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Metacognitive skills and working memory in children with ADHD and the ICTs' Role

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Abstract

Metacognition and working memory from executive functions are higher order cognitive processes that undergo steady improvements throughout childhood. They are of great importance for daily functioning in a variety of domains, including academic achievement. Both concepts have been intensively researched, but little literature has attempted to link them theoretically and empirically. Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder with a high prevalence and high heterogeneity, which is identified as early as childhood, causing problems in almost every aspect of the ADHD child's life. In this paper, we will present research data from around the world that link working memory and metacognitive skills to the development or management of ADHD.

Keywords: Working Memory; Executive Functions; Metacognition; Attention Deficit; ADHD; Hyperactivity

1. Introduction

Metacognition relates to the awareness we have of our own thought processes and the ability to control those processes. A dynamic aspect of metacognition is self-regulation. This relates to the experience, feelings, and thoughts that occur during ongoing cognitive activity (Flavell, 1979; Weinert & Kluwe, 1987). These experiences give individuals internal feedback on the effectiveness of their cognitive monitoring. In some circumstances, adults, and to a lesser extent children, are able to realize that they are using rules and strategies to solve a problem. On the other hand, individuals with Attention Deficit/Hyperactivity Disorder (ADHD) exhibit an inability to use the "stop and think" rule before acting, regardless of the task or situation. The main goal of this paper is to identify some cognitive factors associated with ADHD and working memory, particularly the metacognitive deficits that keep these students from school success. The main deficits, as research shows, are identified in identifying task demands, selecting appropriate strategies and implementing them correctly, actively monitoring their performance, corrective control and evaluating results.

2. Definition of ADHD

Attention Deficit Hyperactivity Disorder (ADHD) is the most commonly diagnosed disorder in school-age children. In recent years, researchers have become interested in ADHD. However, although our knowledge of ADHD has increased significantly, there are still issues that it is advisable to further clarify in order to make the identification, diagnosis and treatment of ADHD and the prevention of its consequences on learning and behaviour more effective.

According to the DSM-V (APA, 2013) it is defined as a neurodevelopmental disorder characterized by six or more symptoms that must be present before the age of 12 years. It must not be explained by another mental disorder. The primary symptoms of the disorder are inattention, hyperactivity and impulsivity. As far as inattention is concerned, it is attention, a cognitive process that involves the ability to select from the environment certain information for more detailed processing and to ignore other irrelevant information and return to the processed stimulus after distraction.

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Children with ADHD exhibit inability to concentrate and sustain sustained attention, particularly during structured activities that require mental effort and do not stimulate interest.

We will mention some characteristics of a child with distraction, such as seeming to daydream, having difficulty focusing attention on details, not being able to consistently follow rules when performing a task, having difficulty maintaining attention to tasks, having difficulty following the rules required to complete an activity, not following through on instructions given, often not completing tasks, seeming as if he/she is not listening when spoken to, asks questions about topics that have just been discussed, has difficulty organising his/her activities, alternates activities, avoids taking on tasks that require constant and sustained mental effort, often loses his/her belongings and forgets daily activities. However, they can concentrate to a satisfactory degree when they are highly motivated to complete an activity. With regard to hyperactivity, it is described as highly increased, unnecessary and uncontrolled motor activity, especially in circumstances and places where similar actions are not permitted.

Characteristics of a child with hyperactivity are that he or she is always moving his or her arms and legs nervously or twisting in place, gets up from his or her seat, has difficulty playing quietly, talks excessively, moves without purpose, makes noise and damage and gives the impression of being unaware of danger. Impulsivity is defined as a reduced ability to immediately inhibit a behaviour based on social rules. Lack of self-control is observed at the level of words, actions and emotion.

Characteristics of impulsivity are that he or she often answers a question before it is completed, has great difficulty in waiting his turn, interrupts conversations, repeats his mistakes, does not consider the consequences of his actions and exhibits irritability and his reactions are disproportionate to the cause. According to the DSM-V the symptoms should last for at least 6 months.

The involvement of poor working memory in the symptomatology of ADHD has attracted considerable research interest. We aim in this paper to investigate the role of working memory assessment in detecting evidence of ADHD in the typical Greek school student population. Research has been conducted to assess the working memory of primary school children through the Working Memory Rating Scale (WMRS) by Alloway, Gathercole, Kirkwood (2008) (the weighted scale was administered in Greek) related to working memory and ADHD. The results of this study showed statistically significant differences in the overall WMRS scale scores and in the scores of its simple questions between children with an ADHD diagnosis and those without ADHD.

3. ADHD & Dyslexia

Dyslexia and ADHD is one of the most common disorders of school-age children, occurring in about 5% of the diagnosed student population. It has been found that dyslexia can co-exist with ADHD in about 40% and this co-morbidity is bidirectional. The co-morbidity may contribute to a better understanding of the aetiopathogenesis of these two disorders and to the formulation of more effective treatment programmes. Some researchers argue that dyslexia causes ADHD symptoms because of the intense dissatisfaction experienced by the child. ADHD and dyslexia stem from independent causal factors.

Children diagnosed with ADHD but without dyslexia have deficits in executive control functions, whereas children diagnosed with dyslexia without ADHD have deficits in language abilities such as phonological information processing, phonological awareness and verbal working memory, but not in executive control functions. Children with a diagnosis of ADHD and dyslexia have both of these types of deficits. Deficits in attention and self-control are among the core symptoms of ADHD and cause problems in the reception of phonological information and in the discrimination of phonemes. The nuclear symptoms of ADHD make it difficult to retain the information contained in the text to be read. Children often do not retain in their memory the information they read, resulting in poor comprehension. At the neurological level, neuroimaging shows that the two disorders are characterised by inversion of symmetry in structures of the prefrontal cortex, smaller volume in the cerebellum and dysfunctions in the temporal cortex.

4. Cognitive level-Executive functioning

For several years, theoretical models of the cognitive-level etiopathogenesis of ADHD have focused on individual cognitive processes. Barkley (1997) states that ADHD is caused by deficits in executive functioning, which are caused by deficits in the ability to inhibit responses. There is no consensus on the definition of executive functioning. The term is used to describe a wide range of 'top-down' cognitive processes that regulate self-control at the cognitive, emotional and behavioural levels and also at the implicit activity level (Ozonoff et al., 2004; Pennington & Ozonoff, 1996). These

types of processes include planning and implementing strategies for problem solving, working memory, starting and ending an activity, inhibiting learned responses but related to performing a task, self-control of actions while performing a task, cognitive flexibility, and language fluency. Executive functioning is controlled by the prefrontal cortex which distinguished executive functions into "cold" and "warm" functions. The observation that the prefrontal cortex constitutes a heterogeneous region with numerous subregions, which differ in both anatomy and functionality. The two types of executive functions differ in the degree of involvement of emotion and motivation of the organism in the performance of a cognitive task. 'Cold' executive functions are usually associated with abstract problems that are not part of a social context, whereas 'warm' executive functions are associated with problems whose resolution requires an appreciation of the emotional significance of the stimuli.

5. Working Memory Definition

Working memory is a brain system responsible for temporarily storing and processing information. It is the ability to hold and successfully process information in a short period of time. It is a system for temporarily storing and managing the information needed to perform complex cognitive processes. It is involved in the collection, initiation and termination of functional information processing. Baddeley and Hitch, in 1974, proposed a multicomponent model of working memory that included the following subsystems, the central one responsible for concentration, the processor, the phonological circuit and the visuospatial notebook. Working memory allows us to perform actions that were planned earlier, solve problems, organize information and maintain attention to the task at hand at any given time (Conway, 2007; Bedard et al., 2007; Cai & Arsten, 2007).

There are mnemonic strategies where techniques are used to aid memory, such as the place method for serial recall. Other techniques that can help children with ADHD to improve working memory are some techniques that include reading instruction.

6. Working memory and ADHD

During the mnemonic process (short-term memory), information that remains for a period of time (up to 30 seconds) is recognised. If more information is required to be retained then recall is required. The processing of stimuli in short-term memory requires the use of strategic mechanisms for repetition, organisation and categorisation of stimuli. This avoids forgetting information about the course of the cognitive task to be processed by the learner.

Long-term memory is the permanent storage of information. The capacity of long-term memory is unlimited. Instead of using strategies, students with ADHD choose the least effective ones. This results in less thorough searching in long-term memory. It is important to mention that the structure of the mnemonic function plays a role. Working memory refers to one's ability to hold a small amount of information and attempt to complete other processes.

Some researchers argue that attentional control processes are complex and reflect a person's ability to maintain a state of alertness, to be able to stay focused on visuospatial stimuli, to the ability to inhibit responses and to regulate or supervise one's actions.

Cognitive control deficits and working memory deficits are associated with ADHD. Students with ADHD show problems in comparing incoming stimuli, organizing, processing and storing them in such a way that they are transferred in an appropriate form to long-term memory. Learning strategies are all behaviours that facilitate the encoding of learning and assist in completing and recalling knowledge. Organised action plans are formulated for this purpose. Some well-known learning strategies are active repetition, synopsis, imagery, paraphrasing, rendering, summarising and processing. The implementation of the programme must be consistent, logical, speedy and simple. Students with ADHD have great difficulty with short-term and working memory, the memory we use when we want to complete an activity.

The limitations in working memory give a different character to the learning process. Deficient working memory has been linked to ADHD. It is tested by reproducing sequences so that the exercise is more difficult for children with insufficient experience. The exercise tests verbal working memory, which is weak in children with language learning disabilities.

Children with behavioural difficulties in ADHD are characterised by poor working memory function. Children with ADHD perform poorly on audiovisual short-term memory tasks as well as verbal and audiovisual working memory tasks. Their verbal short-term memory appears to be preserved intact, suggesting that problems storing verbal information are not fundamental features of this disorder. Working memory problems are the cause of the inattention

and disruptive behavior associated with ADHD. Poor working memory function can therefore cause distraction from activity.

After using a Cogmed program, participants were tested on working memory. They used a test called Stroop to measure executive functions and Raven's progressive matrices to measure intelligence. It has been linked to understanding the dopamine system and its effects on working memory (Klingberg, 2010). Better behaviour was reported after using Cogmed for five weeks. Cogmed software continues to help improve working memory ability, but continues with research being completed to determine the timing and duration of training (Klingberg, 2010). One study that used Cogmed as a means of improving memory asked participants to participate in the program for 35 minutes a day over a six-week period during the school year. Results showed that deficits in working memory were nearly reversed. Other researchers have examined the potential of Cogmed as an intervention versus medication in children with working memory problems and ADHD. Drug use showed an increase only in visuospatial memory performance. Computer-based training, however, showed significant improvements in all areas of working memory. The significant gains in working memory may be due to the intervention of the computer program and the individual and focused attention that participants received because of the experiment. Cogmed recommends training for at least 30 to 45 minutes a day for five to six weeks.

Another software we will mention is "JungleMemory". It is another commercial training program for working memory. This program claims to increase school success and provide help for ADHD, with scientific evidence to support these claims. The online game is aimed at children between the ages of seven and sixteen and lasts just eight weeks.

An additional computer-based tool designed to assess working memory is the Working Memory Rating Scale . It is suitable for detecting working memory deficits in children aged 8-11 years. Students can complete it online or with supervision. The time the student needs is 20 minutes. It is a working memory assessment scale and includes a four-point scale. The Greek WMRS helps to detect ADHD in general education students and is the Greek version of the original working memory assessment scale by Alloway, Gathercole & Kirkwood. It aims to help teachers identify students with working memory deficits and is for students aged 6 to 11 years. The total score on the Greek scale ranges from zero to 60. When green color means the student cannot work and has memory deficits, yellow means the child is likely to have a working memory deficit and red means the student is very likely to have working memory deficits. The Greek scale is a standardized working memory assessment tool for primary school students in Greece. This scale revealed a significant difference between students with ADHD and those without ADHD.

7. Definition of Metacognitive Capacity

Metacognitive abilities are related to higher order functions such as attention, memory, comprehension, planning and self-regulation. They are under the control of the prefrontal region of the brain and are the result of slow maturation. Recent evidence, obtained from brain imaging techniques, even suggests that many of the most advanced forms are only acquired in adolescence or even early adulthood.

8. Metacognition, chronological age and ADHD

Poissant (2005) conducted a study in Canada with a group of 17 students from grades 1 and 2, aged between 6.10 and 8.6, in order to assess their executive tasks and their metacognitive skill which she calls 'metacomprehension'. But one important thing that emerged from the research is that children with ADHD improve with age so that they can make better metacognitive judgments, which is not the case for normal children, whose performance remains the same even at all age stages. Contrary to the researcher's expectations, no significant global differences were found between the control and ADHD groups. The apparent delay of younger children with ADHD is compensated, progressively, as the children get older. In fact, the metacomprehension becomes similar to the normal group of children as they grow older. As a conclusion, the observed differences seem to be better explained in terms of growth rather than in terms of the metacognitive deficit. Children with ADHD will take longer than normal children to reach the optimal level of metacomprehension, thus confirming the idea of a neurodevelopmental disorder in the etiology of ADHD.

In another study by Roebbers (2017) it appears that at the end of the first year of life of children, the emergence of the components of inhibition and working memory is suggested. Children 16 months old were found to respond to 80% of the first conflict tests when given a two-choice test. Targeted behaviors of infants (aged 24-26 months) in a hide-and-seek task are among the earliest indications of emerging metacognitive skills. In contrast, children aged 2.5 years responded to about 90% of the trials when given a three-choice test, which is a much more difficult (in terms of working memory demands) version of the task. This suggests that strong improvements in executive functions occur in this early

age range. Continued improvements in inhibition tasks can also be measured in the second year of children's lives. Around age 3, children can also reliably complete a spatial conflict task. The number of errors or reaction time reflects children's ability to engage in control or inhibition. There are a variety of information or working memory tasks available, and research using such tasks has made it apparent that the capacity of 3-year-old children is, on average, about 3 to 5 items, depending on the task. Schooling itself, as well as direct instruction provided by teachers, are two other factors that influence the development of metacognitive skills in both kindergarten and school-age children. First grade students who received instruction from teachers with a strong mnemonic orientation experienced a stronger, more positive change in metacognitive skills. In older elementary school children, however, metacognitive monitoring is substantially associated with effective monitoring behavior which, in turn, positively affects academic achievement.

9. Metacognition, executive functions and reading comprehension

Alvarado et al (2011) in their research attempted to analyse participants' reading ability and metacognitive strategies as they performed reading comprehension tasks. Their main hypothesis was that those with ADHD will perform worse on metacomprehension tests since they have to invest more cognitive resources to identify words accurately and easily.

The results of the study highlighted that some of the learning issues observed in individuals with ADHD may be more related to their metacognitive functions than to simple reading comprehension, since when subjects' reading levels were equalized, those with ADHD continued to show a clear deterioration in cognitive level. Furthermore, the present study revealed that gender and age, which are relevant variables in reading comprehension, have little discriminative power in assessing metacognitive ability. The excellent sensitivity of metacognitive tests and specificity in detecting ADHD supports the hypothesis that a determinant of low reading achievement is, or is related to, a deficit in executive functions.

An innovation of the present study was to include metacognitive scales as clinical, diagnostic tools and draw inferences from them for psychoeducational intervention. Metacognitive scales (e.g., ESCOLA) make two important contributions in both educational and clinical applications. The first is related to assessment and diagnosis, because it enables us to identify strong and weak aspects of metacognition that are directly involved in reading and indirectly applied to teaching and learning. The second one has a compensatory, re-educational and restorative character. These tools facilitate intervention with specific elements, processes, and variables by providing guidelines designed to make the child "think before they act."

10. Metacognitive skills, working memory and writing in ADHD

Nelba et al. (2018) in their study compared the effects of two metacognitive interventions on writing, working memory, and behavior in students with attention-deficit/hyperactivity disorder (ADHD). The disorder was clinically diagnosed by the multidisciplinary team according to DSM-IV criteria. The first approach consisted of a combined intervention on text production and working memory while the second focused only on working memory.

The "Working Memory Program" (WMP), developed by Nunes' research team (Nunes et al., 2014), at the University of Oxford, was used to improve WM. The WMP considers metacognitive skills as a means of developing and self-monitoring, automatic attention and information use to improve WM. It includes online games with multimedia playback, each with seven levels of difficulty. The games included explicit instruction and training of metacognitive strategies for recalling information, which increased progressively, and which, at times, had to be recalled in the order in which they were presented (direct order), and, at other times, had to be recalled in the reverse order in which they appeared (indirect order). In this study, a version that was translated and adapted, with permission from the authors, for use with Brazilian students was used. The software *Trabalhando com Habilidades de Organização de Textos Harmônicos* (hereafter THOTH) was mainly used to intervene in text production.

The results show the interaction of group and time at the level of articulation and measures of writing processes, suggesting better performance in the group receiving the combined intervention. Both interventions contributed to improved behavior and academic achievement, while only the combined intervention increased the overall quality of narrative text and paragraph organization. ADHD symptom severity was investigated before and immediately after the interventions, suggesting a significant reduction in hyperactivity/impulsivity symptom intensity. In terms of writing, the greatest improvements were observed in (a) the writer's ability to integrate the key elements of a narrative with the ideas intended to be expressed in the text, as measured by articulation level; (b) narrative text structure, described by narrative elements; and (c) improved paragraph structure and use of punctuation marks.

11. Metacognition, memory and motivation in ADHD

The ability to select what is important to remember, to keep track of this information and to recall high-value items leads to the efficient use of memory. The study by Castel et al (2011) examined how children with and without attention deficit/hyperactivity disorder (ADHD) performed in a motivation-based selectivity task in which the items they had to remember were worth different point values. The present study extends the literature on WM by examining how children with and without ADHD strategically focus on and retain high-value information in WM and how this ability changes with work experience as it examines strategic control over the encoding of high-value information.

Children with combined ADHD show impairments in strategic and efficient encoding and recall of high-value items. The findings have implications for theories of memory impairment in children with ADHD and the key role of metacognition, cognitive control and value-based and importance-based directed memory ,when considering strategic memory use.

Zheng et al (2021) investigated the effect of the metacognitive regulation McR intervention in attention-deficit-hyperactivity disorder ADHD on student's astronomy knowledge acquisition and learning motivation. They argued that McR activities depend on the regulatory factors involved and their underlying intentions, which include individual student learning, cooperative learning with peers or classmates, or based on a group collaborative learning process. Insufficient McR development can create student's misperception of knowledge in a science discipline, learning difficulties, and reduce student's learning motivation.

A repeated measures analysis of variance was conducted to compare students' metacognitive ability (knowledge, experience, and regulation), science learning motivation (interest, aptitude, effort, evaluation, and pressure), and science ability (mathematical and spatial skills) pre-test, post-test, and delayed post-test for students' perceptions of instruction in different treatment groups.

Results showed that students' metacognitive ability, motivation to learn science, and science ability increased significantly at posttest and delayed posttest more than at pretest after the intervention program. The McR intervention had a positive effect on the development of metacognitive ability of students with ADHD. The greatest change was found in the knowledge domain, followed by experience and regulation. This study also showed that the group-based interactive learning format is the appropriate format for developing metacognitive awareness in students with ADHD.

Luş & Erensoy, (2020) considered that children with ADHD encounter numerous psychosocial and occupational challenges as they grow up. They argue that it is particularly important to make intervention efforts to understand executive functions, working memory and metacognition and how they relate to each other. The aim of their research was to analyse the relationship between executive functions, metacognitive awareness and symptoms of inattention and hyperactivity/impulsivity. They tried to identify which aspects of difficulties in executive functioning and/or ADHD are most relevant to metacognition in children with this disorder. No significant interaction was found between metacognitive awareness and in executive functions in children with ADHD in the present study group. Also, no significant interaction was found between intelligence level and executive functions in children with ADHD in the present study group.

12. Metacognitive skills, ADHD and mental resilience

The term "emotional resilience" is expressed as the ability to use coping skills (such as changing thought patterns, diverting attention to something else, seeking support and looking for new ways) to regulate the intense negative emotions children feel in the face of adverse life events. Metacognition and emotional resilience may be related to each other, influencing each other in a bidirectional way.

Children who have higher cognitive awareness may also have higher emotional resilience. Children in Turkey are exposed to a long and difficult battle in negative living conditions such as natural disasters (earthquakes), poverty, migration to the hinterland, crowded families and education in academic environments with many children. For this reason, Ünver, H. et al. (2022) had the primary aim of their study to compare the levels of metacognitive awareness and emotional resilience of children with ADHD with typically developing children. The secondary aim was to investigate the relationship between metacognitive awareness and emotional resilience, as well as their relationship with the frequency of adverse life events and symptoms of ADHD, anxiety and depression expressed by parents in children with ADHD.

Based on the results of the present study, metacognitive awareness and emotional resilience were lower in children with ADHD compared to the control group. Emotional resilience was found to increase as metacognitive awareness increased. Metacognitive awareness decreased in the presence of increased ADHD symptoms, anxiety and/or depression expressed by parent questionnaires... Low metacognitive awareness may negatively affect emotional resilience by causing the continuation of dysfunctional thoughts and coping styles. Emotional resilience can also mean gaining the ability to think positively, gaining emotional control, making rational decisions against challenging events, and gaining the ability to manage life's difficulties. Furthermore, as a result of this study, it was found that levels of metacognitive awareness decrease as ADHD, depression and anxiety symptoms increase. There is a correlation between metacognitive traits and levels of awareness and mental disorders, and this correlation may influence the severity of mental disorders.

13. Metacognition, executive functions, ADHD and autism

Deficits in "executive functions" (EF) executive functions are frequently observed in autism spectrum disorder ASD (ASD) and attention deficit hyperactivity disorder (ADHD). The purpose of the study by Panerai et al (2016) was to evaluate the performance of strains of children with ASD and ADHD with comparisons between groups as well as in comparison to a control group.

The results showed a large overlap of dysfunctions in terms of Executive Functions in Developmental Disorders and ADHD and were not indicative of the presence of two truly distinct Executive Function profiles. However, in ADHD, a more severe deficit was found in the inhibition of the strong response (affective/motor). Children with ADHD performed worse overall, revealing impairments in both categorical and phonemic fluency compared to typical, whereas children with ADHD showed impairments only in the fluency category.

14. Metacognition, ADHD, play, games and ICTs

Tamm & Nakonezny (2015) conducted a small randomized trial in a sample of young children carefully diagnosed with ADHD using the Executive Functions training program. Specifically, this study examined whether directed play activities affected functioning related to ADHD symptomatology and Executive Functions. The initial hypothesis was that there would be improvements in Executive Function ratings as well as ADHD symptomatology for the group receiving training compared to the control group.

Encouragingly, children's Adaptive and Emotional Regulation scores were in the normal range ($T < 60$) after the intervention as was their ability to make transitions, tolerate change, problem solve flexibly and switch attention. Significant improvements were also observed for inattention ratings, demonstrating the potential for the intervention to also affect ADHD symptoms. It appears that a program using play-based activities that target aspects of EF, when administered in a structured manner by parents, is a promising approach to improving cognitive ability and inattention in young children with ADHD. The benefits of this type of intervention may be long-lasting and some benefits may not be apparent until long after the initial intervention.

Finally, it's critical to emphasize the beneficial and influential role that all digital technologies play in the field of education in general as well as in metacognitive and executive functions' education. Mobile devices (21-24), a range of ICT apps (25-44), AI & STEM ROBOTICS (45-49), and games (50-52) are examples of the technologies that facilitate and improve educational processes including evaluation, intervention, and learning. Additionally, the use of ICTs in combination with theories and models of metacognition, mindfulness, meditation, and the development of emotional intelligence [53-79], speeds up and improves educational practices and results, especially for students with ADHD.

15. Conclusion

Working memory and ADHD are two very important cognitive skills that are linked but have been studied separately. The articles present neuroscientific aspects of working memory, ADHD and the relationship between them. Working memory plays an important role in the control of perceptual attention. Cognitive skills serve as general tools for retrieving and managing knowledge in a specific domain. For people to move up the Knowledge Pyramid it is necessary to develop metacognitive skills, survival, growth and self-awareness strategies.

Metacognitive ability plays a very important role in Dyslexia and Autism in addition to ADHD. It greatly affects reading ability, writing, motivation and mental resilience. Contemporary interventions promote and focus on developing

alternative methods and approaches to skill learning. This increases working memory and metacognitive ability, two very important parameters for the functioning of children with ADHD.

This article demonstrated the important role of working memory and metacognitive assessment for students with ADHD. We hope to provide additional motivation for readers to investigate further.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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