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Temporal processing impairment in children with attention-deficit-hyperactivity disorder

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ABSTRACT

The current study aimed to investigate temporal processing in Chinese children with Attention-Deficit-Hyperactivity Disorder(ADHD) using time production, time reproduction paradigm and duration discrimination tasks. A battery of tests specifically designed to measure temporal processing was administered to 94 children with ADHD and 100 demographically matched healthy children. A multivariate analysis of variance (MANOVA) and a repeated measure MANOVA indicated that children with ADHD were impaired in time processing functions. The results of pairwise comparisons showed that the probands with a family history of ADHD performed significantly worse than those without family history in the time production tasks and the time reproduction task. Logistic regression analysis showed duration discrimination had a significant role in predicting whether the children were suffering from ADHD or not, while temporal processing had a significant role in predicting whether the ADHD children had a family history or not. This study provides further support for the existence of a generic temporal processing impairment in ADHD children and suggests that abnormalities in time processing and ADHD share some common genetic factors.

1. Introduction

Temporal information processing refers to the analysis of stimulus time patterns. Central systems that decode temporal information and record time series (Mauk & Buonomano, 2004) allow perception and organization of sequences of events and actions and facilitate anticipation or prediction of when future events will occur (Toplak, Dockstader, & Tannock, 2006). A number of theoretical models of how the brain organizes and stores events for the future use have been suggested, and the 'internal clock' model has been widely accepted (Matell & Meck, 2000, 2004). Within this model, Zakay has emphasized the role of attention in temporal processing and proposed an "Attentional-Gate Model" (Zakay, 2000).

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Attention deficit hyperactivity disorder (ADHD) is a cognitive developmental disorder characterized by levels of inattention, hyperactivity, and impulsivity that are age-inappropriate. Growing evidence links ADHD to problems in several aspects of temporal information processing, including duration discrimination, duration reproduction, and finger tapping and it has been suggested that deficits in temporal information processing contribute to poor cognitive and behavioral outcomes (Toplak et al., 2006). However, temporal information processing is a multidimensional construct that has spurred the development of a wide variety of methods designed to quantify its component abilities. Consequently it is difficult to integrate findings across studies of temporal information processing in the field of ADHD.

Two models offer an explanation of how temporal processing might be impaired in ADHD. The most common, behavioral inhibition, argues that poor inhibitory control and interference affect working memory, which subsequently affects temporal processing (Barkley, 1997). In contrast, the delay aversion concept, considers the primary deficit in ADHD is a preference for immediate reward or an aversion to delay (Sonuga-Barke, 2003) rather than a deficit in their working memory. Interconnected circuitry through frontal, striatal, parietal, temporal and cerebellar regions that are involved in time perception, inhibitory control and reward-related behavior have consistently been implicated in the pathophysiology of ADHD (Carmona et al., 2011; Cubillo, Halari, Giampietro, Taylor, & Rubia, 2011a; Cubillo, Halari, Smith, Taylor, & Rubia, 2011b; Posner et al., 2011; Scheres, Tontsch, Thoeny, & Kaczkurkin, 2010; Sonuga-Barke, Bitsakou, & Thompson, 2010), and empirical evidence has shown that children with ADHD have deficits in time production (van Meel, Oosterlaan, Heslenfeld, & Sergeant, 2005), time reproduction (Bauermeister et al., 2005; Carelli, Forman, & Mantyla, 2008; Gonzalez-Garrido et al., 2008; Kerns, McInerney, & Wilde, 2001; Meaux & Chelonis, 2003; Rommelse, Oosterlaan, Buitelaar, Faraone, & Sergeant, 2007; Smith, Taylor, Rogers, Newman, & Rubia, 2002; Sonuga-Barke, Saxton, & Hall, 1998; Toplak, Rucklidge, Hetherington, John, & Tannock, 2003), and motor timing tasks (Rubia, Noorloos, Smith, Gunning, & Sergeant, 2003; Rubia, Taylor, Taylor, & Sergeant, 1999). However, there is no consensus on the performance of time discrimination tasks in ADHD (Radonovich & Mostofsky, 2004; Toplak, Jain, & Tannock, 2005; Yang et al., 2007) and many previous studies of temporal processing in ADHD have been limited by small sample sizes and did not include subtypes of ADHD, e.g., ADHD with inattention, and ADHD with combined hyperactivity and inattention (Richard, Balentine, & Lynam, 2001).

Time discrimination in ADHD might depend upon the length of time interval examined. Some have suggested that the processing of short intervals (less than 1 s) may rely on an internal timing mechanism or cerebellar process, whereas longer intervals (1 s or greater) may access working memory processes (Ivry, 1996; Mangels, Ivry, & Shimizu, 1998). The attentional-gate model predicts that when intervals exceed the range that is relevant for typical sensory events, greater demands is placed on other cognitive functions such as sustained attention and working memory (Mangels, Ivry, & Rapp, 2001). In a previous study (Yang et al., 2007), children with ADHD were asked to discriminate between 2 sets of time interval: one was less than 1 s, the other longer than 1 s. We found that children with ADHD had significantly higher discrimination thresholds than healthy controls, and there was an interaction effect between group and duration. Children with ADHD were also less accurate in discriminating the duration of stimuli. Working memory was associated with the discrimination threshold at a duration of 800 ms after controlling for FIQ in ADHD children.

Discrimination of brief intervals has been represented as a candidate endophenotype for ADHD (Himpel et al., 2009). Since twin and family studies indicate that attention problems have a major genetic component explaining up to 80% of the total variance (van't Ent et al., 2009), confirming a temporal processing endophenotype for ADHD could offer a useful translational tool for further investigation of genetic factors. Therefore we planned a study to replicate and extend our previous findings and investigate whether subtype of ADHD and family history differentially impacts upon temporal processing in ADHD.

We also wished to examine multiple aspects of temporal processing capacity in children with ADHD. For example, the difficulty children with ADHD have in time reproduction task might be explained by an inhibition difficulty rather than a 'pure' temporal processing anomaly (Sonuga-Barke, Saxton, & Hall, 1998). Therefore, in the present study, we employed two time reproduction tasks to rule out the impact of inhibition deficit. One had two conditions: the signaled condition (SC) to control for response inhibition and the unsignaled condition (USC) to reproduce time. Sonuga-Barke et al. have argued that if the subject can respond correctly in the SC while performing poorly in the USC, any deficit could not be explained by inhibition impairment and was due to a temporal processing impairment (Sonuga-Barke et al., 1998). However the latter result has been questioned because the visual structure of the signals used in SC and USC were different (Smith et al., 2002; Sonuga-Barke et al., 1998). In the current study we adapted this paradigm to minimize any visual structural difference in the task conditions.

Another possible confound in the study of time perception in ADHD is the impact of motor demands. The organization of motor output is heavily dependent on the representation of time in the brain, and motor difficulties also characterize individuals with ADHD (Carte, Nigg, & Hinshaw, 1996; Riordan et al., 1999). Moreover, time perception and motor coordination share the same underlying neural system, which is predominantly a right hemispheric fronto-striato-cerebellar network (Smith et al., 2003). Unlike time production and reproduction tasks, the duration discrimination tasks minimize the motor demands of timing performance (Carte et al., 1996; Riordan et al., 1999) and have no speed requirement, therefore time discrimination was also examined in the present study.

Based on previous findings, we hypothesized that children with ADHD would have significant differences in multiple tasks of temporal processing compared to typically developing control children. We also predicted that children with ADHD (probands), with a family history of ADHD, would perform more poorly in temporal processing tasks than those without a family history.