Adjustment of Time Perception in the Range of Seconds and Milliseconds: The Nature of Time-Processing Alterations in Children With ADHD

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Adjustment of Time Perception in the Range of Seconds and Milliseconds: The Nature of Time-Processing Alterations in Children With ADHD

Marco Walg[1], Johannes Oepen[2], and Helmut Prior[3]

Abstract

Objective: The nature of time-processing alterations in ADHD was assessed by means of duration judgments and temporal set-shifting tasks lasting several seconds and milliseconds. **Method:** After training with visual sample stimuli for long and short durations, 31 children with ADHD and 29 controls estimated the durations of test stimuli. During testing, the temporal context was systematically varied by shifting the duration of stimulus sets to longer or shorter intervals. **Results:** Children with ADHD generally overestimated the durations of stimuli on the seconds scale. Their assessment of stimuli on the milliseconds scale can be characterized as less-efficient adaptations to new temporal sets alongside otherwise normal discrimination performance. **Conclusion:** Findings support a pure time perception alteration in ADHD. In addition, results provide first evidence that difficulties in mental set-shifting, which have been reported for other tasks, extend to temporal processing in children with ADHD. *(J. of Att. Dis. 2012; XX(X) 1-XX)*

Keywords

ADHD, time processing, temporal set-shifting

Inattention, impulsivity, and hyperactivity are the main symptoms of ADHD (American Psychiatric Association, 1994). These symptoms may be related to a primary deficit in executive functions, which allow for maintaining appropriate problem-solving sets (Welsh & Pennington, 1988) as well as for optimal decision making and goal-directed behavior in changing situations (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Executive functions include response inhibition, interference control, reasoning, hindsight, anticipation, working memory, set-shifting, and sense of time (Barkley, 1997; Pennington & Ozonoff, 1996). As the capability of timing is rather crucial to such feats (Barkley, 1997), recent reports that abnormalities in timing functions may represent a fundamental component of impulsiveness in ADHD suggest that a more detailed understanding of altered temporal processing in ADHD is required (Rubia, Halari, Christakou, & Taylor, 2009).

A possible link between the processing of time and ADHD is supported by studies on their neural correlates. In particular, a smaller right anterior frontal region (Castellanos et al., 1996; Filipek et al., 1997), a smaller cerebellum (Castellanos et al., 1996), and size reductions in the basal ganglia, especially in the globus pallidus (Aylward et al., 1996) and the left caudate nucleus (Filipek et al., 1997; Hynd et al., 1993), are reported anatomical alterations in ADHD. Furthermore, there is evidence of diminished cerebral blood flow in parts of the frontal lobe and in the basal ganglia (Lou, Henriksen, & Bruhn, 1984; Lou, Henriksen, Bruhn, Börner, & Nielsen, 1989) and of reduced dopaminergic modulation of neurons in the prefrontal cortex (Forssberg, Fernell, Waters, Waters, & Tedroff, 2006; Henze, González-Burgos, Urban, Lewis, & Barrionuevo, 2000). Notably, several of the brain structures affected by ADHD coincide with the presumptive neural correlates of temporal processing.

The processing of temporal information involves a whole set of brain structures, and apparently there are different networks concerned with temporal cues in the range of seconds and milliseconds (Buonomano & Karmarkar, 2002; Ivry & Spencer, 2004; Karmarkar & Buonomano, 2007; Maquet et al., 1996; Mauk & Buonomano, 2004; Nenadic et al.,

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2003; Rammsayer, 1989, 1999; Rao, Mayer, & Harrington, 2001; Rubia & Smith, 2004). Although the processing of time stimuli in the range of seconds involves cognitive processes, attentional resources (Brown & Merchant, 2007), and working memory (Fortin & Breton, 1995), it is suggested that dealing with durations shorter than approximately 500 ms does not require cognitive control (Rammsayer, 1992, 1999; Rammsayer & Lustnauer, 1989). In summary, children with ADHD appear to differ in the brain structures involved in temporal processing, and as different networks for durations on the seconds scale and milliseconds scale are therefore likely, children with ADHD may have a different pattern of temporal processing to stimuli of durations longer and shorter than 500 ms.

Despite increasing evidence for altered temporal processing in ADHD (Toplak, Dockstader, & Tannock, 2006), the specific nature of such alterations is insufficiently understood. In discrimination tasks in which participants had to compare the duration of two similar time intervals, individuals with ADHD made more errors than control participants (Rubia, Noorloos, Smith, Gunning, & Sergeant, 2003) and had a higher discrimination threshold in the range of seconds as well as in the range of milliseconds (Smith, Taylor, Rogers, Newman, & Rubia, 2002; Toplak, Rucklidge, Hetherington, John, & Tannock, 2003; Toplak & Tannock, 2005). In studies where participants had to produce or reproduce durations, individuals with ADHD were less accurate and made larger errors than individuals without ADHD (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Barkley, Koplowitz, Anderson, & McMurray, 1997; Barkley, Murphy, & Bush, 2001; Bauermeister et al., 2005; Cappella, Gentile, & Juliano, 1977; González-Garrido et al., 2008; Kerns, McInerney, & Wilde, 2001; McInerney & Kerns, 2003; Meaux & Chelonis, 2003; Mullins, Bellgrove, Gill, & Robertson, 2005; Plummer & Humphrey, 2009; Rommelse, Oosterlaan, Buitelaar, Faraone, & Sergeant, 2007; Toplak et al., 2003; West et al., 2000).

An interesting explanation for the phenomenon in which children with ADHD tend to underestimate time intervals in production and reproduction tasks (Luman et al., 2009; Luman, Oosterlaan, & Sergeant, 2008; Sonuga-Barke, Saxton, & Hall, 1998) is that children with ADHD might be endowed with an internal clock that runs with a higher rate than in children with typical development (Rubia, Taylor, Taylor, & Sergeant, 1999; Sonuga-Barke et al., 1998). Alternatively, working memory deficits might cause differences in time reproduction (Barkley, Murphy et al., 2001; Bauermeister et al., 2005), and there are studies that support a role of working memory in reproduction performance in children with ADHD (Bauermeister et al., 2005; Smith et al., 2002). Finally, impulsivity might lead to differences in time reproduction (Sonuga-Barke et al., 1998). Impatience is characteristic of the impulsiveness of individuals with ADHD, and they are "notorious for taking shortcuts" (Barkley, 1998, p. 59) and responding prematurely.

If the internal clock in children with ADHD runs faster, things could be just the other way round than is often assumed. Their impulsivity could arise from the fact that, from their subjective point of view, a rather long time interval has already passed. A clarification of these alternatives is crucial for understanding time-processing alterations in ADHD. In the present study, we tackled this problem by comparing time processing in children with ADHD and children in the control group under conditions where impulsivity could not bias the data (forced choice). We also explored the possibility that children with ADHD might show alterations in adjusting their internal timing processes to varying temporal contexts.

The role of the temporal context is suggested by models of relational psychophysics (Sarris, 2004) and would be consistent with temporal reference memory (Wearden, 2004), context effects in neural network models (Karmarkar & Buonomano, 2007), and experience-based expectancies as suggested by functional magnetic resonance imaging (fMRI) studies (Coull, 2004).

A particularly interesting question concerning children with ADHD arises from their reduced mental set-shifting capabilities in the Wisconsin Card Sorting Test (Houghton et al., 1999; Lawrence et al., 2004; Pennington & Ozonoff, 1996; Sergeant, Geurts, & Oosterlaan, 2002). The adjustment to new temporal contexts requires similar general executive functions and can thus be considered a case of temporal set-shifting. As temporal set-shifting in ADHD has not been investigated to this day, the present study is the first to address this issue.

The experimental design of our study complies with the most relevant considerations for an improved understanding of temporal processing in ADHD and its relationship to the central executive. First, we used two distinct time scales, one on seconds and one on milliseconds, to account for the likely existence of separate neural and cognitive systems for processing stimuli on each respective time scale. Second, we used temporal context shifts to address whether there are differences in temporal set-shifting. Finally, we used duration judgments with a forced two-way choice to make sure that possible differences between ADHD children and controls cannot be caused merely by impulsivity but reflect true differences in the perception and memorization of temporal stimuli.

Method

Participants

A total of 60 children between 10 and 14 years of age participated in the study. All participants were patients in a children's rehabilitation hospital. The ADHD group comprised 31 children (26 boys and 5 girls; *M* age = 11.7, *SD* = 1.3) clinically diagnosed according to European guidelines (compare Taylor et al., 2004) with ADHD (combined

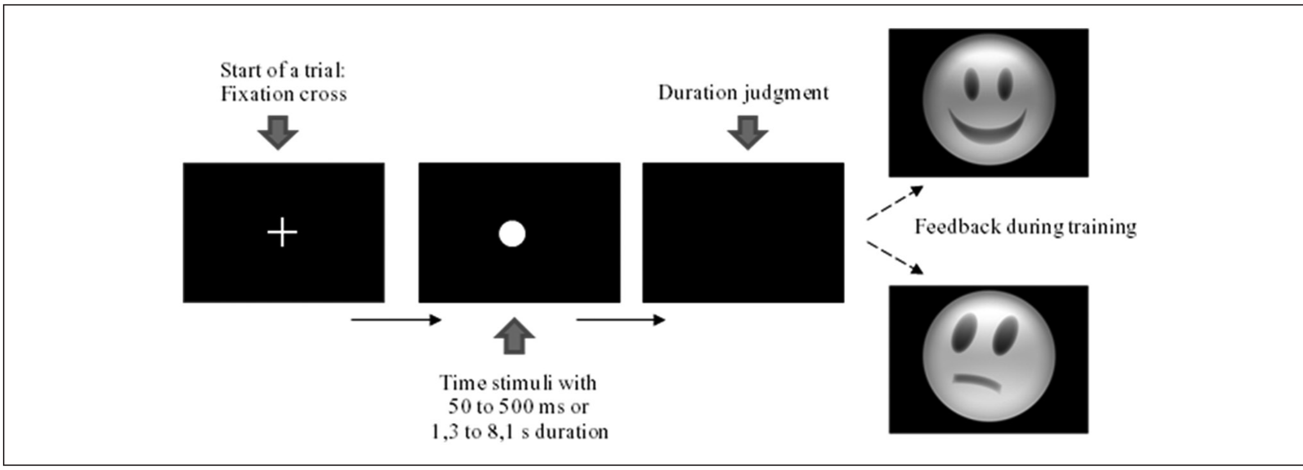

Figure 1. A sequence of one trial started with the presentation of a fixation cross
Note: A white circle is shown for the ensuing target duration, which the participant must judge as either long or short by pressing the respective key. During the training stage, participants were given positive feedback on-screen in the form of a green happy face following correct responses. Negative feedback was given in the form of a yellow sad face following incorrect responses.

subtype) by experienced pediatricians or psychiatrists. They were regarded as unmedicated, as no stimulants had been administered for at least 24 hr prior to testing. The control group comprised 29 children (19 boys and 10 girls; *M* age = 11.9, *SD* = 1.4). The participants in the control group had respiratory diseases without any known effect on cognitive functioning. Any kind of relevant comorbidity, such as affective disorders, was an exclusion criterion for either group.

The diagnosis of ADHD was confirmed for all participants using the German version of the Strengths and Difficulties Questionnaire (Goodman, 1997) and a shortened form of Conners' Rating Scales (Steinhausen, 2002). The first test was completed by the children's parents and the second one by the clinical staff. Scores for participants in the ADHD group had to be above the cutoffs for hyperkinetic symptoms, whereas scores for the control group had to be below the cutoff values for both tests. In addition, the existence of ADHD symptoms and the absence of comorbidities were checked in a structured clinical interview that assesses the diagnostic criteria for psychiatric disorders in children according to the *International Statistical Classification of Diseases and Related Health Problems, 10th Revision* (ICD-10). If the answers from children and their parents suggested the existence of any comorbidity, like affective disorder, learning disorder, or conduct disorder, individuals were excluded. Furthermore, comprehensive behavioral observations by the clinical staff were used to confirm the ADHD diagnosis. Participants' IQs were assessed using the Culture Fair Intelligence Test (CFT 20-R) (Weiß, 2006). Participants with IQs below 80 were excluded. Before the beginning of the study, children and their parents were informed in writing about the investigation, and informed consent was obtained from all participants.

Experimental Procedures

There were two individual test sessions, one with stimuli on the seconds scale and the other with stimuli on the milliseconds scale. To reduce the likelihood of carryover effects, there was a break of at least 5 days between individual sessions.

A two-alternative two-forced-choice method was applied, as it has been used earlier in related psychophysical research (Cangöz, 1999; Sarris, 2004; Sarris & Zoeke, 1985). Duration stimuli on all tests were visual (see Figure 1). At the beginning of a trial, a white fixation cross was presented in the center of a computer screen against a black background. A white circle was then shown for the target time duration. Subsequently, participants were asked to judge this stimulus as either "long" or "short" by pressing one of two buttons. Premature responses were precluded. Participants started the next trial by pressing the space key. Target time durations were presented in a balanced order.

The point of subjective equality (PSE) was assessed as a dependent variable for each participant based on the stimulus judgments. By definition, PSE is the value of a time duration that is judged with a 50% probability as long and a 50% probability as short (cf. Sarris, 2004). It reflects the time duration that can be allocated to neither of the two concurrent categories "long" or "short" by a participant, and thus the threshold between "long" and "short" judgments. The PSE takes lower values with an increasing number of "long" judgments, whereas more "short" judgments lead to a higher PSE.

Table 1. Stimulus Values and Theoretical PSE Values of the Three Test Series (C1, C2, C3)

Time stimuli in the range of seconds	1.3	1.8	2.5	3.3	4.5	6.0	8.1
Time stimuli in the range of milliseconds	50	75	110	160	235	345	500
Series C1	■	■	■	■	■		
			PSE				
Series C2		■	■	■	■	■	
				PSE			
Series C3			■	■	■	■	■
					PSE		

Note: PSE = point of subjective equality. The square symbols indicate which durations were presented in each of the test series.

An initial training stage established a temporal frame of reference and an anchoring PSE. Three subsequent test series shifted the temporal set to longer or shorter durations. During the training stage, a pair of durations was presented. If the participants judged the shorter stimulus as "short" or the longer one as "long," a green happy face appeared on the screen as positive feedback. If participants provided an incorrect response, a yellow sad face appeared (see Figure 1). The criteria for successfully completing the training module were at least 90% correct responses within 26 training trials. On the seconds scale, training stimuli were 1.3 and 2.5 s long in the ascending condition, and 4.5 and 8.1 s long in the descending condition. On the milliseconds scale, the respective durations were 50 and 110 ms in the ascending condition, and 235 and 500 ms in the descending condition.

In a subsequent series of three tests, participants were presented with stimuli of five different durations a total of 8 times, respectively. No feedback was given during this stage. Table 1 shows the sets of stimuli for the various test series. The three series were presented in either ascending (C1, C2, C3) or descending (C3, C2, C1) order. In the seconds task, as well as in the milliseconds task, the direction of set-shifting was fully balanced. Although the test was within participant in the milliseconds task, it was between participant in the seconds task to limit the duration of the session and avoid exhausting the participants' capacity to sustain attention.

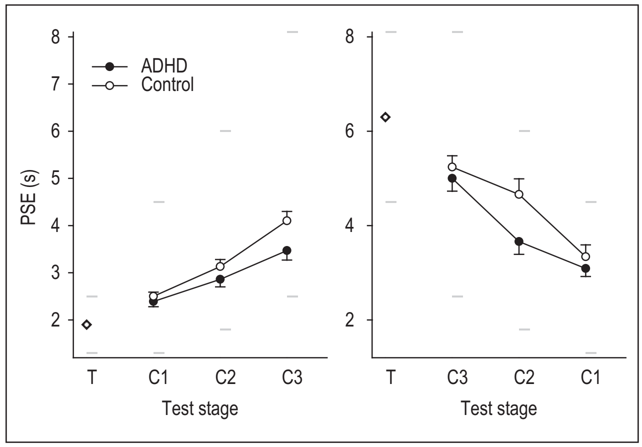

Figure 2. Results of the duration judgments on the seconds scale showing mean PSE values (with standard error) in the three test series (C1, C2, C3) under ascending and descending conditions

Note: PSE = point of subjective equality. Gray lines show the upper and lower boundaries of the stimuli durations in training (T) and in the various test series. The diamond indicates the anchored PSE of the training session, which was preset due to the contribution of only two stimuli and the presence of feedback.

Results

IQ Scores

There was no significant divergence in IQ scores between the ADHD group (*M* IQ = 105, *SD* = 13) and the control group (*M* IQ = 106, *SD* = 14; *t*-test; $t = -.29$; $df = 58$; $p = .77$).

Gender

The influence of gender was assessed for every task using an exploratory (multivariate) analysis of variance with gender as a between-participants factor. No significant gender differences were recorded in any task.

Duration Judgments on Seconds Scale

Participants from the ADHD group showed significantly lower PSE values (indicating a higher amount of long judgments) than controls in either set-shifting condition.

A total of 28 children with ADHD and 27 control participants finished the training stage successfully. In every test series (C1, C2, C3), participants of the ADHD group judged more stimuli as long than members of the control group. Lower PSE values in ADHD children (see Figure 2) prevailed in the ascending condition, $F(1, 28) = 2.79$; $p = .05$; $\eta^2 = 0.09$, as well as in the descending condition, $F(1, 22) = 3.84$; $p = .03$; $\eta^2 = 0.15$.

A main effect of the repeated measures factor PSE demonstrates that individual's judgments followed the context shift in both conditions: As Figure 2 illustrates, the PSE of both groups shifted to longer durations under the ascending condition, $F(2, 56) = 59.43$; $p < .001$; $\eta^2 = 0.68$, and to shorter durations under the descending condition, $F(2, 44) = 50.14$; $p < .001$; $\eta^2 = 0.70$. An interaction group × context series, $F(2, 44) = 3.60$; $p = .04$; $\eta^2 = 0.14$, resulted from a relatively larger shift in judgment from stimulus context C3 to context C2, followed by a smaller shift from C2 to C1 in participants with ADHD. An opposite shift in judgment was observed in the control group.

An analysis of how participants split the range of time stimuli in the two different shifting conditions showed that control participants split the range of durations into the categories, short and long, by about 33% to 66% in the ascending condition and 60% to 40% in the descending condition. The respective values in the ADHD group were 25% to 75% in the ascending condition and about 50% to 50% in the descending condition. When the direction of changes between subsequent contexts is considered, that is, the bisection in the ascending condition seen from the bottom and in the descending condition seen from the top, there is no significant difference in the control group (p = .18) in contrast to a notable difference (p < .05) in participants with ADHD. The compromise between the preceding context series and the new context series was therefore made fairly similarly in the ascending and the descending conditions by participants in the control group, whereas the judgment of participants with ADHD demonstrates an asymmetric pattern, which corresponds to the overall bias toward "long" judgments.

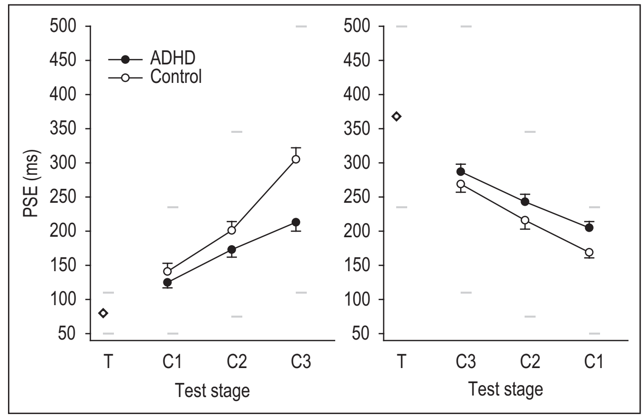

Figure 3. Results of the duration judgments on the milliseconds scale showing mean PSE values (with standard error) in the three test series (C1, C2, C3) under ascending and descending conditions

Note: PSE = point of subjective equality. Gray lines show the upper and lower boundaries of the stimuli durations in training (T) and in the various test series. The diamond indicates the anchored PSE of the training session, which was preset due to the contribution of only two stimuli and the presence of feedback.

Duration Judgments on Milliseconds Scale

Children with ADHD differed from control participants in the ascending and descending conditions; however, the direction of deviation was different for the two shifting conditions.

A total of 18 participants met the training criteria (10 control participants; 8 participants with ADHD) in the ascending condition and 42 participants (20 control participants; 22 participants with ADHD) met the training criteria in the descending condition. The frequency at which the training criteria were met did not differ between test groups in either the descending (χ^2 = .01; df = 1; p > .90) or ascending condition (χ^2 = .39; df = 1; p > .50). However, there was a marked difference between the respective conditions: Whereas 70% of the participants reached the criterion on the discrimination of 345 and 500 ms (descending condition), only 30% of the participants reached criterion of the ascending condition on the discrimination of 50 and 110 ms (Fisher's exact test, p < .001).

As no differences can be attributed to the order of the presentation, neither the descending, $F(1, 38) = 0.59$; p = .45, nor the ascending condition, $F(1, 14) = 0.07$; p = .79 (ANOVA with PSE as a repeated measure and the order of presentation as a between-participant factor), these data were pooled for further analysis. In terms of PSE, there was a main group effect in the ascending condition, $F(1, 16)$ = 9.21; p < .01; η^2 = 0,37, and descending condition, $F(1, 40)$ = 4.31; p = .04; η^2 = 0,10. In the ascending condition, children with ADHD judged more stimuli as long than control children, leading to lower PSE values. In the descending condition, participants of ADHD group judged fewer stimuli as long, resulting in higher PSE values in comparison with control group (Figure 3).

In addition, there were context effects in the descending condition, $F(2, 80)$ = 55.81; p < .01; η^2 = 0,58, and ascending condition, $F(2, 32)$ = 71.02; p < .01; η^2 = 0,82: Over the course of the three test series, PSE values shifted to longer durations in the ascending condition and to shorter durations in the descending condition. The interaction of group factor with repeated measures factor (PSE course) in the ascending condition, $F(2, 32)$ = 7.87; p < .01; η^2 = 0,33, shows that the shifting of PSE values progressed faster in control participants than in participants with ADHD. There was no significant interaction in the descending condition, but adaptation to new temporal sets was less efficient in participants with ADHD than in the control group. For the third new set, almost all stimuli were rated as short by children with ADHD.

An analysis of how participants split the range of durations in the different context conditions again demonstrated a notable difference between the ADHD group and the control group. The control group's judgments were close to the arithmetic mean throughout, with no difference between the ascending and descending conditions, $F(1, 28)$ = 0.41; p = .53, whereas a difference was observed in the ADHD group, $F(1, 28)$ = 27.66; p < .0001. When the direction of change is considered (from the bottom in the ascending condition and from the top in the descending condition), a split in the duration ranges in a one-third to two-third ratio is evident among participants with ADHD (35% vs. 38%), with no significant difference in either case, $F(1, 28)$ = 0.58; p = .45. Thus, control participants adjusted to a new set of durations in a balanced manner and were not influenced by the preceding temporal set. In contrast, in participants with ADHD, the mean of the new range of durations represents a compromise between the current and the preceding context.

Discussion

Significant context effects were found in all tasks. Time processing in participants with ADHD differed from that of control participants on the seconds scale as well as on the milliseconds scale. For durations on seconds scale, individuals with ADHD perceived time intervals as longer than control participants did. This supports the hypothesis that a faster internal clock is present in participants with ADHD. On the milliseconds scale, individuals with ADHD followed shifting contexts less efficiently than control participants. Although updating in the control group was fast and only based on the temporal set at hand, there was a carryover from preceding temporal sets in participants with ADHD. Overall, the manner in which participants coped with repeated adjustments to temporal frames of reference suggests an alteration in temporal set-shifting in ADHD.

Evidence of a Faster Internal Clock in Participants With ADHD

The results provide strong support for the presence of a faster internal clock in participants with ADHD on the seconds scale. In this time scale, there was a persistent bias in the ADHD group whereby individuals judged time intervals as longer. In contrast to the results from production or reproduction tasks, the current findings cannot be explained by deficits in response inhibition or working memory deficits. If the temporal frame of reference is established during the training module and earlier test series were to have been less stable in participants with ADHD (prediction of a working memory deficit hypothesis), then participants with ADHD should have had a faster adjustment to new temporal contexts regardless of the direction of context shifts. Although participants of the ADHD group adapted more quickly than control participants in the descending condition, they did not do so in the ascending condition. Therefore, findings on the seconds scale support the presence of a faster internal clock in participants with ADHD. This is consistent with other evidence (e.g., Pollak, Kroyzer, Yakir, & Friedler, 2009), which suggests that alterations in timing can be separated from compromised working memory or delay aversion.

Alterations in Temporal Set-Shifting in Children With ADHD on Milliseconds Scale

In contrast to judgments on the seconds scale, there was no general tendency in the ADHD group to judge time intervals on the milliseconds scale as longer. Interestingly, their training performance was quite similar to controls. The markedly reduced number of participants who met the training criteria for the discrimination between 50 and 110 ms was distributed evenly among participants of both groups. Thus, the principal capability of children with ADHD to discriminate very brief durations was comparable with that of control participants.

There appears to be a rather specific alteration in children with ADHD regarding time processing on the milliseconds scale, as the divergence from the control group during temporal set-shifting was striking. In the ascending as well as in the descending conditions (Figure 3), both groups followed the principal direction of the context shifts. Although the PSE values of controls were adjusted in a manner that suggests quick updating to the new temporal set, the PSE in participants with ADHD reflects a compromise between the current and the preceding frame of reference.

Impairments in mental set-shifting have been assessed using the Wisconsin Card Sorting Test. Performance tends to be impaired in participants with ADHD (cf. Lawrence et al., 2004; Pennington & Ozonoff, 1996; Sergeant et al., 2002). Our present results are the first to demonstrate a similar impairment in the temporal domain, as these deficits also emerge when test participants adapt to new temporal contexts.

Evidence of Two Timing Mechanisms

The different pattern of results on each time scale supports the model in which two separate timing mechanisms on the seconds scale and milliseconds scale exist (for a review, see Mauk & Buonomano, 2004). Despite their more stable performance, participants in the control group demonstrated the influence of preceding temporal frames of reference on the current stimulus range on the seconds scale. A comparable carryover was absent in the milliseconds scale. Furthermore, the general trend for deviations differed between the two time windows. In the range of seconds, children with ADHD generally overestimated, and in the range of milliseconds, the deviation of their estimates was determined by the preceding temporal frame of reference.

Practical Implications

Reduced mental set-shifting capability and deficits in temporal processing imply a high risk for impaired academic functioning (Biederman et al., 2004; Prevatt, Proctor, Baker, Garrett, & Yelland, 2010). As the results from the present study indicate deficits in temporal set-shifting and an accelerated internal clock in participants with ADHD, implications for the treatment of ADHD and appropriate measures in educational settings ensue. The successful mastery of complex tasks demands an ability to adequately manage time and appropriately structure lengthy, complex tasks into shorter subtasks. If genuine time perception alterations can be identified in participants with ADHD, this could help facilitate specialized instruction for students with ADHD that incorporate more short breaks and shorter lessons. Moreover, the presence of a faster internal clock in ADHD participants may result in reinforcing effects that wane more quickly (Sagvolden, Johansen, Aase, & Russell, 2005). Immediate reinforcement as a means of behavioral shaping might be more important in participants with ADHD. Aside from these educational consequences, evidence of a rather specific alteration of time perception in ADHD might be of interest for differential diagnosis (see also Rubia et al., 2009). The tasks used in this experiment can be easily administered. As they allow for the separation of altered time perception from other factors that cause premature responses, they may be helpful in the differential diagnostics of ADHD. Future studies of time estimation should therefore compare ADHD children with children being affected by other psychiatric disorders, in particular affective disorders.

The findings suggest a specific alteration of time processing in ADHD. Both presumptive mechanisms for temporal processing are affected but in different ways. On the seconds scale, the internal clock appears to run faster, therefore durations are perceived as longer. On the milliseconds scale, the ability of temporal set-shifting is impaired in children with ADHD, although the principal capability to discriminate between brief durations is unaffected. These results support the recent triple-pathway model of ADHD (Sonuga-Barke, Bitsakou, & Thompson, 2010). According to this model, alterations in timing are dissociable from inhibition and delay deficits, therefore timing deficits might be the core of a subset of symptoms in ADHD.

Declaration of Conflicting Interests

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