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Time Perception is a Focal Symptom of Attention-Deficit/Hyperactivity Disorder in Adults

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Attention-Deficit/Hyperactivity Disorder (ADHD) is classically associated with symptoms that include inattentiveness, hyperactivity, and impulsivity together with a variety of other observable externalized symptoms. ADHD has also been associated with specific internalized cognitive symptoms, including restlessness and emotional impulsivity. This disorder has been recognized as a lifelong condition and can be recognized by a variety of unique cognitive phenomena. In addition to the frequently ignored affective symptoms exhibited by individuals diagnosed with ADHD, problems with time perception have been noted, although these are considered to be secondary issues. Temporal shifts in cognitive processing, however, may be at the very root of ADHD-related symptoms, given the importance of coordinated signal translation in the construction of behavior. In this review, we consider the evidence that suggests that differences in time perception are a central symptom in adults with ADHD. Some of these differences include the feeling of time moving faster, which causes difficulties in prospective time tasks and inaccuracies in time estimation tasks. We analyze the literature from both neurological and psychological perspectives and include an assessment of tools that can be administered via computer to measure time perception. We also suggest several computer-based methods that might be used to address problems with time perception in both children and adults. We strongly recommend the inclusion of ADHD symptoms associated with time perception in the next revision of the Diagnostic and Statistical Manual of Mental Disorders (DSM) published by the American Psychiatric Association.

Keywords: **Attention Deficit Disorder with Hyperactivity • Impulsive Behavior • International Classification of Functioning, Disability and Health**

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Background

Attention-deficit/hyperactivity disorder (ADHD) is a lifelong neurodevelopmental condition that has been reported in all age groups. ADHD has been identified primarily in boys and young men, due to a possible gender bias with respect to its diagnosis. The most common symptoms of ADHD are impulsivity and inattention. ADHD is also characterized by other externalized behaviors, such as interrupting others during conversations, physical restlessness, and anger reactivity. These symptoms have been used to define categories of ADHD, which include patients who are predominantly inattentive (ADHD-I), patients who are predominantly hyperactive and/or impulsive (ADHD-HI), and patients exhibiting combined symptoms (ADHD-C). The hyperactive presentation is more common in childhood ADHD, while the inattentive and combined presentation is reported more frequently in adults.

The diagnosis of ADHD is based on observed behaviors that have been evaluated by mental health professionals. The diagnosis also relies on assessments provided by parents, teachers, or legal guardians of potentially affected children and self-reported questionnaires based on present and past childhood symptoms that are administered to adults [1]. Although not mentioned as diagnostic criteria in the most recent version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) of the American Psychiatric Association, affected individuals also exhibit affective symptoms, including anxiety, anger, and emotional dysregulation. We note that differences in time perception are also among the most significant aspects of ADHD [2,3].

ADHD is frequently treated with medications that include psychostimulants. Medication is typically administered together with behavioral therapy. This therapeutic approach has resulted in improvements in all age groups both with respect to central (ie, inattention) and secondary symptoms (ie, inaccurate perception of time) [4]. However, the clinical description of ADHD as it is currently formulated does not provide a full understanding of the disorder in light of recent research, as it focuses only on primary symptoms and does not consider critical secondary characteristics, such as time perception. Other models have been explored in an attempt to explain secondary ADHD symptoms that are not included in traditional diagnostic criteria. For example, Barkley [5] suggested that differences in executive functioning in the prefrontal cortex may be an important aspect of ADHD and may explain differences in time perception reported among children and adults with this disorder. Similarly, Sonuga-Barke and colleagues [6] introduced a triple pathway model in which temporal processing, inhibitory control, and delay-related deficits were perceived as independent neuropsychological components in patients with ADHD.

Smith and colleagues [7] identified problems with time perception as a central feature of childhood ADHD. It is important to recognize that most of the research on time perception and ADHD has been conducted on children because, until recently, ADHD was recognized as a disorder only present in childhood [8-10]. Nonetheless, recent findings suggest that some aspects of time perception may also be major problems in adults with ADHD [11]. A recent study that was conducted on a small cohort of young adults revealed definitive anomalies with respect to time perception that were similar to those seen in children [12]. Based on our observations and these recent findings, we believe that differences in time perception should be viewed as a central symptom and a core aspect of the diagnosis of ADHD in adults. In this review, we present findings that suggest that altered time perception may be an important component of adult ADHD based on previous studies conducted primarily in children.

Time Perception and ADHD

Time perception is the subjective experience of the passage of time and the process of arranging one's life according to an inner cognitive clock. Many models have been introduced in the attempt to characterize mechanisms associated with human time perception [13]. Our ability to experience time is highly complex and multifaceted; these observations contribute to the methodological differences used in time perception research.

A variety of experimental tasks are used to measure time perception. The most common tasks that are used in research on time perception and ADHD involve prospective or retrospective time estimation [14]. In studies involving prospective time estimation, subjects are asked to perform tasks and are told that they will be asked to estimate the time required once the tasks have been completed. In studies involving retrospective time estimation, subjects are asked to perform tasks and afterward are asked to estimate the time required for their completion [14]. Differences in retrospective time estimates are observed among patients diagnosed with ADHD even when compared to those with other psychiatric disorders [15].

Time monitoring is another important part of time perception that is frequently altered in individuals with ADHD. For example, children without ADHD tend to increase time-monitoring activities in a final interval of a timed task or event. However, individuals diagnosed with ADHD primarily as children appear to be responding to a more rapid "inner clock" and thus have the tendency to be inaccurate and to display impulsive behaviors while performing the same tasks [8].

Based on semi-structured interviews and observation, Nielsen [16] suggested that ADHD might be considered as a "matter of difference in temporal experience and rhythm."

Prospective memory processing also seems to be affected in individuals diagnosed with ADHD, which may have a direct impact on time perception among those with ADHD. Prospective memory, which is the ability to remember activities that are to be performed in the future (eg, parents needing to pick up a child from kindergarten), has also been assessed in research and developing interventions to address issues associated with ADHD and time perception [17]. Children with ADHD tend to perform poorly when asked to reproduce the duration of a task or stimulus that had been presented previously. These differences in time perception were not caused by intellectual disabilities or problems with working memory [11].

Processing speed is another cognitive factor that is altered in individuals diagnosed with ADHD, most notably among those with the inattentive-type presentation. In these cases, affected individuals take longer to assess and complete simple tasks. Processing speed is measured by various psychometric assessments, including the Wechsler Intelligence Scale for Children (WISC)-IV and the more recent WISC-V tests [18]. Individuals with more impulsive presentations of ADHD are frequently hampered by the need for stimulation on seemingly boring tasks such as computer-assisted time perception tests rather than with issues associated with processing speed. Smith and colleagues [7] have suggested that alterations in time perception are both concrete and unique aspects of childhood ADHD.

Neurological Aspects of Time Perception in ADHD

Time perception and time management are crucial for complex cognition and effective functioning in everyday life. The functional, timely coordination of stimuli from the external environment (bottom-up) and internal structures (top-down) forms the foundation of action generation. Time-related shifts in cognitive processing, thus, can have a great impact on the formation of abnormal behavior. Time perception can be affected by numerous neurological and interoceptive factors. No single brain region has been identified as responsible for time perception. This function appears to be dispersed throughout the central nervous system and is intrinsically associated with brain connectivity and communication. There seem to be some implicit differences in the mechanisms underlying time perception and time estimation. Time perception has been attributed to brain activity in the basal ganglia and motor centers, while time estimation is more closely associated with the prefrontal cortex and is dependent on dopaminergic pathways [19]. Time distortions have been reported in disorders known to involve dopaminergic signaling, including schizophrenia and Parkinson's disease as well as ADHD. The drugs used most commonly to treat the symptoms of ADHD include stimulants (eg, amphetamines and methylphenidate) that act on dopaminergic pathways and

have normalizing effects on time-related tasks [20]. Frontal lobe activity is connected to the capacity to carry out time estimation tasks as well as with attentiveness; thus, the connection between ADHD symptoms and time perception is perhaps not all that surprising [21]. Brain areas that have been associated with time perception include the left prefrontal cortex, the anterior cingulate, and the supplementary motor area. Results from a magnetoencephalography (MEG) experiment performed by Wilson and colleagues [22] that featured individuals with ADHD before and after medication revealed increased activity in the prefrontal cortex, the anterior cingulate, and the supplementary motor area and superior time perception after taking medication. Similar abnormalities were observed by this group in a MEG study that focused on the functionality of the Default Mode Network (DFM), which is a central hub in the brain that is active during self-reflection and mind wandering and, thus, is responsible for the inhibition of bottom-up attention [22]. Disturbed connectivity within and between regions of the DFM, specifically the medial prefrontal cortex and the posterior cingulate cortex, were uncovered, which may further support the attention-related time estimation anomalies seen in ADHD. This study also confirmed the improved activity, especially in the medial prefrontal cortex, upon administration of stimulant medication [23].

One of the main problems associated with time perception that has been widely noted among individuals diagnosed with ADHD is time estimation. This problem can lead to significant difficulties in assessing the amount of time that has passed or the amount of time that might be required to perform a specific task. This impairment was noted to have a significant impact on academic achievement in college students with ADHD when compared to that of their unaffected peers [12]. It is important to recognize that the lower levels of academic achievement observed in student with ADHD are not attributable to a lower intelligence quotient (IQ) but may be largely due to issues such as differences in time perception. These differences can be linked to issues that involve brain connectivity, such as abnormal frontoparietal coupling for specific stimulus-response tasks and reduced fronto-cerebellar connectivity during time discrimination tasks [24]. The strong interconnection between time perception issues, neurological differences, and behavioral outcomes has led some researchers to emphasize the importance of treating disorders of time perception as a central rather than a secondary issue in ADHD. In their recent review of neuroimaging studies, Noreika and colleagues [25] discussed the pronounced differences in perception and functioning as well as (as mentioned above) a notable normalization of these anomalies in response to administration of drugs (eg, methylphenidate). The authors also emphasized the need to differentiate differences in time perception from issues associated with working memory. They also noted that impulsivity, which has been recognized as a central symptom of ADHD, is also most likely connected to issues related to time perception.

Furthermore, Walg and colleagues [15] considered the possibility that processing speed, time estimation, and time discrimination might be used to differentiate between authentic versus “pseudo” ADHD in childhood psychiatric assessments and might be introduced as addenda to tests used to determine intellectual abilities (eg, the WISC-IV). Of note, results from previous studies that used the WISC-IV to evaluate adolescents with ADHD revealed that, despite similar IQs, lower test scores among those with ADHD could be directly attributed to slower processing speeds [9]. This finding is important to consider, as differences in time perception in children with ADHD were recently attributed to impulsivity rather than problems with processing speed [26]. Many of the cognitive distortions identified in children with ADHD and other neurodevelopmental disorders have led to the development of software and computer programs that can be used for assessment and skills training. Results from a recent study revealed that specific programs that were developed to improve working memory resulted in a direct enhancement of the coupling of the frontoparietal network with other task-oriented regions of the brain. This phenomenon might be considered directly as it relates to ADHD and similar disorders [27].

Computer-Based Diagnostics and Training Tools

The use of modern technology in psychological assessments and therapy has resulted in many benefits, including access and availability at all times of day, the possibility of using services at home, and more precise control of individual activities during the assigned tasks. The time perception tests that were formerly carried out on paper in the presence of a clinician can be administered via a computer and even, via Smartphone. Several important differences have been reported in studies of individuals with ADHD that were carried out using computer-assisted time perception tests. For example, numerous reports have documented poor performance by individuals with ADHD when evaluated with computer-assisted time perception tasks, although this was not the case when affective stimuli were included (eg, pictures with facial expressions), as this may serve to focus and maintain their attention on the task at hand. Interestingly, individuals with ADHD outperformed their non-ADHD counterparts on tests of time perception that included affective stimuli [28]. The results of this and similar studies might be used to develop critical diagnostics and might also play a helpful role in symptom management. Use of the computerized progressive attentional training (CPAT) program has resulted in promising outcomes for children and adolescents with ADHD who are undergoing training for sustained attention and executive functioning; the CPAT program is based on incremental increases and provides more challenging attention-related tasks along with specific point rewards [29]. In their recent review of evidence-based approaches focused on the use

of telemedicine in ADHD, Benyakorn and colleagues [30] identified computer games that sustained attention as an effective therapeutic modality. The authors also identified 3 components of time perception that were altered in individuals with ADHD: motor timing, perceptual timing, and temporal foresight. Although there are effective computer programs that address temporal foresight, including those that teach people how to use calendars as reminders for upcoming activities, there are currently no programs that combine all 3 of these aspects. This might be addressed sometime in the near future.

One recent example of the use of information technology for the diagnosis and management of ADHD in young children is the computer game known as Timo’s Adventures, which can be accessed at [Link]. The interactive game assesses reaction times, time estimation, and attentiveness, and is an effective method for evaluating critical cognitive abilities in children with ADHD, including those that are frequently compromised (ie, time estimation, discrimination, and prospective memory tasks) [31]. Results of a meta-review of data published since 2020 revealed that specifically-designed video games can be very effective for the assessment and management of ADHD symptoms [32]. This is a constructive approach toward working with this patient cohort. Children and young adults with ADHD tend to have very high rates of video game use, a finding that can be directly connected to disorders in impulsivity and the addictive nature of these games. Addictive use of these games might serve as an effective feedback loop, as symptoms of ADHD drive impulsive gaming, while impulsive gaming results in worsening ADHD symptoms. Thus, constructive games might be a strong and effective therapeutic tool for the diagnosis and treatment of these individuals [33,34]. Indeed, approaches to ADHD and other neurodevelopmental disorders through the use of video games and other interactive software are currently at the forefront of pediatric practice. As just one example, the inability to control one’s eye movements, a prominent characteristic of children with ADHD, can be measured using specifically-designed video games [34].

Conclusions

Numerous observations have documented a connection between disordered time perception and childhood ADHD. Based on these findings, we have suggested that additional studies might be designed that aim to investigate potential connections between time perception and adult ADHD. We previously noted the importance of considering multiple aspects of time perception, including the Zimbardo Time Perspectives Inventory, in order to integrate time with diagnostics and treatments of ADHD symptoms [35]. We had previously noted important differences in time perspectives in a nationwide sample of Czech adults with ADHD. Given our preliminary results,

we believe that a significant expansion of time perspectives and measurements of time perception is needed for a more complete assessment of ADHD and to devise better methods for its treatment [36]. It is also important to note that research into the use of computer-based assessments has yielded contrasting results, with some researchers finding that a purely digital approach to adolescents with ADHD was only minimally effective [37], while others reported positive results using interventions crafted to resemble video game-like programs [38]. To the best of our knowledge, there are no comprehensive

diagnostic tools that include ADHD diagnostic criteria and that can be used to diagnose executive function deficits, such as differences in time perception. Any tool of this nature should incorporate factors associated with time perception (eg, time reproduction, time production, and motor timing) and should also include subjective questionnaires designed to assess time-related difficulties in everyday life. In this realm, we believe that computer-assisted time-based tasks might be quite useful as additional tools used for diagnosing and managing ADHD, most notably in adults.

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