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WORKING MEMORY IN AUTISM: A REVIEW. EXECUTIVE FUNCTION OR COMPLEXITY THEORY?

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ABSTRACT

Autism is a disorder of neural development characterised by social impairments, communication difficulties, and by restricted and repetitive activities, and executive function (EF) problems are often seen throughout the spectrum.

Working Memory (WM) is a temporary storage system under attentional control that actively holds multiple pieces of transitory information in the mind. WM is a part of the executive functions, which is an umbrella term for cognitive processes that regulate, control, and manage other cognitive processes, for instance planning and attention.

This article shows that studies supporting either executive function or complexity theory do not correlate and that attention should be oriented not to performance levels in WM tasks but to the strategies and resources employed in verbal and visuospatial memory during the life cycle.

KEYWORDS: Working Memory, Autism, Executive Functions, Complexity Theory.

INTRODUCTION

As is well known, children with Autism Spectrum Disorder (ASD) have a developmental disorder, but this does not necessarily lead to cognitive impairment.

Often, in literature, we read about patients with excellent cognitive skills called "erudite skills". These can include the ability to, for example, remember complex architectural structures in detail and reproduce them in a drawing; calculate on which day of the week someone was born, starting from the date of birth; remember train times; or become prodigies in music, calculation, etc.

For over fifty years, autism has been a source of constant questions and fruitful research by individual professionals (psychologists, psychiatrists, neurologists, etc.) and increasingly specialised teams in order to provide detailed information and plausible answers about the development of the human mind. Many questions have been answered through much of this research (genetic origins of the disorder, extraneousness of maternal behaviour, validity of some educational interventions, etc.), although the

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actual causes of the disorder and its course, as well as entirely appropriate treatments, still remain to be discovered.

According to the most accredited and well-known definition, "autism is a set of neurological disorders that prevents the person from correctly processing information from the external environment" (Guazzo, 2003; Frith, 2003).

The etymology of the term ("autism", from the Greek "autòs" meaning "self"), introduced by Bleuler in 1911, refers to a personal condition of self-isolation and self-exclusion from social activities – being able to maintain contact only with oneself, a prerogative of a purely schizophrenic disorder.

About thirty years later, Kanner (1943) and Asperger (1991) separately observed psychotic children (their patients) and fixed the main characteristics of autism:

1. Rejection of social contact: Kanner considers it the main disorder of autism. From birth, the child seems not to grasp the stimuli coming from the external environment. They develop a self-centred game and struggle to experience meaningful relationships, even with the mother. However, there is no empirical confirmation to this hypothesis.

2. Abnormalities in language and absent or deficient communication: children with this syndrome are not able to use language correctly, with severe semantic fall, presenting echolalia, pronominal inversion and literal interpretation of content. Facial expression is deficient and hypomobile.

3. Good cognitive skills: the IQ of some of these children is relatively "normal" (even if more than 70% are intellectually disabled), so they are able to learn words and deeds, semantically and communicatively worthless, through continuous repetition. Abstract logical thinking is adequately developed, but autistic children still show difficulties in learning (especially in school). Moreover, some subjects may present peculiar talents (e.g. playing a musical instrument, painting, etc.).

4. Repetitive behaviour: it has been noted that the children in question displayed an exceeding amount of repetitive, stereotypical and obsessive behaviours, constituting an unchangeable routine if not by the child himself. Change could cause reactions of anxiety, bewilderment and panic.

In the last twenty years, there have been many studies aimed at understanding the biological and neuropsychological causes of autism. Data collected mainly from comparisons between monozygotic and dizygotic twins seem to indicate the dominant role of the genetic heritage in the onset of the disorder (Bailey, Le Couteur, Gottesman, Bolton, Simonoff, Yudza, Rutter, 1995), even if, due to its complexity, it is not attributable to the action of a single gene but probably to a few hundred genes. Studies have also included the influence of unknown environmental factors that contribute to the manifestation of the disorder. All these elements have made identifying the genetic factors involved a very difficult and arduous task. Nevertheless, in recent years, research has made considerable progress, both in molecular biology and in malfunctioning different limbic structures (amygdala and hippocampus), cerebellum and frontal lobes (Vargas et al., 2005).

The assumption that frontal cortex dysfunction has a specific role in autism is not surprising. It dates back to the investigation of Damasio and Maurer (1978), who compared autistic individuals to subjects with frontal lobe damage, investigating their executive functions (planning, working memory (WM), impulsivity control, mental inhibition and flexibility, initiation and monitoring of actions). This study implicitly also posed the problem of better understanding and defining the functionality of WM in the population of autistic individuals.

Working memory and learning

Every day we acquire a series of information that we store in our memory and then use when the opportunity arises. We often have to remember a phone number, do an arithmetic operation mentally, keep in mind the directions to the new restaurant they opened in the city, etc. Therefore, in situations such as these, we must not only possess information that is accessible to the mind. We must, also, at times, engage in real thinking about it, changing it and adapting it to the context. This function of simultaneous encoding, storage, retrieval and reasoning of data is called working memory.

This definition derives from the previous concept of MBT and, often, the two functions are still conceived as synonyms, even if one is a temporary storage of information and the other a combination of storage and manipulation of the same (Hill, 2000; Miller, 1956; Cowan, 2001; Atkinson & Shiffrin, 1968; Brown, 1958; Craik & Lockhart, 1972; Baddeley & Hitch, 1974).

Baddeley and Hitch (1974) propose, instead of the modal model of Atkinson & Shiffrin (1968), a more complex and detailed model: the multi-componential model.

The three-component model

The first version of the multi-component model, designed in the 1970s, had three basic components: two short-term sectors, one for acoustic or verbal information (phonological loop), the other for visually and/or spatially coded items (visuospatial notebook). Both were controlled and governed by the central executive, which allowed information to pass from one sector to another in an integrated and coordinated way.

To make this procedure clear, a simple example can be given: let us think about the house we live in and mentally count all the doors within the house. In performing this elementary exercise, we probably used a visual image of our home (visuospatial notebook). Then, one might suppose, we counted mentally or verbally all the doors (phonological loop). To do this, it was necessary for our central executive to choose a strategy and apply it.

The idea that verbal WM can include a "mental hearing" (that listens to the digits when they are read) and a "mental voice" (that repeats the same digits internally) guides us towards the efficiency of the phonological loop. These metaphors allow us to perceive a system consisting of two sub-components: respectively, a phonological warehouse and an articulated repetition process.

Once the verbal information has been visually received and codified, it acquires an acoustic-phonological value. To prevent it from being forgotten, a cognitive process is triggered that keeps it firmly in the memory for a short period of time, and here we rationalize the concept of "loop". Of course, this only applies to the visual material. In the case of auditory stimuli, such as spoken speech, the work of the phonological loop is automatic and largely simplified.

It is understandable that it is necessary to take into account certain characteristics so that the WM can act correctly: 1) its functionality is related both to the incisiveness of the "phonological process" and to that of the “articulated process”; 2) if, for some reason, the phonological loop should be damaged, its role could be integrated by the central executive and the visuospatial notebook; 3) the phonological loop model admits that the phonological warehouse and the articulated repetition are independent systems and, consequently, can be separated. When the items stored in memory are phonologically similar, (i.e. when, by pronouncing them, they have the same sound), their recovery becomes more difficult (phonological similarity effect).

Another difficulty is expressed by the length of the items: words, such as “university, individual, sacrilege, etc.” are remembered less than “home, man, flight” (effect of word length). The explanation for this does not lie so much in the number of syllables that make up each word but rather in the time taken in the mind number.

The task par excellence of the visuospatial notebook, instead, is to develop and navigate through a mental image, as when we are asked to describe, for example, a famous building such as the Colosseum. This ability, however, is not related to a better performance of visual memory. The fact that people are able to produce vivid memories in their minds does not mean that these memories are a mirror of reality; in fact, most of the time they are somewhat flawed.

Since the second half of the last century, several studies have attempted to examine spatial manipulations in the laboratory. Among others, Finke and Slayton (1988) can be remembered for devising a well-known procedure: imagine a capital “J”, then imagine a capital “D”, turn the “D” 90 degrees to the left and place it over the “J”. What does the figure look like? The answer is an umbrella.

Pearson, Logie and Gilhooly (1999) subsequently tried to give validity to the processes implemented in the management of the task described above with another test: four, six or eight geometric figures (squares, triangles, circles and the like) were presented to the participants, which were to be used to compose an object. This object was then given a name and, finally, drawn. If, after 2 minutes, they had not yet produced anything, the subjects only had to enunciate the geometrical figures that were presented to them.

Since, in such an experience, the phonological loop and the visuospatial notebook work in an integrated way, the loop was taken out of play with the articulatory suppression. Instead, to reduce the role of the notebook, the individuals involved were asked to touch a series of points in space with their hands (tapping). Thus, tapping damaged the participants' ability to compose new objects, while articulatory suppression abrogated the ability to remember the geometric figures seen. Moreover, the visuospatial notebook elaborated two types of information: a spatial one, like the arrangement of furniture in one's kitchen, and a visual one, like the image of one's favourite painting. Thus, it could be composed of two distinct systems that Logie refers to as visual cache (a passive phonological storage) and inner scribe (an active process of spatial repetition). This distinction seems to be the reason why, when you want to learn how to associate pairs of words, you have to combine them into a composite image (for example, cow and chair can be best remembered by imagining a cow sitting on a chair).

The multi-component model assumes that the WM is governed by the central executive, which performs four essential tasks:

1. Focusing attention on the task in front of you: this is evidenced by the reduction of attention on complex tasks (such as a game of chess) through articulatory suppression (spatial tapping, etc.).

2. Dividing the attention between two or more tasks: this ability is highly compromised in patients with Alzheimer’s disease. In an experiment conducted by Baddeley et al. (2001), a group of patients with Alzheimer’s and two control groups, old and young, were subjected to two distinct tasks: tracking and a span of figures test. At the beginning of the experiment, in order to balance the performance level of the three groups, the span of figures and the tracking ability for each subject were fixed, as was the time limit given to perform the activities. All three groups showed a deterioration in performance when the two tasks were combined, and for Alzheimer's subjects, this performance drop was very noticeable. However, it was only noticeable in these cases and not when the tasks were performed individually (Guazzo, Allen, Baddeley & Della Sala, 2020).

3. Switching from one task to another: in one study (Baddeley, Chincotta and Adlam 2001), the task of adding or subtracting one from a given number was used (for example, given seven, the answer should be eight in the first case and six in the latter). The subjects had to complete a column of additions (45, 56, etc.) or a column of subtractions (98, 76, etc.), or they had to alternate the operations: add to the first number, subtract to the second and so on (56, 87, etc.). In the latter condition, the performance slowed down considerably, especially when the alternation was accompanied by articulatory suppression.

4. Cognitively transforming and manipulating the information contained in memory: this can then be fixed and impressed for longer or shorter lengths of time.

Recent neuropsychological studies, in support of Baddeley and Hitch's model, believe that there is a structural and functional independence between visuospatial and verbal WM. In fact, they are associated to two different brain areas: the verbal WM is related to the left hemisphere (which is also responsible for linguistic functions) and the non-verbal to the right hemisphere (which also concerns spatiality processes).

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The four-component model

The three-component WM model illustrated in the previous section reveals some unclear and misleading points, which led Baddeley to a correction in 2000 (Baddeley, 2000).

The first misleading point concerns the explanation of the link between the multi-component model itself and long-term memory. To better understand this, try to read the following sentence and then close your eyes and try to remember it: "The teacher tried to explain the geography lesson to Matthias but was not very successful". We can say that this task was quite easy and satisfactory. Let us try now with this one: "The teacher tried to explain the geography lesson to Mattia, but she didn't find great success". There is little to say, remembering it seems practically impossible.

At this point, we need to remember that the span of words in a sentence with full meaning is fifteen, whereas it is around five or six for a sentence without logical and grammatical links. One solution for succeeding in the above task is to group words into chunks, which work, as we know, on the basis of MLT. So, how do WM and long-term memory interact?

Another difficulty concerns the ability humans have to remember seven or more digits, and since two or three of these depend on the loop, where are the others kept? If they stay in the visual MBT, how does it connect to the phonological MBT? Ultimately, the images built on the MLT do not seem to depend on the "visuospatial" and "phonological" subsystems, so where do they reside when we judge their vividness?

To answer all of these questions, Baddeley has introduced a fourth component into the model: the episodic buffer. It acts as an auxiliary buffer when the other two are overloaded or malfunctioning and also as a site where we can integrate more information, both verbal and spatial, together. Moreover, it is the place where all the complex information of short duration, such as a temporal episode (hence the name "episodic"), is stored. The concept of episodic buffer, however, is still in its embryonic stage; few scientific studies have actually tested its potential and usefulness. Nevertheless, on a theoretical level, it has served to create a bridge between Baddeley and Hitch's storage-centred component model and the more attention-centred models, such as Cowan's model. In doing so, the buffer generated at least a first junction between the WM and the MLT.

Individuals, in general, show huge differences in the ability to keep items in their WM. One of the main studies on this approach, which was aimed at understanding and analysing these differences in detail, was born from the work of Daneman and Carpenter (1980). They established an experimental condition in which participants were asked to read sentences and then recall the last word from each of them, for example:

A lady found an abandoned puppy and decided to take it home.

Finally, winter is over, the sunny days have arrived.

The film seen last night at the cinema was not the best, but I think it will still be a great success.

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The words to remember, then, are “home”, “arrived”, and “success”. The span is typically between two and five sentences. The two scholars have demonstrated their starting hypothesis that WM guides the ability to store information and, at the same time, processes it.

Analysis of some studies on individual differences and working memory

Cowan (1999, p. 62) defined WM as a set of cognitive processes that keep information in a more accessible than ordinary state. According to this definition, WM is regulated by MLT and supported by attentional processes. The activation, however, is temporary and, if not maintained by active verbal repetition or firm attention, it decays. The memory thus activated is multidimensional, similar to the episodic buffer intended by Baddeley: the only difference is that Baddeley asserts that the items come from MLT and then are represented in the buffer, while Cowan believes that "the addresses of the MLT locations are maintained (Ericsson & Kintsch, 1995). In summary, Cowan is interested in WM capacity, which he reduced to four chunks rather than seven, as originally hypothesised by Miller; Baddeley, contrarily, gives more weight to the peripheral functions of WM and its neuropsychological connotation, such as the importance of a verbal subsystem.

Turner and Engel (1989), on the other hand, have shown that measurements of the overall span of figures can be predictive of language storage and formulation. They carried out an experiment in which a new measure is created, the span of operations, whereby the words to be remembered precede arithmetic operations: sun, 6 + 2 - 3 =?; dog, 8 - 2 + 5 =?; and so on; after which the subjects must remember the words. According to Engel, safeguarding the items in memory from proactive interference (i.e., from the tendency to recall items already stored) is really difficult to accomplish in a complex digit span task. To explain his theory of inhibitory control, Engel introduced a simple experiment. He asked participants to remember three lists of words presented in succession; each list included ten words, each from a different semantic category (e.g., a colour, an animal, a craft). By using the same lists in several tests but with different words, the lists were remembered with increasing difficulty. The performance worsened for those who had a reduced WM span, and the fact that the first list was almost always recalled correctly made it clear that the problem lay in interference and not in learning ability.

In another study, Conway, Cowan and Bunting (2001) asked subjects to repeat a sequence of numbers presented to one ear and ignore the messages addressed to the other. Among the messages to ignore was the name of the subject itself. This showed that, although they were given a precise instruction, subjects with reduced span would eventually notice their own name and not the numbers, presumably because they found it more difficult to exclude irrelevant material. The resource-sharing model was devised by a team of French researchers, who reworked Turner and Engel’s span task operations, adapting it to a simple reading of letters. The task of the experiment participants was to remember a list of words while processing a series of letters sequentially. The difficulty lay in the lack of time and concrete space that the subjects had for repeating the words either in their minds or verbally in order to fix them in the best way.

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Neuroscience and working memory

A typical experimental procedure is to implant electrodes into the individual brain cells of a waking monkey in order to record their activity in response to precise stimuli.

In a study by Goldman-Rakic (1988), a monkey was trained to stare at a point in the centre of a screen and hold its gaze steady even after a bright stimulus was presented to it in one of eight different positions on the board. After a duration of 2, maximum 30 seconds, the animal was given a signal of permission to move its gaze to the exact spot where the new stimulus was presented (delayed response task). If the task was done correctly, the monkey received a reward (usually food). The electrodes showed that some neurons were active in the monkey's frontal lobe during the task, while others were activated during the retention period. Therefore, it was surmised that this was where the WM was located. Later, however, it was noted that other cells in other areas of the brain behaved in the same way. Therefore, it was assumed that the frontal regions were involved in a larger system, to verify the multi-component model.

The experiment was repeated once the monkey had learned all the instructions but after part of the cortical tissue had been removed from its prefrontal cortex. After the lesion, the animal still managed to perform, unless stimuli were presented in the areas normally coded by neurons in the compromised area. In this way a mnemonic scotoma or mnemonic blindness was produced.

In another experiment, Jonides and Smith (1997) used positron emission tomography (PET) to study WM under two distinct conditions: verbal and visuospatial. In the first one, four letters were shown to the research participants, followed by a letter-probe (a letter used as a memory probe). Subjects had to say whether or not the letter-probe had already been shown previously, even if a basic condition had already been administered in which the stimulus and the probe were presented together. Therefore, two areas were activated in the left hemisphere during the task: the one between the parietal and temporal lobes, responsible for the storage of phonological information, and the Broca area, which is functional to the production of spoken language.

In the case of visuospatial memory, the participants were presented with a set of three dots, followed, after an interval of time, by a circle. They had to say whether the circle was in the same position as the three dots. This was done each time, after there had already been a condition in which the two stimuli were presented simultaneously. This time, the active areas were the right hemisphere’s (Vogan, Morgan, Smith & Taylor, 2019).

In general, neuroimaging studies show that execution processes tend to be associated with the frontal areas, and this is largely understandable through the N-back task: subjects are presented with a succession of items and asked to press a button every time there is a repetition. The task is easy when the repetition is immediate (7, 5, 4, 3, 3); it gets complicated, however, when the item to “report” does not coincide with the one immediately preceding it but with the one preceding it by two places (7, 5,

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4, 3, 4). We can observe, therefore, that the task becomes increasingly complicated as the interval grows because we have to keep in mind an increasingly extended sequence.

With this task, a frontal activation increases proportionally to the load of the central executive, but, at this point, a question is legitimate: "How does this work in subjects with a deficit in executive functions, such as subjects with autism?" (Koshino, Kana, Keller, Cherkassky, Minshew & Just, 2008).

In summary, as already explained, the model of Baddeley and Hitch (1974, 2000) is, among the various models on WM, still the most well-known and approved in the scientific community, as the explanation of the individual components and their integration is complete. However, it is not without difficulties, which Baddeley (2012) himself exposes in his research as unresolved perplexities, questions-principles of possible future research. In fact, the distinction between the central executive, as suggested by Baddeley (2012), and the limited capacity component presented in the Cowan model (1999) is unclear. What is also unclear is how the cognitive functions monitored and governed by the central executive are really organised and interrelated. Finally, it is unclear how it is possible to explain the central executive based on a single factor, for example, inhibition.

With regard to the episodic buffer, the controversies that have arisen relate to understanding how to measure its capacity, or how to favour repetition, or understanding what the role is of emotions in its functioning. The explanation of the phonological loop, on the other hand, does not clarify whether it is necessary to remember non-verbal information, such as music or the sounds of nature. Finally, with regard to the visuospatial notebook, the nature of its repetition and its analogy, or presumed analogy, with the phonological loop has not been well highlighted (Vogan, Francis, Morgan, Smith & Taylor, 2019).

Working memory in autism

The question at the end of the previous section poses the problem of better understanding and defining the functionality of WM in the population of people with autism. The research that we will consider is structured around two different hypotheses:

1. WM deficits in autistic subjects are due to deficits in executive functions (executive functions, EF theory) (Alsaedi, Carrington & Watters, 2020);

2. WM deficits in autistic subjects are related to the difficulty and complexity of information manipulation and processing, and disorders of executive functions are secondary to major cognitive deficits (complexity theory) (Kercood, Grskovic, Banda & Begeske, 2014; Habib, Harris, Pollick & Melville, 2019) (Tab. 1).

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Table 1 – Main characteristics of accuracy in Executive Function Theory and Complexity Theory studies.

Authors	Participants	Diagnosis criteria	Assessment	Main results
Executive Functions Theory				
Benetto, Pennington & Rogers (1996) *Data Analysis* ANOVA Mixed-model *t*-Test Fischer Correlation	ASD: n. 19 Age: M = 15.95 yrs Clinical Comparisons TD: n. 19 Age: M = 15.23 yrs	CARS WISC-R Stanford Binet Test of Intelligence	Memory and Working Memory Measures Sentence Span Counting Span Wisconsin Card Sorting Test	Students with ASD performed significantly lower than comparisons on measures of temporal order memory, source memory, supra-span, free recall, working memory, and EF, but not on short- and long-term recognition, cued recall, or new learning ability. Significant correlation in the scores of Digit Span Forward (from WISC) and other WM subtests: Counting Span, and Sentence Span.
Guerts & Vissers (2011) *Data Analysis* ANOVA Mixed-model Regression Analysis	HFA: n = 23 (16 ASP, 2 autism, 1PDD-NOS, 4 ASD) Clinical Comparisons Control: n = 23 Age: range 51–83 yrs	Social Responsiveness Scale Diagnosis by Autism specialists	WM-Spatial Span from the Wechsler Memory Scale-III The Sustained Attention to Response Test (SART); Tower of London (Planning)	Elderly with HFA had more problems with visio-spatial WM, sustained attention, and fluency than controls; other cognitive domains were intact. In previous studies, children and adults with autism d demonstrated deficits in planning and cognitive flexibility. In this study, with the elderly with

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				autism, these deficits did not seem to be present, suggesting that the deficits disappear with aging.
Steele, Minshev, Luna & Sweeney (2007) *Data Analysis* ANOVA Mixed-model Fischer Correlation	HFA: n = 29, Age: M = 14.83 yrs, Clinical Comparisons TD: n = 29 Age: M = 16.93 yrs,	DSM IV criteria ADOS ADI-R	Spatial working memory task from CANTAB presented on computer monitor.	Subjects with autism showed difficulty in remembering which boxes had been previously chosen and in adopting reasoning strategies, compared to individuals with typical development. Their errors/omissions were greater as the memory load was higher. The results of this experiment led to the finding that deficient problem-solving competence is related to the limitations of working memory capacity in autism.
		Complexity Theory		
Alloway, Rajendran & Archibald (2009) *Data Analysis* MANOVA	AS: n. 10; Age: M=8,8 years DCD: n. 55; Age: M=8,8 years ADHD: n. 83; Age: M=9,10 years SLI: n. 15; Age: M=9,2 years	ADOS DSM IV criteria British Picture Vocabulary Scales-II Test for Reception of Grammar	Automated Working Memory Assessment (AWMA) Working Memory Test	Language impairments were associated with selective deficits in verbal short-term and working memory, whereas motor impairments (DCD) were associated with selective deficits in visuo-spatial short-term and working memory. Children with attention

Hotelling T-Test MANCOVA			Battery for children	problems were impaired in working memory in both verbal and visuo-spatial domains, whereas the children with AS had deficits in verbal short-term memory but not in any other memory component. These deficits seem to be related to an inability to organize planning and problem solving strategies.
Griffith, Pennington, Wehner e Rogers (1999) ***Data Analysis: St. 1*** χ^2 Analysis ***Data Analysis: St. 2*** ANOVA Mixed-model Cross-Time Correlation	*Study 1* ASD: n. 18; Age: M= 4,3 yrs Control: n. 17; Age: M=4,3 yrs. *Study 2 (Longitudinal)* ASD: n. 13 (subset of children) Control: n. 11 (subset of children)	Diagnosis by Autism specialists ADI-R	A not B Object Retrieval A not B with Invisible Displacement 3-Boxes Stationary and Scrambled 6-Boxes Stationary and Scrambled Spatial Reversal	The results of these studies pose a serious challenge to the executive dysfunction hypothesis of autism. This work, in fact, subtracts importance and effectiveness from EF theory, going in favour of Complexity theory. The deterioration of working memory associated with the spectrum of autistic disorders is not a product of central executive dysfunction, but of a deficit of the cognitive system. Upstream of the theory there are the assumptions that subjects with autism do

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				not adopt strategies to facilitate memorization and that working memory capacities are undermined when the items to be remembered increase in complexity.
Williams, Goldstein & Minshew (2006) *Data Analysis* t-Test F-Test Varimax Rotation	HFA: n. 38 Age: range 8-16 years Control: n. 38 Age: range 8-16 years	DSM IV criteria ADOS ADI-R	Wide Range Assessment of Memory and Learning (WRAML)	The resulting profile of memory abilities in the children with autism was characterized by relatively poor memory for complex visual and verbal information and spatial working memory with relatively intact associative learning ability, verbal working memory, and recognition memory. A principal components analysis indicated that the factor structure of the subtests differed substantially between the children with autism and controls, suggesting differing organizations of memory ability.

Note: ASD: Autism Spectrum Disorder; HFA: High Functioning Autism; AS: Asperger Syndrome; SLI: Specific Language Impairment; DCD: Developmental Coordination Disorder; ADHD: Attention Deficit Hyperactivity Disorder; ADOS: Autism Diagnostic Observation Schedule; ADI-R: Autism Diagnostic Interview-Revised; CANTAB: Cambridge Neuropsychological Test Automated Battery.

DISCUSSION

In summary, it emerges from this review that 1) people with autism had lower scores on WM measurements than people with typical developmental development; 2) people with autism made more mistakes, used fewer strategies and demonstrated lower performance on tasks requiring cognitive performance: flexibility, planning, problem solving; 3) people with autism used a higher spatial WM load, especially with the increasing complexity of tasks and under dual task conditions; 4) people with autism also scored lower on the WM-Math component of IQ tests and in the verbal component associated with problems of adaptation and restrictive and repetitive behaviour; 5) similarities in WM performance were found among individuals with autism and with specific learning difficulties in mathematics (Rabiee, Vasaghi-Gharamaleki, Samadi, Amiri-Shavaki & Alaghband-Rad, 2020; Estratopoulou & Sofogi, 2019).

This article shows that the studies that support either executive function or complexity theory do not correlate and that attention should be oriented not to performance levels in WM tasks but to the strategies and resources employed in verbal and visuospatial memory during the life cycle (Friedman & Sterling, 2019; Demetriou, Lampit, Quintana, Naismith, Song, Pye, Hickie & Guastella, 2018).

Further studies, therefore, should focus mainly on individuals with high functioning autism in order to have a more homogeneous group and to develop therapies that improve the psychophysical conditions of the subjects, which could lead to them integrating better into society.

Strategies to improve working memory

Given that WM is one of the most influential theoretical constructs in the field of cognitive psychology, the recent clamour that this investigation has caused is mainly due to the observation that the WM can be trained and, therefore, improved. The effects of such training are twofold: they have both immediate value and visibility (e.g., improvements in visuospatial and verbal WM tasks, together) and a posteriori (e.g., positive performance in intelligence tasks and IQ increase).

In any respectable study, to validate the importance of WM training, it is necessary for

- participants to be randomly assigned to the sample so that there are no numerous variables influencing the results.

- each group to be tested before and after the training (pre-test/post-test drawing).

- both samples, the experimental and the control sample, to be obligatorily submitted to the training, even if not to the same procedure, so that the positive results cannot be attributed to the researchers' expectations and the negative results, on the contrary, are considered to reflect a useless and ineffective procedure.

Holmes, Gathercole and Dunning (2009) have devised three methods to reduce WM difficulties:

1. The first approach concerns the adaptation of the child with difficulties to the classroom context and the ability of teachers to transmit strategies to facilitate the memory and information retrieval. It is guided by seven key principles that are designed to reduce failures and errors in homework and accelerate the ability to learn:

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- First step: inform teachers about WM (what it is, what it is for, in which school activity it is essential, etc.) and assist them in the selection of problem children;

- Second step: observe how children with WM deficits deal with their difficulties psychologically;

- Third step: evaluate pupils' learning activities by identifying which might be the most complicated and dividing the class into "more or less capable";

- Fourth step: reformulate these activities to reduce the WM load (decrease information, increase familiarity and meaning of materials, simplify the activities themselves);

- Fifth step: detect any problems when children try to remember instructions and information (students are asked to repeat things over and over again, both to the whole group and individually, so that the child is not afraid to ask for explanations if he or she has not grasped something);

- Sixth step: promote memorisation using posters, word and number lists, personalised dictionaries, audio recorders, etc.;

- Seventh step: encourage pupils to adopt cognitive strategies (ask for help, write down information, make verbal, written or even just mental links, etc.).

2. The second approach to alleviate the problems associated with the reduced ability to work involves teaching memory strategies, such as repeating in-formations out loud or between oneself and oneself, creating a story or sentences from words heard or read, generating mental images. Such strategies are born already from childhood.

Recently, in two related studies, St. Clair-Thompson et al. (2008) observed how cognitive strategies can improve WM over time. They used a computer video game, Memory Booster, which imposed and encouraged the use of repetition, visual imagination, storytelling and group adaptability. The participants (children aged six and seven in one group, and seven and eight in the other) completed two training sessions per week, each of about 30 minutes, for 6–8 weeks. In the first study, they were tested on verbal and visuospatial memory before and after training, noting that there was great verbal improvement in the younger group. These results were replicated in the second study, in which, again, the younger group showed a clear improvement in following the information. In a second study in 2010, St. Clair-Thompson et al. stated that although cognitive strategies are considered a tool to improve memory, in reality the benefit cannot be transferred to other activities, such as reading or calculating.

3. The final approach sees the repetition of WM tasks as a way to damage it.

Recently, many WM training programs have been created, but they are not specifically created to research autism and are not easily accessible to everyone, as they are only available, for a fee, on the Internet. Therefore, access is limited for those who do not know how to use the Web or who do not

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have access to it. Moreover, their effectiveness and efficiency have not been adequately and scientifically proven and, more than a rehabilitative product, they seem to be a commercial product.

One of the most used and widespread tools is the CogMed, created by Klingberg and collaborators (Klingberg, Forssberg & Westerberg, 2002; Klingberg, Fer-nell, Olesen, Johnson, Gustafsson, Dahlström, Gillberg, Forssberg & Westerberg, 2005). It is a program tested on individuals with attention deficit and/or learning disabilities and it is available in as many as thirty countries. It is computer-aided and can be administered either at home or in specific facilities (clinics) under the supervision of a qualified instructor.

The complete program includes

First interview

Start training

Five weeks of training

Final meeting

Follow up after 6 months

Access to the Cogmed Training Web (which allows all users to see their results and how the training progresses online)

Cogmed Extension Training (lasts 12 months; allows the user to further refine the acquired skills and to verify the expected long-term results).

The duration of each trial ranges from 30 to 45 minutes, for a total of eight tasks per day, which vary depending on the type, duration and intensity of the treatment.

There are three different versions: the Cogmed JM and RM are respectively created for pre-school children and puberty-age subjects and are largely based on the structure and content of video games. The task of the "Asteroids" is to test visual-space ability, as the child has to recreate a sequence of asteroids that light up one at a time, pointing at them with the mouse. An example of a verbal test is the "Input Module", in which the child has to reproduce a sequence of heard stimuli in reverse.

The Cogmed QM, however, is intended for adults, and is similar to previous versions, with the exception that the tasks are presented in a more complex way.

Researchers expect the subjects, after the five weeks of training, to be able to take more initiative in interacting with others, to better understand the orders (e.g., those given by the teacher or employer) and to carry out various activities autonomously and independently. The aim of the program is also to improve school performance in the case of children, especially in text comprehension and mathematics, and to increase the ability to concentrate and resist distraction in the case of adults.

However, the issue is much more complex. During training, people usually advance to a higher level, but this does not mean that their memory capacity has improved. This may be due to the frequency with which the subjects perform the tests and the subsequent storage of the tests.

The use of Cogmed leads to immediate results, therefore, and not to long-term improvements, (i.e. it does not specifically lead to a satisfactory or so-called normal WM performance).

Another reasonably well-known program, but always subject to the same critics, is Jungle Memory. It is used both at school and at home, for children aged seven to sixteen who have learning and concentration problems, especially dyslexia and autism. It includes a five-week training period, with tests performed four times a week. The expected results are an improvement in school performance, an increase in personal self-efficacy and a greater disposition to relational and social behaviour.

More functional and constructive are the tasks of matrices with regard to the training of the visuospatial WM, while for the verbal skills the tasks of repetition and elaboration of lists of words and/or numbers are pre-fertilised.

CONCLUSION

WM in autistic subjects is compromised in important ways. Moreover, there appears to be a "cascade" process originating in the memory system that negatively influences the whole cognitive domain. However, one must exert caution before generalizing these indications, given the limited number of published data on the matter.

DECLARATION

The author declares that there is no conflict of interest.

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