often they change shape and localization: a certain tic is followed by another in a different part of the body, with the same progression of the sensorial cortex. So anatomic localization, complexity and gravity of tics vary in time. Tics can appear in different ways, from simple intermittent muscle jerks with a short duration, to a complex square of involuntary coordinated rapid movements, which are often preceded by an unpleasant sensation which diminish with the movement execution. Complex tics can be motor behaviors with no apparent goals, as squat down, kneel down making pirouettes while walking, jump … (Jankovic, 1997; 2001; Fastame, 2009).

The manifestations of the disease often start with simple tics involving the muscles of face (winking or grimaces) and neck (rapid torsions of the head) and successively can extend to arms and legs and evolve in complex tics. Even though people with TS can suppress tics with a voluntary effort, the inner need to carry out such motor acts intensifies until an explosion of tics when they stop trying to resist. Many people trying to suppress tics for a long period experiment panic attacks.

Tics are the more visible manifestation of this syndrome, which is more complex and articulated, involving more impairments which are often not correctly identified, or mistaken for other, and which could represent the most important problem for a certain subject. It is therefore correct to speak about "psychopathologic spectrum" of TS, to indicate the disturbs linked to it, such as anxiety, obsessive compulsive disorder, attention deficit hyperactivity disorder, oppositive-provocatory behaviors and LD.

2. Diagnostic criteria for Tourette Syndrome

TS was classified by the fourth version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR: American Psychiatric Association, 2000) as one of several tic disorders "usually first diagnosed in infancy, childhood, or adolescence" according to type (motor or phonic tics) and duration (transient or chronic). Transient tic disorders consisted of multiple motor tics, phonic tics or both, with a duration between four weeks and twelve months. Chronic tic disorder was either single or multiple, motor or phonic tics, which were present for more than a year. TS is diagnosed when multiple motor tics, and at least one phonic tic, are present for more than a year.

Diagnostic criteria for TS, according to DSM-IV-TR, are as follows:

- Both multiple motor and one or more vocal tics have been present at some time during the illness, though not necessarily concurrently. (A tic is a sudden, rapid, recurrent, non rhythmic, stereotyped motor movement or vocalization.)
- The tics occur many times a day (usually in bouts) nearly every day or intermittently throughout a period of more than 1 year, and during this period there was never a tic-free period of more than 3 consecutive months.
- The onset is before the age of 18 years.
- The disturbance is not due to the direct physiologic effects of a substance (e.g. stimulants) or a general medical condition (e.g. Huntington disease or post-viral encephalitis).

The fifth version of the DSM (DSM-V: American Psychiatric Association, 2013), published in May 2013, reclassified TS and tic disorders as motor disorders listed in the neurodevelopmental disorder category, and replaced transient tic disorder with provisional tic disorder, but made few other significant changes.

3. Diagnostic criteria for learning disabilities

A LD is a neurological condition that interferes with an individual's ability to store, process, or produce information.

LD can affect one's ability to read, write, speak, spell, compute math, reason and also affect an individual's attention, memory, coordination, social skills and emotional maturity.

The four diagnostic criteria for LD, according to DSM-V, are:

- A persistent difficulty in learning academic skills for at least 6 months despite intervention targeting the area(s) of difficulty. The areas of academic skill difficulties include: word decoding and word reading fluency, reading comprehension, spelling, writing difficulties (such as grammar, punctuation, organization, and clarity), number sense, fact and calculation, mathematical reasoning.
- The affected academic skills are substantially below expectations given the individual's age and result in impaired functioning in school, at work and in daily living activities.
- LD is readily apparent in the early years, however it is not to be diagnosed until the onset of school years; in some individuals the disorder is not apparent until the onset of a demand for higher-level skills.
- The academic and learning difficulties occur in the absence of: intellectual disabilities, visual or hearing impairments, mental disorders (e.g. depression, anxiety, etc.), neurological disorders, psycho-social difficulty, language differences, lack of access to adequate instruction.

4. Contributions from literature and clinical experience

People with TS frequently show the presence of LD at (often late) school age. Nevertheless, literature investigating the correlation between TS and LD is unfortunately very limited.

The main contributions in literature come from studies based on questionnaires (Jagger et al., 1982; Burd, Kerbeshian, Comings & Comings, 1987; Cook, Bornhoeft & Fisher, 1988) and parents' reports (Erenberg, Cruse & Rothner, 1986).

About the incidence of this correlation, literature suggests that approximately half of the children with TS shows LD (Hagin, Beecher, Pagano & Kreeger, 1982; Golden, 1984; Burd et al., 1988; Hagin & Kugler, 1988).

Previous studies on the disturbs' onset evidenced that in some children the appearance of learning difficulties coincided with the appearance of tics (Burd et al., 1988).

Concerning the neuropsychological aspects some authors, using specific tests, found a great number of neuropsychological diseases in children with TS (Lucas, Kauffman & Morris, 1967; Sand, 1972; Incagnoli & Kane, 1981; Ferrari, Mathews & Barabas, 1984; Shapiro, Shapiro, Young & Feinberg, 1988). Often there is a discrepancy between skills (as IQ scores) and school results (Siegel, 1989). Studies investigating the relationship between IQ and school's achievements revealed that LD appear in 50% of children with TS (Joschko & Rourke, 1982; Bornstein, Carroll & King, 1985; Hagin & Kugler, 1988). It's important to point out that these studies have been realized with very limited group of experimental subjects and further confirmations are therefore required.

About the learning areas involved by disturbs, Burd et al. (1988) found that 51% of the subjects showed the presence of LD in at least one field and 21% in two or more areas.

Investigating the specific impaired learning abilities, Burd et al. (1992) revealed that students with TS had more difficulties in decoding written text (dyslexia), in the observance of orthographic rules (dysorthographia) and with arithmetic computation (dyscalculia).

Observing comorbilities, Burd et al. (2005) analyzed the medical charts of 5.450 tourettics, finding that 22.7% of the sample showed the presence of LD. In this group, 80% of the subjects showed the presence of ADHD in comorbility.

As for tics, also the other symptoms of TS leading to low school's achievement are often evaluated as problem-behaviors (Burd et al., 1988) but it's by now univocal the consideration of the need to deeply analyze the neuropsychological aspects involved.

In the clinical experience children and kids with TS and dyslexia are also dysgraphic, they tend to invert letters, wrap to the wrong line while reading, block on single words, go back to the already written text and trace over the words (sometimes making a hole in the paper sheet). Often while writing, tics of the hand appear (wrist beating, muscle contractions).

Adding to this situation the presence of dysorthographia too, it's easy to understand how their school compositions achieve very lower results than they could do thank to their effective skills.

Kids with TS and dyslexia and/or dysorthographia find difficulties in memorizing informations presented in sequence, have poor metaphonological abilities, find difficulties operating with syllables and converting graphemes into their corresponding phonemes. For that reason, kids with dyslexia and dysorthographia have an inadequate "phonemic awareness", that is they meet difficulties in recognizing the right phonemes associated to letters. This is why they are less accurate in tasks requiring the fusion of single phonemes to identify the corresponding word or, vice versa, they don't succeed in segmentation tasks consisting in presenting a word and recognizing the single sounds by which it is composed (Fastame, 2009).

Literature about LD has documented that students with reading and writing difficulties often satisfy the criteria for the diagnosis of dyscalculia too, therefore they are weak in memorizing multiplication tables and procedures necessary to solve algorithms (Cornoldi, 1999).

As regards writing difficulties, the clinical experience evidences the presence of visual-motor integration problems: often for people with TS, tasks requiring to see material, process it and write, are very difficult and need much time to be executed. The same happens with works requiring copying, completing long written tests, producing a clean and neat handwriting and completing the work in a limited time. Frequently, children who have no problems to catch and understand even complex concepts don't get to complete with success their work, due to visual-motor difficulties.

Furthermore, it happens that tourettic children are not able to write quickly enough to get to stop important informations on a sheet, for examples while taking notes during a lesson, and this becomes an obstacle also for studying. Or sometimes, to compensate their working memory problems, they need to write (or read) so quickly, that the final written material is no more good to make further elaborations and corrections, and also not more readable.

Frequently they make words segmentation and fusion mistakes; tourettic children can indeed show difficulties in spelling tasks. Finally, problems with written mathematical calculations appear, often inserted on the incapability to organize the required task in a tidy table allowing operations execution.

Concerning children with TS' specific difficulties, a significant element is the presence of echolalia, both in the shape of repetition of own or other's words, and continuing coming back to the written words. Now it's possible to hypothesize that every child activates a minimum of echolalia or palilalia during writing, but in children with TS this mechanism is so excessive to

block them. And it concerns both reading and writing activities, often compromising their execution: the child stays blocked on the repetition, stops to read or write a word again and again, many times ("looping") and can't achieve to go on with the execution of his work (Bronheim, 1991). He can get, as already said, to make a hole in the sheet, for the continue tracing out of a word with the pen, or otherwise he goes beyond the block but only with the appearance of different tics, as eye blinking and more frequently beating wrist and elbow on sheet and desk.

People with TS show language impairments such as speech blocks, stutter, repetitions, as much as reading and writing anomalies can be observed. These phenomena can be a compensative system for the nervous system.

Often, tourettics stop while reading a word and continue repeating it. A repetition mechanism of the same single word comes into play, hindering the subject to go further reading. Such phenomena frequently correlate with tics and compulsive behaviors, confusing to the observer's eyes, the base mechanism which activate them. It is possible that all this happens as an effect of the dopamine-colinergic system, intended to compensate the state of tension produced by the difficulty to integrate brain areas and sensory-motor schemes which do not correctly work (e.g. for an incorrect temporal alignment between visual and auditory areas and the motor cortex).

According to Lurija (1984), spoken and written language are the two motor systems through which humans communicate, differing only for the final motion. Effectively speech, reading and writing require a movement first, and therefore represent complex processes based on the efficient enactment of a complex action, resting on more primitive movements which need to be effectively acquired by the subject and on information processing between different brain areas. When this doesn't happen during the first developmental phases in early childhood, or it happens in anomalous or not adequate ways, then trying to rehabilitate the subject's reading skills becomes impossible and is unuseful, without compensating the learning of the primitive schemes at the base, first (Delacato, 1972; 1980).

5. Reading and writing disabilities in a neurodevelopmental approach

The neurodevelopmental model effectively explains the functioning of both TS and LD and can be a crucial approach to understand the correlations between these two clinical conditions and the high impact of LD in people with TS, in comparison to the incidence in people without TS.

According to Delacato (1959), neurological organization is the physiologically optimal condition existing uniquely, and in its most complete expression, in human beings, and it's the result of a global and uninterrupted ontogenetic neural development which summarizes the neural phylogenetic development. This progression is an interdependent continuum; so if a superior developmental level is not correctly functioning or not completed, the inferior levels become operative and dominant: if an inferior level is incomplete, all further higher levels are impaired, both concerning their localization in the Central Nervous System (CNS), and in relation to the chronology of their development.

Through phylogenesis the human has developed his cortex. And however he still maintains neurological structures and functions of inferior levels, which were necessary during evolution.

Some researchers think that human supremacy is not the result of the acquisition of cells inside of the cerebral cortex, but rather the result of the functional specialization that humans have achieved with the use of the cerebral cortex itself.

Reading, as written language, proceeds from left to right (by European cultures): people pass to the next line or paragraph from left to right (and here is when the contralateral scheme appears); left-handed persons notoriously would proceed from right to left. Some students write numbers overturned or inverting the single digit's order (e.g. 142 for 124), they read or write inverting the letters' order (e.g. "il" for "li", "tra" for "tar"). Tourettics frequently start writing a sentence from the middle of the sheet or they show excessive falls of the writing line to the right or to the left.

In order to understand such phenomena, we can refer to the concepts of laterality and correct acquisition of dominance, the main themes of the neurodevelopmental model, elaborated by Dr. Carl Delacato.

The acquisition of lateral dominance (and subsequently of lateral servance) effectively contributes to human executive functions, orientation into space and time, perceptual, motor and linguistic coordination, and represents an essential condition in reading, drawing, writing, putting numbers in columns and mathematical calculation performances.

Recent studies by the University of Cagliari about laterality through digit exercises with both hands evidenced problems and difficulties in the execution and inhibition during tasks involving right and left functions in people with TS (Marrosu et al., 2011).

Lateral dominance concerns upper limbs (arm-hand), lower limbs (leg-foot), eye and ear, and can appear as coherent and well defined or mixed and not coherently defined.

Different levels of laterality can be observed: it can be right, left, natural crossed (upper limbs contralateral to lower limbs), natural mixed (right or

left, depending to the action, e.g. eating with the right hand and writing with the left), natural ambidextrous (same tendency and ability to use both limbs), obstructed (rarely right obstructed), with interferences, right oriented to left (rarely left oriented to right), in physiological delay.

Lateral dominance is a genetic condition, which can be subjected to contrasts and is determined by a process called "lateralization".

Lateralization is a neurobiological process of affirmation and stabilization of cerebral and corporeal laterality, which is outlined very early (according to Gesell at birth, as shown by the Tonic Neck Reflex; for other authors at the age of 4 months; according to Delacato at the age of 2 years, for others more at 4/5 or 6/7 years) but normally becomes stable at around 5 years and ends at 12 years.

It is an adaptation strategy, which makes human actions more efficient, a continuing process, which leads to praxic spontaneous or intentional readjustments (Le Boulch, 1984)

Effectively, it is interesting to consider which school performances are directly connected to the lateral dominance of the pupil and, therefore, which learning problems can be reconducted to laterality. In fact, people with lateral dominance problems meet some difficulties in working from left to right (they would prefer to proceed from right to left), in closing circles (they would close or they do close circles clockwise), in crossed schemes (movements from right to left and from left to right), in spatial and temporal orientation, in smart horizontal movement on the lines of numbers, in following number sequences (e.g. in numeration, oral calculations, expressions, …).

Therefore, in lateral problems, the main fields of complexity are:

- Reading: because written language proceeds from left to right. While reading, people passes to the next line or paragraph from left to right and, while reading a book, reads first the page on the left and then the one to the right, but turns pages from right to left.
- Writing: for the same reasons, but also because, for example, circles can be closed counterclockwise (for right-handed) and clockwise (for left-handed), and because to "attach" graphemes people needs to proceed fluently from left to right, and there are also crossed grapheme groups (e.g. "sc", in cursive writing).
- Mathematical skills: expecially writing numbers (they are oriented in a direction and, if composed by more digits, they proceed from left to right), numerations (move in time and space), putting numbers in columns (move into space and must be written from left to right), mathematical operations (are written from left to right but are executed from right to left, except for divisions), borrows and amounts carried forward (move to the left or

to the right). The same happens with multiplication tables, expressions, equations, summaries, verb conjugation.

In TS not every child shows evident laterality problems, even though they are present in a higher percentage than in the non-TS sample, but reading and writing problems (in particular dysgraphia) and mathematical calculations are more numerous. These phenomena seem to indicate that it's not correct to correlate every learning disability (at least in TS) with laterality problems. Other sensory problems (e.g. regarding the sense of hearing) and processing problems (hand's motor activity organization) can be at the basis of the impairment, such as in both TS and LD (Morciano, 2015).

Furthermore, also concerning non-tourettic people with LD, many authors move away from the tendency to consider reading and writing problems as if they could come only from phonetic decoding difficulties.

Underlining the link between learning abilities and motricity (and not only with codification), Crispiani (2011) describes dyslexia, dysgraphia and dyscalculia as a neuro-motor, and not a neuro-linguistic disturb, and more pertinently as a sequential dyspraxia.

It's important to consider that in TS with LD decoding problems in phonetic reception seem to be present, but laterality problems are certainly involved in a higher percentage. Effectively TS can be defined as a sort of sensory-motor stutter (Morciano, 2015).

A crucial aspect to understand the neurodevelopmental model is the concept of laterality. Delacato underlines how humans and a few superior mammals (e.g. primates like the lemurs from Madagascar) present a neurological condition characterized by at least two phenomena:

1. The specialization of brain areas mainly responsible of certain functions and the functional differentiation of the two hemispheres with consequent scission of nervous control on the two hemi-bodies; aspects of the asymmetry between the hemispheres of the CNS.
2. The crossed system as privileged correspondence of a hemisphere to the opposite (contralateral) hemi-body. These are tendential conditions, which appear with many exceptions and differences.

As an effect of this, humans tend to express movement and perception (visual and auditory) laterally and following a crossed direction, from right to left or vice versa, than walk crossing upper and lower limbs, cross the harm direction with the head, make crossed actions (from one side to the other, e.g. using instruments, throwing a ball …).

The condition of laterality, which is a neurological and praxic fact, not to be confused with the gnosic fact (the individual's internal awareness of the right and left sides of the body), is linked with the condition of lateral dominance.

Lateral dominance too is a human prerogative corresponding to the dominance of a cortical hemisphere on the other. This gives rise to fundamental phenomena for correct writing and reading abilities: better hemispheric specialization, better neuronal activity between hemispheres, better efficiency of the crossed system, better ability and primacy of the contralateral limb in respect to the opposite, better directionality of human acting into space (horizontal, vertical, oblique), better execution of motor and perceptive crossed schemes.

As well as four areas, specialized in linguistic decoding and production, are set in the dominant hemisphere (left for right-handed), it is equally important that the writing function is based in the dominant hemisphere for what concerns both vision and hand (dominance coherence). Evidently, it is possible to write also in absence of eye-hand dominance coherence, at the price of a major neurologic tension, writing difficulties, tics …

6. Development steps afferent to the language function

We have seen how among the probable causes of LD there can be also a "bad" lateralization or "dyslaterality" and the lacking acquisition of eye-hand dominance coherence. Delacato sustains that dyslexia is caused by the insufficient monolateral dominance only, and in order to understand this, it's useful to refer to the four developmental steps. He makes an essential premise first: given that humans are the only living beings whose motor and perceptual faculties obey to the principle of laterality, lateralization means habitually using eye, ear, hand and foot, based on the same side of the body. Generally the right, sometimes the left. Lateralization absolves the task to make tactile, visual and acoustic messages converge in the dominant brain hemisphere, opposite to the dominant hemi-body, the one in which linguistic functions are based. If lateralization is not perfect, there is no concentration of the linguistic functions in a unique cerebral hemisphere. Instead, there are dispersions and interferences in recording, storing and decoding graphic and acoustic symbols of language.

Theories have been submitted to test by Delacato first, and then by work groups referring to him, mainly in the United States, except for an Italian team in Campania.

The theory has been considerably revisited including, today, different primary dysfunctions of the sensorial systems, remaining however stable in its main structure.

To synthetically expose the theory: being neurological organization of the whole CNS (from spinal cord to brain) differenced in receptive area (pos-

teriorly located) and expressive area (frontally located), it is useful to refer to possible schemes of maturation and development of the two different functions, divided in receptive and expressive channels.

The perspective of the neuro-developmental model (from Fay to Delacato) is effectively psycho-educational, and implicates referring to developmental scales. Such scales recall both receptive channels, which should be reopened with rehabilitation practices, and expressive channels, which should be re-educated when they have been distorted by a bad reception.

Receptive channels are:

1. Sight: starts at birth time with reflex to light and proceeds through different steps from sensory-motor to gnosic ability, which is well acquired with grapheme's decoding and writing comprehension.
2. Hearing: starts at birth with reflex shock and proceeds in steps until language comprehension acquisition (through gnosic decoding of graphemes).
3. Touch: starts at birth with reflex contractions and proceeds until the ability to recognize three-dimensional objects only through touch.

Expressive channels are:

1. Mobility: starts at birth with movement without change of position and proceeds through different steps until normal human contralateral walk.
2. Manual competence: starts at birth with reflex grab and proceeds through steps until manual dominance, the ability to make signs and write.
3. Language: starts at birth with neonatal scream and proceeds until human language.

Referring to a developmental profile it is possible to evaluate the neurological organization level of the child, to determine his maturation degree in each significant area, which step he didn't experience and which he has not completed. The cure then consists in supplying the child the opportunity to experiment that step correctly and develop the lacking function.

During the first years of life of every human being different developmental phases of cerebral functions come in succession:

- STEP 1 (0-6 months): the child crawls on the belly like a reptile, making leverage on the right arm and leg to push the body forward. In a successive moment he makes leverage on the left arm and leg. Each time an eye is oriented to the floor or to the bed, wherever he is crawling.
- STEP 2 (6-12 months): the child moves on hands and knees and uses simultaneously both body sides: when moving forward he uses contemporarily left knee and right hand with the palm placed to the floor, successively right knee and left hand. Delacato defines such way to move "crossed scheme".
- STEP 3 (12-18 months): the child makes his first attempts to stand up. Initially he leans to furnitures; then the erected position offers him, sud-

denly, a new way to discover. The "right" way to walk is acquired when the right foot moves forward contemporarily to the left arm as a counterweight. Then the left foot with the right arm. In such phase the child still uses both cerebral hemispheres. At the end of this step, he walks erect, understands the meaning of some words and has his own, though little, vocabulary.

- STEP 4 (18 months - 6/7 years): it's the step of monolaterality: one of the two cerebral hemispheres becomes dominant and absolves the role of linguistic hemisphere.

Evidently lateralization depends on the child's experience of these steps, and therefore linguistic ability, too. If for any reason like environmental lacking or pathologic factors, a child hasn't correctly gone through each step, he *could* find reading difficulties. At this point, it is essential to verify and eventually provide to activate a rehabilitation strategy to recover the steps, which were not adequately experimented, and the related motor schemes, which have not been correctly and effectively acquired.

Summarizing, according to Delacato, lateral dominance – present in every individual, also in case of severe cerebral lesions – constitutes a relevant factor in neurological inter- and intra-hemispheric processes and, therefore, in all human performances requiring a high exchange in neuronal inter-hemispheric circuits, as in global and rapid motricity, speech, writing and reading, …

The condition of lateral dominance, as a neurological and praxic fact (not to be confused with the only gnosic fact of knowing the right and the left), joins the one of laterality. Dominance and laterality are a whole phenomenon of neurobiological nature, therefore it is a cerebral dominance.

Thanks to the experience, during childhood, of the homolateral (II) and contralateral (X) movement, the brain is organized to control the right hemi-body with the left cerebral hemisphere and the left hemi-body with the right hemisphere. During the different activities into space, when laterality is well defined, an element of the dominant side (e.g. the right eye during reading or writing) assumes the leading role and then the activity results well organized and easy. The system proceeds in a determined order. When this doesn't happen there is a sequential and organizational difficulty.

A well-balanced organization, convenient to the organism and its cognitive processes, involves the equilibrium between these two elements, automatic reflexes (primary or primitive reflexes) and voluntary movement. When dominant laterality is not yet defined, the activities of the neocortex and frontal and pre-frontal cortex result extremely complex and stressful. Orientation, movement into space and then reading, writing and speech result hard and confused activities if aware, automatic proprioception and definition are lacking. Where there are such difficulties, at least four pathological

situations (separated but also associated) are probable: stutter, ADHD, tic syndrome and LD. When stress (as neurological tension) is so high to disturb even frontal symbolic functions, a psychiatric pathology (OCD, psychosis) is possible, too.

7. Which senses are involved in reading and writing: motor action related to sensory reception

According to the Neurodevelopmental Model, two aspects regarding the onset of LD are crucial: laterality and the role played by sight.

Concerning laterality, in some subjects with dyslexia, exposed to neuroimaging controls, an anomaly of the natural asymmetry of the left temporal region is revealed. A study by Galaburda (1985) shows a symmetry of the temporal planum, which is generally more extended in the left hemisphere in 70% of the cases.

Morphological alterations of the perisylvian cortex, noticed in Galaburda's works, regarded the presence of microdysgenesis with ectopia or dysplasia distributed in the perisylvian areas of both hemispheres, particularly the left one. Involved areas included the anterior portion of Broca's area, a part of Wernicke's, the parietal lobe and parietal operculum, areas involved in oral and written linguistic elaboration (Sabbadini, 1995).

Furthermore sight seems to be involved in a crucial way. Neuroanatomical alterations have been revealed also in subcortical areas, devoted to visual and aural perception, which have been related to dyslexic's difficulties at more peripheral level of sensorial and perceptive processing.

Livingstone (1991) has revealed a reduction of the size of neurons in magnocellular stratum of the lateral thalamic geniculate nucleus, associated to the functional deficit of the magnocellular visual system in dyslexic people (Sabbadini, 1995).

If writing and reading processes take shape as motor actions related to sensorial reception, the need to correctly pass through all developmental steps, effectively acquiring the mastery of visual, aural and tactile competence, and to well develop mobility, then language and finally the manual ability clearly appears. As we have seen, they all develop along a continuum, a path made of steps that cannot be skipped and upon which superior competences cannot be effectively acquired if inferior ones are not well handled. Neurodevelopmental levels that have not been completed always imply neuro-functional anomalies, which can be observed with brain-imaging techniques because, as Fay said, "the function creates the structure". Therefore, it would be a

mistake to attribute such disturbs only to the cerebral structure's anomaly: the localist perspective should be passed by a processual and plastic vision of the nervous system.

8. Conclusions

Literature investigating the correlation between TS and LD shows a high impact of writing, reading and mathematical difficulties in people with TS, especially at school age.

In a neurodevelopmental perspective, both literature and clinical experience show that, at the basis of TS symptoms, there is often a not efficient organization of the CNS, due to insufficient or incomplete experience of the basic steps through which the related motor schemes can be efficiently acquired. From this perspective, tics and other tourettic symptoms can be seen as compensatory strategies, activated by the CNS to achieve balance.

Studies by Burd et al. (1988) evidenced that in some children the appearance of learning difficulties coincided with the appearance of tics and evidenced the need to deeply analyze the neuropsychological aspects of this correlation.

On the treatment side, it appears clear the need to adopt a neurodevelopmental perspective to work on the causes of both clinical conditions, TS and LD, in an integrated approach.

Therefore, it would be interesting to investigate this correlation in a neuropsychological perspective, not only to better understand the underlying functional aspects, but also to properly plan good rehabilitation strategies to apply in everyday clinical practice.

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