

# BMJ Open Perceptual timing in children with attention-deficit/hyperactivity disorder (ADHD) as measured by computer-based experiments versus real-life tasks: protocol for a cross-sectional experimental study in an ambulatory setting

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## ABSTRACT

**Introduction** The goal of this study is to get a better understanding of the fundamentals of perceptual timing deficits, that is, difficulties with estimating durations of explicitly attended temporal intervals, in children with attention-deficit/hyperactivity disorder (ADHD). Whereas these deficits were repeatedly demonstrated in laboratory studies using computer-based timing tasks, we will additionally implement a more practical task reflecting real-life activity. In doing so, the research questions of the planned study follow a hierarchically structured path ‘from lab to life’: Are the timing abilities of children with ADHD really disturbed both in the range of milliseconds and in the range of seconds? What causes these deficits? Do children with ADHD rather display a global perceptual timing deficit, or do different ‘timing types’ exist? Are timing deficits present during real-life activities as well, and are they based on the same mechanisms as in computerised tasks?

**Methods and analyses** A quasi-experimental study with two groups of male children aged 8–12 years (ADHD; controls) and with a cross-sectional design will be used to address our research questions. Statistical analyses of the dependent variables will comprise (repeated) measures analyses of variance, stepwise multiple regression analyses and latent class models. With an estimated dropout rate of 25%, power analysis indicated a sample size of 140 subjects (70 ADHD, 70 controls) to detect medium effect sizes.

**Ethics and dissemination** Ethics approval was obtained from the ethics committee of the Faculty of Medicine, University of Rostock. Results will be disseminated to researcher, clinician and patient communities in peer-reviewed journals and at scientific conferences, at a meeting of the local ADHD competence network and on our web page which will summarise the study results in an easily comprehensible manner.

**Trial registration number** DRKS00015760

## Strengths and limitations of this study

- The assessment of perceptual timing abilities in children with attention-deficit/hyperactivity disorder (ADHD) by means of more real-life tasks allows for a more ecologically valid evaluation of the relevance of laboratory-confirmed timing deficits.
- The use of an optimised set of predictors along with a comprehensive number of established perceptual timing paradigms allows for a refinement of theoretical models of disturbed timing processes in children with ADHD.
- The collection of predictor data and timing task performance data independently from each other, that is, at two separate experimental sessions, enhances predictive validity of the planned regression analyses.
- The cross-sectional study design with two experimental sessions might cause larger dropout rates during data collection when compared with designs with only one experimental session.
- Including only boys for methodological reasons (increasing between-group sensitivity by reducing within-group heterogeneity; the prevalence of ADHD is two to three times higher in males) reduces generalisability of our study results, therefore potential gender effects should be examined in further studies once the underlying mechanisms have been established in more detail in the current study.

## INTRODUCTION

The examination of time perception abilities in subjects with attention-deficit/hyperactivity disorder (ADHD) has a long tradition. It was initiated with the dissemination of Barkley’s theory of ADHD as a timing disorder.<sup>1</sup> He argues that a disturbed sense of time in subjects with ADHD results

from their impaired ability to withhold immediate behaviours, which makes it impossible for them to bring their behaviour under the control of higher-order and goal-directed cognitive processes, the so-called executive functions (EF). The latter comprise time management abilities such as planning, ordering events and allocating the amount of time for activities. These abilities in turn require more basic time processing abilities like time perception (ie, the experience of time and durations of activities) and time orientation.<sup>2</sup> As Noreika *et al*<sup>3</sup> showed in their review, time perception and time management are disturbed in subjects with ADHD. Disturbed timing abilities are also reflected by the diagnostic criteria for the disorder.<sup>4</sup> Therefore, treatment of time processing dysfunctions might be a promising approach in reducing the core deficits of the disorder. However, the prerequisites of time management dysfunctions, that is, alterations in time perception, are not yet sufficiently understood.

Research in this domain encompasses two fields, motor and perceptual timing. Whereas motor timing refers to the temporal organisation of motor behaviour as measured by free tapping or rhythm reproduction, perceptual timing encompasses tasks that require the estimation of explicitly attended temporal intervals.<sup>3</sup> A variety of perceptual timing paradigms have been applied in the domain of ADHD, including tasks that require temporal judgements in the range of milliseconds and those in the range of seconds. The former evaluate the ability of the child to discriminate between stimuli that differ in their presentation time for only several milliseconds (time discrimination tasks), imposing requirements especially on perceptual acuity. The latter, in contrast, require additional cognitive resources, as they ask the child to provide a verbal duration estimation of a previously presented stimulus (time estimation), to produce a previously specified time interval, for example, by pressing a response button (time production), or to infer the duration of a stimulus that had been previously presented for a defined time interval and to indicate this time interval subsequently by pressing a response button (time reproduction). Based on our experimental findings using these four paradigms,<sup>5</sup> we recently proposed a model of disturbed perceptual timing in children with ADHD, consisting of two distinct but partially overlapping neurocognitive mechanisms: (i) working memory (WM) and attention processes that cause time estimation and time production deficits and (ii) WM and motivational processes that cause time reproduction deficits. Moreover, we found time discrimination deficits in these children as well, but these deficits were not explained by our predictor variables.

### Is time discrimination impaired in children with ADHD?

Although time discrimination deficits in children and adolescents with ADHD have been well documented,<sup>6–13</sup> a consistent valuation of these findings is hampered by the fact that many of the tasks put additional demands on cognitive resources needed for successful task

mastery, obscuring the presence or absence of a primary time discrimination deficit in ADHD. In more detail, successful management of perceptual timing tasks seems to depend on different functions, such as (i) WM which is crucial for holding temporal reference information online during task processing, (ii) attention to time such as attention allocation to the ongoing task and adjustment of motor responses and (iii) inhibition of premature responses.<sup>14</sup> Whereas this was found to be true for paradigms that operate in the range of several seconds,<sup>5</sup> the body of literature suggests that these mechanisms may also play a role for temporal processing in the range of milliseconds, that is, time discrimination. For WM, it was shown that children and adolescents with ADHD were more impaired in their time discrimination performance depending on the duration of the stimuli that had to be compared with each other (the constant reference stimulus was either presented for 300, 800 or 1200 ms), and WM was associated with task performance at longer (800 ms), but not at shorter (300 ms) presentation duration.<sup>13</sup> Another study group did not find group differences in time discrimination performance for long stimulus durations.<sup>15</sup> What might at a first sight seem contradictory can be explained by low experimental sensitivity. In that study, subjects were asked to compare stimuli with durations of 1300, 1400 and 1500 ms with a reference stimulus that was always presented with a duration of 1000 ms. Thus, the most difficult condition incorporated a time difference of 300 ms between the stimuli that had to be evaluated, but results from our study group<sup>7</sup> suggest that children and adolescents with ADHD might be only impaired in their differentiation abilities at smaller time differences.

Taken together, the effect of stimulus presentation duration at which WM processes may influence time discrimination abilities in children and adolescents with ADHD is not sufficiently clarified. According to our state of knowledge, only two studies have been published so far using regression analytic designs including this predictor, which reported contradictory outcomes. Whereas in one study, WM predicted time discrimination abilities at long (1000 ms), but not at short (200 ms) stimulus durations,<sup>11</sup> another study found this association at short stimulus durations (400 ms) as well.<sup>10</sup> However, when compared with the first study, the second study used a longer inter-stimulus interval (ISI, 1000 vs 500 ms), which might be an alternative explanation for this predictive association, as the first stimulus has to be kept in mind until the second stimulus is displayed on the screen. Reviewing studies with correlational designs, Yang *et al*<sup>13</sup> also report a significant association between WM and time discrimination abilities at long (800 ms), but not at short (300 ms) stimulus durations, which is in line with the study by Toplak and Tannock.<sup>11</sup> However, Smith *et al*<sup>9</sup> did not find an association even at long stimulus durations (1000 ms).

In sum, the impact of WM on time discrimination performance appears to be plausible when stimulus durations and/or ISI comprise a duration of at least 800–1000 ms. This assumption is in line with recent findings showing

that time intervals in the range of milliseconds are differently processed—on a neuronal basis—than time intervals in the range of several seconds. Time intervals below one second are processed within a network comprising primarily the basal ganglia and the cerebellum, whereas longer time intervals especially recruit cortical structures such as the prefrontal cortex and the supplementary motor area.<sup>16</sup> In this sense, WM should be crucial only for timing performance from about 1 s and longer, when temporal characteristics of the experimental stimuli have to be analysed and information has to be held in mind until the comparison stimulus is displayed. Beyond WM, time discrimination performance in children and adolescents with ADHD was associated with measures of attention and impulsivity, but only in studies using longer stimulus presentation durations<sup>5 14</sup> and longer ISI.<sup>17</sup> In addition, we suggested delay aversion and its secondary adaptations, that is, the motivational tendency to escape from delay by investing less time in a task if this helps to reduce overall experimental duration,<sup>18</sup> as a further potential predictor of disturbed timing processes in ADHD. This assumption is indirectly supported by our recent findings on negative effects of task repetition on time reproduction performance in children with ADHD<sup>5</sup> and positive effects of financial rewards on time reproduction performance in adults with ADHD,<sup>19</sup> considering the fact that reward was found to compensate for effects of delay aversion in children with ADHD.<sup>20</sup>

The first aim of this study is to investigate the specific and combined effects of stimulus presentation duration and ISI duration in the genesis of time discrimination deficits in children with ADHD. We aim to examine the question whether or not time discrimination abilities are disturbed in these subjects beyond the influence of executive, attentional and motivational dysfunctions, that is, if they display a ‘pure’ time discrimination deficit. We expect that these children do not suffer from a time discrimination deficit when stimulus presentation duration and ISI are very short but that deficits emerge when either of these durations is rather long, with the most marked deficit emerging when both durations are long. Furthermore, we will explore the impact of neuropsychological measures of WM, sustained attention, inhibition and delay aversion on timing performance in these different experimental conditions.

#### **What are the determinants of the ADHD perceptual timing deficit?**

With reference to our recently published research,<sup>5</sup> the second aim of our study is to optimise the set of predictor variables relevant for perceptual timing to further refine our proposed model of the causes of disturbed perceptual timing processes in children with ADHD. In this optimised and enhanced replication study, we will (i) add motivational predictors (Choice Delay Task [CDT]; see below) which have not yet been examined systematically in relation to perceptual timing abilities in children with ADHD but which seem to be highly relevant especially

for estimations of longer time intervals, (ii) ‘fine-tune’ the predictors in order to increase their reliability (eg, avoiding ceiling effects as generated by fairly simple tasks) and content validity (eg, modelling the relevant components of WM in a more differentiated way) and (iii) reduce the number of initial predictors by creating composite scores. The proposed study will contain the most comprehensive predictor analysis in the published literature of perceptual timing in ADHD with regard to the set of predictors and sample size. This study allows for a comprehensive analysis of associations between all four perceptual timing tasks (time discrimination, time estimation, time production and time reproduction) and the identification of shared or distinct cognitive mechanisms that affect perceptual timing task performance in children with ADHD.

#### **Is there evidence for distinct ADHD timing subtypes?**

According to the Diagnostic and Statistical Manual of Mental Disorders (DSM)-IV criteria, ADHD is not a uniform construct but is subdivided into an inattentive, a hyperactive/impulsive and a combined subtype.<sup>4</sup> A similar non-conformity is true for the cognitive deficit profile of the affected subjects. For example, linking ADHD symptom dimensions with cognitive dysfunctions, Thorell<sup>21</sup> showed that inattentive symptoms were predicted by executive dysfunctions but not by delay aversion (ie, the motivation to avoid waiting times which are perceived as abnormally aversive). Hyperactive/impulsive symptoms, in comparison, were predicted by delay aversion but not by executive dysfunctions. On the other hand, a recently conducted meta-analysis mitigates these findings, as it showed that the combined and the inattentive ADHD subtypes hardly differed from each other in their cognitive dysfunction profile. For this reason, the discriminant validity of the ADHD subtype classification with regard to cognitive dysfunction profiles has been called into question.<sup>22</sup> Likewise, the authors of another large-scaled study<sup>23</sup> concluded that the ADHD subtype classification reflects differences in quantity rather than in quality, as they found the combined subtype generally to be more strongly impaired than the inattentive subtype across all measured cognitive domains, with no specific differential performance patterns emerging. From a neurocognitive view, these results support the change from the former DSM-IV ADHD ‘subtype’-designation into ‘presentations’ in the current DSM-5 nosology.

Rather than differentiating the cognitive profiles of ADHD subjects by drawing on the predefined ADHD subgroups or symptom dimensions, cognitive subtypes of ADHD may be alternatively detected by statistical cut-off procedures. For example, defining an impairment criterion by identifying those children with ADHD who performed poorer than the worst 10% of the control children, Nigg *et al.*<sup>24</sup> found that 23% of the children with ADHD suffered exclusively from an inhibition deficit, 15% suffered exclusively from increased delay aversion and 23% suffered from both deficits, whereas 39%

were unimpaired in these domains. Alternatively, statistical methods such as latent class analyses were able to differentiate—at the neuropsychological level—subjects with ADHD with poor cognitive control from those with slow and variable response timing, independently of any a priori classification.<sup>25</sup> Interestingly, these two groups together represented only 51% of the study subjects, leaving room for further relevant dimensions of impairment such as disturbed timing processes which have been suggested as a further aetiological factor of ADHD,<sup>26</sup> besides the psychological dimensions of inhibition, inattention and delay aversion.<sup>1 27</sup> However, it is unknown so far if all subjects with ADHD demonstrate a global perceptual timing deficit, or if some subjects differ from others in their perceptual timing profiles. If the latter is the case, it would be interesting to specify (i) which ‘timing types’ exist, (ii) whether or not these timing types correspond to those identified within the control group and (iii) how these timing types are related to ADHD-related neurocognition (eg, can we detect a ‘time reproduction type’ whose performance is primarily predicted by delay aversion?). Such specific predictor-subtype associations might allow—in the medium term—to develop individualised therapeutical interventions in subjects being significantly impaired in their everyday timing abilities.

#### **Does the ADHD timing deficit manifest itself in everyday activities?**

Surprisingly, no study has been conducted so far examining timing abilities and their determinants in children with ADHD outside the laboratory, that is, with regard to real-life activities. In other words, the ecological validity and the clinical relevance of previous experimental findings remain unclear as we do not know whether laboratory timing deficits translate to everyday activities in these children. Moreover, we do not know if these deficits—if present—are based on the same mechanisms as in the laboratory, and if they are associated with clinical symptoms reported by parents and other caregivers.

The only ecological study to our knowledge has been conducted in a community-based sample of children aged 8–12 years<sup>28</sup> and has used two timing tasks, a computer game (higher attentional load) and a pleasant reading task (lower attentional load). The aim of that study was to compare task-related timing performance in relation to different performance modalities. In brief, perceptual timing can be classified according to whether subjects know in advance that a judgement on time is required (prospective timing) or not (retrospective timing). In the sense of an attention allocation model, both conditions differ in their amount of attention that is directed either to time or to other situational aspects such as tracking the content of a film, listening to the text of a song or performing a specific task, for example, a computer game or a reading task. It is assumed that subjects in the prospective condition—when compared with subjects in the retrospective condition—spend more attentional resources to time and, as a consequence, report longer

and less variable durations compared with those who are asked for their judgements afterwards.<sup>29 30</sup> In line with their hypotheses, Bisson *et al*<sup>28</sup> found longer duration estimations for prospective than for retrospective timing. However, contrary to their expectations, duration estimations were larger for the gaming task than for the reading task, although the former should have attracted more attention, leaving less attention to time and therefore being perceived as shorter. Importantly, these differences were not attributable to motivational factors in terms of task appreciation and self-efficacy expectations, but might be attributable to task-specific aspects. Although unique in this field, this study can be criticised for several reasons: (i) both tasks differed with regard to their complexity and degree of novelty, (ii) different cognitive processes were likely to be involved in performances on both tasks which might alternatively explain the results, (iii) only one target duration was used, that is, estimated durations could not be plotted against different target durations in order to compose an estimation function (eg, underestimation of short and overestimation of long intervals) and (iv) the authors did not link task performance to basic cognitive functions which are thought to be relevant for interval timing, not allowing a clear conclusion on their findings.

To the best of our knowledge, no published study has examined real-life perceptual timing abilities in children with ADHD compared with controls which is the fourth aim of our study. We will use everyday equivalents of the time estimation, time production and time reproduction paradigms, thereby trying to overcome the aforementioned study limitations. To accomplish this goal, we will (i) keep comparable—across tasks—level of task novelty, task demands (ie, involved cognitive processes) and task difficulty (ie, complexity), (ii) use different target durations and (iii) examine potential predictors of timing performance, thereby (iv) controlling for task-related motivational factors. For reasons of comparability with laboratory findings, we will limit our research to the visual domain (as most of the studies so far used visual stimuli). (v) We will further examine whether children with ADHD, when compared with controls, perceive larger time distortions in specific situational contexts that may affect how the passage of time is perceived (eg, fascination during current activities, being with others, waiting situations), and how these time distortions are related to timing task performance. For this research question, we will apply a German adaptation of the Metacognitive Questionnaire on Time (MQT).<sup>31</sup>

To address our research questions, we designed a cross-sectional experimental study with two experimental groups of male children (ADHD; controls) and two experimental sessions (session 1: performance of the predictor tasks; session 2: performance of timing tasks) which will be completed 2 weeks apart from each other in an ambulatory setting. The hypotheses and expected outcomes of our planned investigation are summarised in [box 1](#).



## Box 1 Hypotheses and expected outcomes

### Research question 1: is time discrimination impaired in children with attention-deficit/hyperactivity disorder (ADHD)?

**Hypothesis 1:** subjects with ADHD are not impaired in their time discrimination abilities as long as working memory (WM) is not involved in task completion.

**Expected outcomes:** using a time discrimination task with experimental variation of both stimulus duration (short or long) and inter-stimulus interval (short or long), we first expect a group×task repetition interaction effect, demonstrating that controls show a stable performance across all task versions (SS, SL, LS, LL), whereas subjects with ADHD show significant differences for various combinations. For the respective post hoc analyses, we expect that (a) in the ADHD group, performance in the SS condition will be superior to the SL and LS conditions, and these performances will be superior to the LL condition; (b) that the ADHD group, when compared with the control group, will be impaired in their performance in all conditions except for the SS condition, with the deficit being most marked in the LL condition.

**Hypothesis 2:** neuropsychological measures of WM, sustained attention, inhibition and delay aversion will not predict task performance when stimulus presentation duration and interstimulus interval are shorter than 1 s. For presentations and intervals >1 s, we expect at least the WM to predict test performance.

**Expected outcomes:** we expect WM to predict the time discrimination threshold in all task versions except for the SS condition in all children. Adding the diagnostic group variable to the regression model will not significantly alter this association. Among all predictors included, we expect the strongest association between WM and task performance.

### Research question 2: what are the determinants of the ADHD perceptual timing deficit?

**Hypothesis 1:** all perceptual timing tasks that include intervals of several seconds (ie, time estimation, time production, time reproduction) share a common pathoneuropsychological mechanism in children with ADHD, that is, WM deficits will predict dysfunctional task performance.

**Expected outcomes:** for all timing tasks, we expect performance deficits in the ADHD group (main effect of the diagnostic group). Group differences in general task performance (combined score for all time intervals) are expected to be associated with a larger increase of errors with increasing time interval length in the ADHD group, but not or to a lesser extent in the control group (interaction effect between diagnostic group and interval length). We further expect a WM deficit in the ADHD group (main effect of diagnostic group). For the regression analyses, we expect WM to substantially predict timing performance in all children, with no additional variance explained by adding the diagnostic group variable to the model.

**Hypothesis 2:** beyond this common timing mechanism, attention deficits will specifically predict time estimation deficits and time production deficits whereas motivational alterations will specifically predict time reproduction deficits in children with ADHD.

**Expected outcomes:** we expect the ADHD group to be impaired in sustained attention and to show increased delay aversion (main effects of the diagnostic group). For the regression analyses, we expect sustained attention, but not delay aversion to predict time estimation and time production performance, and we expect delay aversion, but not sustained attention, to predict time reproduction performance. Adding the diagnostic group variable as a predictor to the regression models will not significantly alter these associations. As impulsivity was also found

Continued

## Box 1 Continued

to affect timing performance, we include inhibition as a further regressor, with no specific a priori hypothesis.

### Research question 3: is there evidence for distinct ADHD timing subtypes?

**Hypothesis 1:** children with ADHD do not suffer from a global perceptual timing deficit, but different 'timing types' exist.

**Expected outcomes:** this exploratory research question which will be addressed by latent class analyses does not build on a priori hypotheses about timing-related ADHD subgroups.

### Research question 4: does the ADHD timing deficit manifest itself in everyday activities?

**Hypothesis 1:** laboratory timing deficits in the range of seconds as measured by computer-based tasks (CBT) translate to more everyday activities in children with ADHD.

**Expected outcomes:** we expect timing performance on the different subtasks of the Toolbox Sorting Task (TST) to be impaired in the ADHD group (main effect of group). Group differences in general task performance (combined score for all time intervals) are expected to be associated with a larger increase of errors with increasing time interval length in the ADHD group, but not or to a lesser extent in the control group (interaction effect between diagnostic group and interval length).

**Hypothesis 2:** a similar task association pattern is found for the CBT and the TST.

**Expected outcomes:** both for the CBT and for the TST, we expect time estimation and time production performance to be correlated, whereas time reproduction performance will not be correlated.

**Hypothesis 3:** performances in CBT and TST are predicted by the same neuropsychological measures.

**Expected outcomes:** we expect WM to predict timing performance in all versions of the TST. Moreover, we expect sustained attention, but not delay aversion to predict TST time estimation and time production performance, and we expect delay aversion, but not sustained attention, to predict TST time reproduction performance. Adding the diagnostic group variable to the regression model will not significantly alter these associations.

**Hypothesis 4:** both performances in CBT and TST are associated with distortions of time perception in everyday life.

**Expected outcomes:** we expect that performance on both the computer-based timing tasks and on the TST are correlated with the Metacognitive Questionnaire on Time scores.

## METHODS AND ANALYSES

### Participants

We will examine male children with ADHD aged 8–12 years as well as typically developing control children. Importantly, all children have an understanding of temporal units, as the handling of time (ie, time units, dates, time spans which are assessed by means of measurement, estimation, comparison and calculation) is part of the curriculum for primary schools in Mecklenburg-Vorpommern and takes usually place in the second or third class (ie, around the age of 7 or 8), depending on the individual prerequisites within the class. The patients will be consecutively recruited from the inpatient and outpatient clinics of the Department of Child and Adolescent Psychiatry, University Medicine Rostock, Germany and from local child and adolescent psychiatrists who are serving

the community through private practice. Control subjects will be recruited from primary and secondary schools via flyers that will be distributed by their teachers after a consultation with the headmasters and after approval has been obtained by the State Education Authority Rostock.

### Diagnostic procedure

For all children, the diagnostic procedure includes the German version of the Kiddie-Sads-Present and Lifetime Version (K-SADS-PL),<sup>32</sup> which is a semi-structured interview to assess lifetime and current psychiatric diagnoses based on DSM-IV criteria. The diagnostic interview will be conducted by a trained psychologist with the parent who accompanies the child to the investigation. All modules of the K-SADS will be administered in order to be able to apply the exclusion criteria properly and to provide complete information on comorbid psychiatric diagnoses. For a diagnosis of ADHD, children have to currently fulfil the relevant number of diagnostic criteria (presence criterion), with symptoms of the disorder being present in two or more settings (pervasiveness criterion) and causing a reduction of the quality of social, academic or occupational functioning (impairment criterion). To obtain parental and teacher ratings of the children's behavioural and emotional problems, German versions of the Child Behaviour Checklist (CBCL/6–18R)<sup>33</sup> and the Teacher Report Form (TRF/6–18R)<sup>33</sup> will be used. The severity of ADHD symptoms will be further assessed by means of the German Parental and Teacher Report on ADHD symptoms (FBB-HKS)<sup>34</sup>, using a 4-point rating scale (0=not at all; 3=very much). As ADHD is associated with a high comorbidity of oppositional defiant disorder and conduct disorder, we will additionally record parental and teacher ratings on the respective symptoms by means of the German Parental and Teacher Report on disruptive behaviour symptoms (FBB-SSV).<sup>34</sup> The children's IQ will be assessed by means of a German adaptation of Cattell's Culture Fair Intelligence Tests that includes two age-related subscales (CFT 1-R<sup>35</sup> and CFT 20-R<sup>36</sup>).

### Exclusion criteria

Exclusion criteria for all participants include an IQ < 80, neurological (eg, seizure history) or endocrine (eg, thyroid dysfunction) disorders known to affect brain function, head injury with loss of consciousness, current depressive disorder, lifetime schizophrenia spectrum disorder, autism spectrum disorders and insufficient German language skills (lack of capacity to consent; lack of understanding the instructions).

### Tasks and measures

Perceptual timing abilities will be assessed by means of a time discrimination task, a time estimation task, a time production task and a time reproduction task. All perceptual timing tasks are adaptations from our latest study.<sup>5</sup> Additionally, the children will perform real-life equivalents of computer-based super-second perceptual timing tasks (the 'toolbox sorting task'). Further tasks measuring

WM (n-back task, span tasks), sustained attention (continuous performance task [CPT]), inhibition (stop signal task [SST]) and delay aversion (CDT) will be performed as predictors of perceptual timing performance.

### Computer-based perceptual timing tasks

#### *Time discrimination task*

Participants are shown a red and a green circle in quick succession, which hardly differ in the duration of their presentation. They are then required to decide which of the circles is presented for a longer duration.<sup>9</sup> One of the circles (the reference stimulus) is always presented with a fixed duration ('short' condition: 300 ms; 'long' condition: 1300 ms); the other one is initially presented with a slightly longer duration ('short': 600 ms; 'long': 1600 ms) but will then be successively shortened by 15 ms intervals. In each successive trial, colours and positions are randomly interchanged in order to rule out guessing strategies. The two circles are separated by a fixation cross which is shown for 300 ms ('short') or 1300 ms ('long'), respectively. Stimulus presentation durations and ISI durations will be varied systematically depending on whether WM is believed to affect ('long' condition) or not to affect ('short' condition) time discrimination performance, based on the study findings outlined above. Consequently, manipulation of stimulus presentation and ISI duration allows for four experimental conditions: (i) short stimulus presentation (reference stimulus: 300 ms), short ISI (300 ms), (ii) short stimulus presentation (reference stimulus: 300 ms), long ISI (1300 ms), (iii) long stimulus presentation (reference stimulus: 1300 ms), short ISI (300 ms), (iv) long stimulus presentation (reference stimulus: 1300 ms), long ISI (1300 ms). Subsequent to the presentation of the second circle, a delay of 500 ms is introduced, followed by the instruction to choose one of the circles by responding with either the left or the right mouse button. Response windows are not fixed. Correct answers are followed by a reduction in the presentation duration of the longer circle by 15 ms, while incorrect answers are followed by an increase of 15 ms. This staircase method was introduced by Levitt.<sup>37</sup> The point of subjective equality between the circles, that is, the point at which subjects fail to discriminate the presentation duration of the circles adequately and assess them as being equal, serves as the dependent variable. The sensitivity threshold will be computed according to the study by Smith *et al.*<sup>9</sup>

#### *Time estimation, time production and time reproduction tasks*

In the *time estimation task*, children will be presented with yellow 'smiley faces' which are shown for a certain time interval, and they will then have to infer the duration for which the smileys were shown on the screen. In the *time production task*, the children will see a number on the screen, which is a time in seconds, and they will be asked to press the left mouse button until they are under the impression that this time span has elapsed. In the *time reproduction task*, children have to infer the duration

of smileys presented on the screen at first and then are again asked to press the left mouse button as long as the 'smiley' had occurred earlier on. During the button press phase, a green smiley will be displayed on the screen in both tasks. In the time reproduction task, the presentation of the smiley will be signalled by a 3 s countdown. The time intervals are 2, 6, 12, 24, 36, 48, 60 and 72 s. The time intervals will be presented twice, in two successive blocks, and will be randomised within the blocks. In order to become familiar with the task demands, each child will perform a 5 s test trial before each task. After all timing tasks have been completed, the children will be asked about their strategies during task performance (eg, counting the seconds in their heads), and these will be recorded. To rule out the possibility that overestimations and underestimations would average each other out, the absolute value of the deviation between the specified and the produced time interval (ERR), as a measure of accuracy, serves as a dependent variable, reflecting the overall magnitude of error regardless of its direction. Additionally, an accuracy coefficient score (AC) will be computed, whereby the produced time interval is divided by the specified time interval, reflecting under-reproduction (scores <1.00) and over-reproduction (scores >1.00).

### Real-life perceptual timing tasks

A 'Toolbox Sorting Task' (TST) will be designed to address real-life perceptual timing abilities. The children will be presented with a toolbox whose bottom will be filled with ironmongery (screws, nuts, washers) in two different sizes (small, large) and which must be sorted into one of the six corresponding storage compartments further up, depending on type and size. The storage compartments will be clearly labelled with icons of the respective ironmongery. In different experimental conditions which will be presented at random, the children will be asked (i) to watch the experimenter sorting the items and to indicate how long he or she was sorting (time estimation), (ii) to sort these items themselves for a certain period of time (time production) and (iii) to watch the experimenter sorting the items and then to sort themselves for the same period of time (time reproduction). We will use three different time intervals for each task: 1, 5 and 10 min.

### Predictor tasks

#### WM tasks (*n*-back; digit span)

Diverse models of WM focus on different aspects of information processing within the WM which include, for example, the storage, updating and manipulation of information as well as interference control, that is, the protection of information processing against external or internal distractors.<sup>38</sup> Empirically, tasks that have been applied to measure WM were indeed found to form distinct modality and process-specific factors,<sup>39–41</sup> and children with ADHD display WM dysfunctions which tap into these different subdomains, including verbal and non-verbal storage processes as well as executive processes.<sup>42–43</sup> The n-back task is a frequently used measure of WM.<sup>44</sup>

<sup>45</sup> In this task, subjects are shown, in quick succession, sequences of visual stimuli such as numbers or letters and they are asked to decide whether the displayed stimulus matches the one that was presented *n* positions before, with task difficulty varying as a function of *n*. Whereas the 1-back task seems to capture mainly the *updating* function of WM, the 2-back task seems to measure primarily *interference control*.<sup>46</sup> Therefore, the *n*-back task seems very well suited as a predictor of timing performance, especially in the range of several seconds and for time discrimination performance in tasks with WM involvement, where temporal information must be updated (ie, counting the number of time units) and the process of counting must be shielded against distraction. The *n*-back task seems to be insensitive to stimulus modality.<sup>40</sup> As information *storage* is also crucial for timing performance (ie, keeping in mind the duration of presentation of two stimuli for their later comparison), we will further implement the simple span paradigm. In this kind of tasks, subjects are presented with series of stimuli, for example, numbers or letters, of increasing length and they are asked to repeat these series subsequently in the same order (forward condition) or in the reverse order (backward condition). As the backward condition requires cognitive manipulation which exceeds pure storage processes, at least in children,<sup>47</sup> we will only use the forward condition. A verbal and a visuospatial task will be used, as the respective storage components were separable in children populations<sup>48</sup> and might be both relevant for timing performance.

We will apply a modification of an *n*-back task which was recently used in children and adolescents with ADHD and which produced a robust load effect in the absence of ceiling effects.<sup>49,50</sup> As we will examine younger subjects, we will omit the 3-back condition in order to avoid excessive demand, but we will increase the number of experimental blocks and the number of stimuli within the blocks for the remaining conditions in order to increase the tasks' between-group sensitivity. In brief, we will use a letter *n*-back task with two conditions (1-back, 2-back), with four blocks per condition, separated by a 5 s instruction screen, indicating the subsequent *n*-back condition. Each block contains 30 stimuli (33% targets). Block order and stimulus order within the blocks are fully randomised. The stimuli will be presented for 1 s, followed by an ISI of 2 s. Subjects have to indicate for each stimulus whether it is a target (left mouse button) or a non-target (right mouse button). The task will be preceded by one sample trial per condition (15 stimuli, 4 targets), and these will be presented in ascending order. The following DVs will be derived from the *n*-back task: perceptual sensitivity (*d'*), measuring the degree to which targets can be distinguished from non-targets; *d'* is a composite score that takes both hits and false alarms into account, thereby avoiding DV inflation and ensuring appropriate DV validity,<sup>51</sup> the drift rate *v* (the rate at which an individual accumulates information from an encoded stimulus to make a forced choice response) and boundary separation *a* (speed/accuracy trade off) according to the diffusion model<sup>52,53</sup>;



mean response time (RT) and the intraindividual coefficient of variation (ICV). The ICV is computed as the ratio of the individuals' response time variability (SDRT) and mean RT and takes RT group differences into account.<sup>54</sup>

The 'digit span' subtest from the Wechsler Intelligence Scale for Children-Version V<sup>55</sup> and the block-tapping test (BTT)<sup>56</sup> will be used as measures of verbal and visuospatial WM span, respectively. Task administration (ignore the discontinuation criterion) and scoring (count digits rather than trials correct) will be modified in order to improve task validity.<sup>57 58</sup> The number of correctly reproduced elements ( $N_{\text{corr}}$ ) is selected as the DV for each task.<sup>57</sup>

#### Continuous performance task

Sustained attention refers to the ability to maintain a tonic state of alertness over an extended period of time<sup>59</sup> (p. 360). In tasks of perceptual timing, this is relevant, for example, for making effective use of strategies such as internal counting, or for correct response timing. Sustained attention is frequently measured by continuous performance tasks. Here, the subject is required—over a longer period of time—to identify targets, usually letters or numbers, among non-targets. It has been shown that children with ADHD have more difficulties than controls in differentiating targets from non-targets (perceptual sensitivity,  $d'$ ) and that they need more time to be sure about their decisions (drift rate,  $v$ ).<sup>59</sup> However, CPTs that have been used in ADHD samples so far were criticised as being too easy to measure substantial between-group differences in performance accuracy,<sup>59</sup> whereas specific versions of the CPT like the Conners' CPT<sup>60</sup> and the 'A-X' CPT<sup>61</sup> or its figural equivalents<sup>62–64</sup> are too complex in that they put additional executive demands in terms of inhibitory and interference control. On the first point, task difficulty with regard to  $d'$  may be increased by implementing shorter ISIs<sup>59</sup> and by using stimuli that differ from each other in quantity rather than in quality, as it was demonstrated that under the latter circumstances, performance deteriorates more strongly in tasks with successive trials and high event rates.<sup>65</sup> Therefore, we developed a forced-choice figural CPT with high event rates, low executive demands and stimuli that are graded in quantity in the style of the vigilance subtest from the test battery of attentional performance (TAP).<sup>66</sup> In this task, a horizontal bar dynamically oscillates around the centre of the screen with varying intensity (up to 30 pixels), and the test person has to detect a significant and infrequent change of the amplitude (upward swing of 60 pixels). In our task, we will use static instead of dynamic stimuli (a grey bar in front of a black background) and the subject has to indicate, as fast as possible, whether a target (left mouse button) or a non-target (right mouse button) is presented. The task consists of 600 trials including 15% target stimuli. The stimuli are presented for 200 ms, and the ISI is 1300 ms which is below the most frequently used ISI of 1500 ms of studies that were included in the meta-analysis by Huang-Pollock *et al.*<sup>59</sup> The following

DVs are used: perceptual sensitivity ( $d'$ ); drift rate ( $v$ ); boundary separation ( $a$ ); RT; ICV.

#### Stop signal task

Impulsivity which can be described as an individuals' response 'that is executed with insufficient forethought, planning or control, and is therefore inaccurate or maladaptive'<sup>67</sup> (p. 215) is a core symptom of ADHD,<sup>4</sup> and one of the most widely used tasks examining the ability to withhold prepared motor responses in children with ADHD is the stop signal task.<sup>68</sup> This task requires the subject to respond as quickly as possible to a target stimulus ('go') but to withhold the response when a stop signal is presented in a varying time interval shortly after the presentation of the target stimulus ('stop'). In contrast to tasks with consistent stimulus-stop association like the Go/NoGo task (ie, one stimulus always indicates a 'go' response whereas another always indicates a 'stop' response), the SST uses inconsistent stimulus-stop associations (ie, the same stimulus can require either a 'go' or a 'stop' response, depending on whether it is followed by a stop signal). As a result, the SST is less susceptible to effects of practice with increasing time on task, that is, controlled top-down inhibitory processes (vs automatic bottom-up inhibitory processes as facilitated by associative learning) are required to a larger degree for successful task completion.<sup>69</sup> In children with ADHD, meta-analyses indicate slower response times, increased response time variability and a slowed process of stopping,<sup>70–72</sup> which might primarily reflect attention deficits,<sup>72</sup> as well as an impaired probability of inhibition.<sup>71</sup>

In this study, we will use an SST with a spatially compatible stimulus-response mapping, as already used in previous research,<sup>73–75</sup> in order to minimise the impact of additional executive demands on task performance.<sup>76</sup> The task consists of four blocks with each containing 64 trials. In each trial, children are asked to respond as quickly as possible to an airplane pointing to the left or to the right (directions equally distributed) with the respective mouse button but to withhold their responses when a 'stop' signal is presented. The 'stop' signal which is a white cross superimposed on the 'go' stimulus<sup>74</sup> occurs in 25% of the trials ( $n=16$ ), half of the time with a left-pointing airplane and half of the time with a right-pointing airplane. Each trial has a duration of 2500 ms, and the 'go' stimulus is presented 500 ms after trial onset with a duration of 1000 ms. The rest of the time, a white central fixation point is presented. The initial stop signal delay (ie, the delay between 'go' stimulus onset and 'stop' stimulus onset) is set at 250 ms but is increased by 50 ms after successful inhibition (increased difficulty) and decreased by 50 ms after unsuccessful inhibition (decreased difficulty) in order to achieve 50% successful inhibition on stop trials for each participant. The SST will be preceded by 32 practice trials (16 'go' trials, 16 'stop' trials). In order to keep the children from response slowing, we will impose feedback at the beginning of each block, urging the children to respond as fast as possible to the 'go' stimulus while



also inhibiting their responses if the 'stop' signal occurs. The following DVs will be computed for each block separately and will then be aggregated across blocks: stop signal reaction time (SSRT), that is, the time needed to stop the initiated motor response; number of correct inhibitions (CI); number of omission errors (OE); RT and ICV from the 'go' trials. The SST measures are explained in more detail by Logan<sup>68</sup> and Verbruggen and Logan.<sup>77</sup> Data from participants who score below 70% in performance accuracy on the 'go' trials will be excluded.<sup>78</sup> As the 'mean' method of SSRT calculation is susceptible to the shape of the RT distribution and to group differences in RT, we will calculate SSRT by the block-based integration method.<sup>79</sup>

#### Choice delay task

The CDT<sup>80</sup> was designed to test for delay aversion, that is, the motivational tendency to reduce delay—even in expectancy of suboptimal performance outcomes—in order to reduce the negative emotional states associated with delay. In this task, individuals are presented with repeated trials incorporating the same basic choice between two reward options differing in size and delay to delivery (typically 1 unit after 2s and 2 units after 30s). Whereas perfect performance in terms of profit maximisation implies always choosing the large delayed reward, the proportion of disadvantageous (ie, small but more immediate) choices indicates delay aversion. Importantly, the actual delay is experienced by the participants, implicating high ecological task validity. In our recently conducted meta-analysis on 22 CDT studies,<sup>81</sup> we showed that subjects with ADHD are apt to choose small immediate over large delayed rewards almost twice as often as non-affected controls which corresponds to a small-to-medium effect size (ES) of  $d=0.36$ . For the current study, we will use the CDT as described by Sonuga-Barke *et al.*,<sup>80</sup> which showed high group differentiation in our previous studies with children with ADHD.<sup>7 12</sup> The number of choices for the large delayed reward (LRC) is used as DV.

#### Further measures

##### Metacognitive Questionnaire on Time

The MQT<sup>31</sup> is a 12-item questionnaire which was designed to measure perceived time distortions, that is, perceived speeding or slowing of time—in everyday situations with specific attentional (eg, focusing attention to time) and emotional (eg, being bored, being sad) characteristics. Given attentional problems<sup>4</sup> and emotional dysregulation<sup>82 83</sup> as core deficits of ADHD, we will use a German adaptation of the MQT self-perception scale eligible for our age group, consisting of self-rating and parental rating, to examine the presence and the degree of time distortions in children with ADHD compared with controls. Assuming that children who are more susceptible to contextual factors perceive larger time distortions and are therefore less precise in their timing performance (ADHD), whereas children who are less sensitive

to contextual factors perceive less time distortions and are therefore more precise in their timing performance (controls), we will further examine whether the degree of perceived time distortions is associated with performance on the perceptual timing tasks. The MQT sum score will serve as the DV. The authors (professor Droit-Volet) already approved the intended adaptations.

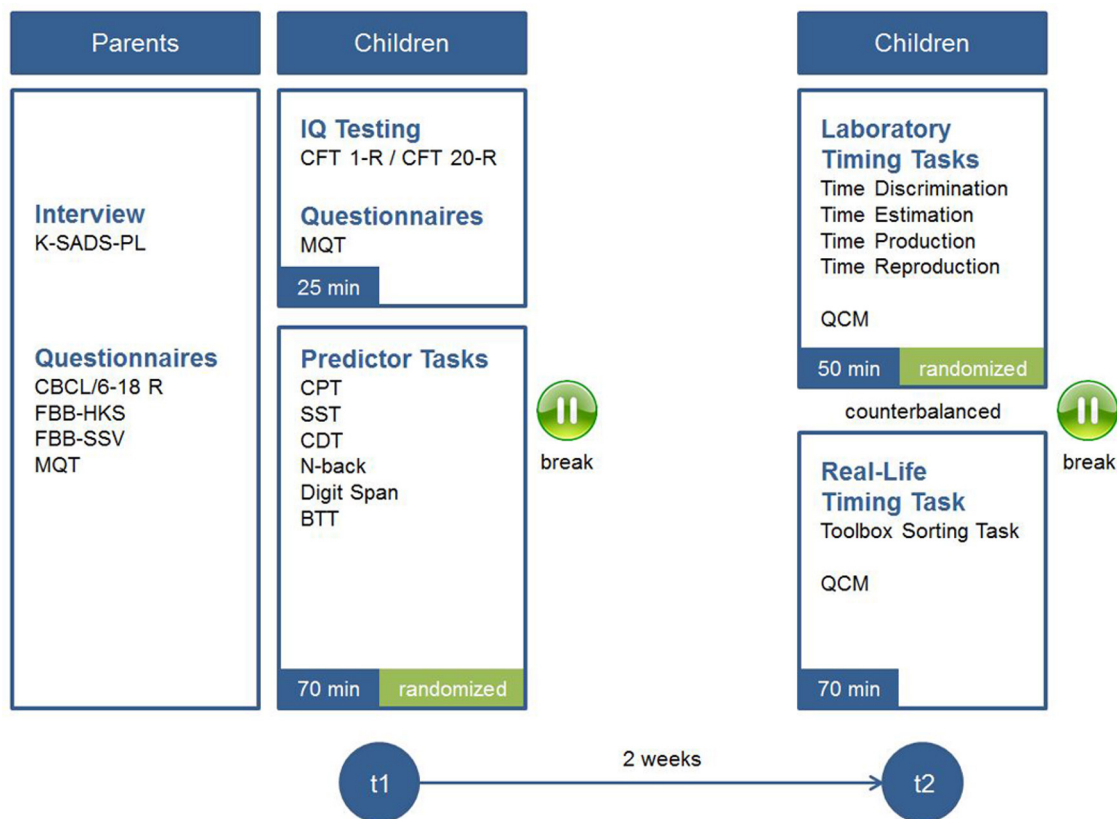
##### Questionnaire of Current Motivation

This 18-item questionnaire was designed to assess current motivational aspects regarding task completion by means of the following four subscales: challenge, interest, probability of success and apprehension of failure.<sup>84</sup> The Questionnaire of Current Motivation (QCM) will be considered as a possible covariate of interest in the present study in order to rule out task-related motivational explanations other than delay aversion which might alternatively cause group differences in experimental timing task performance (eg, computer-based vs real-life timing tasks). A short version of the QCM consisting of two items from each scale will be read aloud to the children and, if necessary, will be explained to them, while the children rate their judgements.

#### Experimental procedure

A quasi-experimental study with two groups of male children aged 8–12 years (ADHD; controls) matched for age and IQ at the group level and with a cross-sectional design with two experimental sessions will be used to address our research questions. Data collection will be divided into two experimental sessions in order to avoid cognitive overload and demotivation in the participants. Whereas the first session will comprise the measurement of the predictors and IQ testing, all children will perform the computer-based tasks and the real-life timing tasks in counterbalanced order at the second session. The experimental procedure is depicted in [figure 1](#). Data collection is scheduled for spring 2019 over a period of 3 years. The study protocol was registered in the German Clinical Trials Register (ID: DRKS00015760).

Prior to study participation, all children and their parents will be informed about the aim of the study in a more general way as taking part in some experiments about concentration and time estimation, comprising two experimental sessions. Session one will comprise the measurement of the predictors, that is, all children will perform the following tasks in randomised order to avoid sequence effects: n-back, digit span, BTT, CPT, SST and CDT. Additionally, the children will undergo IQ testing and will fill in the child version of the MQT. The whole testing procedure will take about 100 min. In the meantime, the parents undergo clinical diagnostics of their children, that is, they will perform the diagnostic interview and fill in the questionnaires. They will also be given the questionnaires for distribution to the class teachers (TRF), which they have to return filled at the next experimental session. In the second session, the children will perform the laboratory timing tasks



**Figure 1** Schematic illustration of the experimental procedure. BTT, block-tapping test; CDT, choice delay task; CPT, continuous performance task; K-SADS-PL, Kiddie-Sads-Present and Lifetime Version; MQT, Metacognitive Questionnaire on Time; QCM, Questionnaire of Current Motivation; SST, stop signal task.

(50 min) and the real-life timing tasks (70 min), again in randomised order and in a counterbalanced fashion. The QCM will be filled in once before the laboratory timing tasks and for the second time prior to TST task completion. In order to avoid attention overload and demotivation, a relaxing break of about 20 min will be scheduled for both sessions after half of the tasks have been solved (first session) or between the laboratory and the real-life timing tasks, respectively (second session). During the break, the children will be offered to play table football or air hockey. All experiments will be conducted between 08:00 and 12:00 hours at the premises of our outpatient clinic at the Department of Child and Adolescent Psychiatry, University Medicine Rostock, with about 2 weeks lying between the experimental sessions. At all sessions, the children with ADHD will discontinue their stimulant medication at least 48 hours before testing, in so far they are not drug-naïve. Before each task, the children will be given comprehensive and standardised instructions and will be asked to repeat the instructions using their own words. Then, they will be asked to work in a quiet and concentrated way. The tasks will be performed in a quiet room with only the experimenter and the child being present at the time of investigation. Moreover, standard operating procedures for test implementation will be established and researchers will be trained for uniform interventions. At the end of the second session, a detailed

final discussion will be conducted with the parents and their children on the specific study aims, and the families receive a gift voucher of their choice (eg, toy store, electronics store, bicycle shop) of €80 (children) and €25 (parents) for their time and travel expenses as compensation for their participation.

### Sample size calculation

For sample size estimations, a priori power analyses were conducted using G\*Power,<sup>85</sup> based on average ES (Cohen's  $d$ )<sup>86</sup> derived from meta-analyses for the predictor tasks, and on previous studies of our own working group that have used the same tasks and age groups for the timing tasks (table 1). Except for the time discrimination sensitivity threshold which shows large heterogeneity, most ES are medium-sized, predominantly moving in a range between  $d=0.50$  and  $0.70$ . Therefore, we selected an estimated medium population ES of  $d=0.60$  for our sample size calculations in order to obtain 80% power to detect experimental group differences, applying a significance level of  $p<0.05$ . Analyses revealed a required maximum total sample size of  $n=90$  (ANOVAs for the predictor analyses) for the group comparisons, that is,  $n=45$  children in each experimental group. As dropout rates up to 25% might be expected for the SST which is the most demanding cognitive task,<sup>67</sup> another  $n=12$  children will be required in each group, resulting in a total of 57

**Table 1** Effect sizes (d) for sample size estimations based on a priori power analyses

Domain/Task	Effect sizes	Publications
Working memory	<i>Span tasks</i> : spatial storage: d=0.85; verbal storage: d=0.47 <i>N-back task performance</i> : 2-back performance accuracy: d=0.59*	Martinussen <i>et al.</i> , <sup>43</sup> Kasper <i>et al.</i> <sup>42</sup>
Sustained attention	CPT: <i>d'</i> : d=0.98; <i>v</i> : d=0.75; <i>a</i> : d=0.16; omission errors: d=0.62; commission errors: d=0.55; RT: d=0.37; SDRT: d=0.56	Huang-Pollock <i>et al.</i> <sup>59</sup>
Inhibition	SST: SSRT: d=0.58–0.64; RT: d=0.45–0.52; SDRT: d=0.72–0.73	Alderson <i>et al.</i> , <sup>70</sup> Lijffijt <i>et al.</i> , <sup>72</sup> Oosterlaan <i>et al.</i> <sup>71</sup>
Delay aversion	LRC: d=0.61†	Marx <i>et al.</i> <sup>5</sup>
Time discrimination	Sensitivity threshold: d=0.22–0.83	Marx <i>et al.</i> <sup>5,7</sup>
Super-second timing	ERR: d=0.47–1.23; AC: d=0.21–0.43	Marx <i>et al.</i> <sup>5,7</sup>

\*Mean ES from four 2-back studies included in the study by Kasper *et al.*<sup>42</sup>

†Value refers to ES in non-rewarded paradigms (value corresponds to a transformed log OR of 1.11).

AC, accuracy coefficient; CPT, continuous performance task; ERR, absolute timing error; ES, effect size; LRC, number of choices for the large delayed reward; RT, response time; SDRT, standard deviation of the response time; SST, stop signal task; SSRT, stop signal reaction time.

children per group. Assuming medium ES for the regression analyses as well, a total sample size of n=127 would be required. Therefore, we decided to include n=70 children in each experimental group.

### Data analysis

The data will be analysed using IBM SPSS Statistics for Windows, V.23.0. Tests of the group differences in socio-demographic data will be performed using t-tests for independent samples, and the group differences in clinical data will be assessed by means of multivariate (CBCL; TRF) and univariate (FBB-HKS; FBB-SSV; CFT) analyses of variance (MANOVA; ANOVA). Group differences in timing task performance will be analysed by means of repeated measures ANOVAs with experimental group as the independent variable, task condition (time discrimination task), time intervals and blocks (time estimation, time production, time reproduction) as the within-subjects factors, and time discrimination threshold (time discrimination task) and ERR and AC (time estimation, time production, time reproduction) as the dependent variables. In all timing task analyses, the QCM sum scores will be included as a covariate of interest in order to control for confounding effects of group differences in task-related motivation. Group differences in predictor task performance will be assessed by means of ANOVAs (CPT; SST; digit span; BTT; CDT) and repeated measures ANOVAs (n-back; within-subject factor: n-back level), with all analyses being conducted with experimental group membership as the independent variable. Prior to analyses, the raw data will be z-transformed to examine extreme outliers ( $z > 3.0$ ), and these outliers will be replaced by the respective group means. The significance level for all of the tests is  $p < 0.05$ . The partial eta-squared ( $\eta_p^2$ ) is reported as a measure of the ES. For regression analyses, the number of predictors will be reduced by calculating the following sum scores in order to avoid

redundancies and to reduce multicollinearity: *v* (n-back; CPT), *a* (n-back; CPT), mean RT (n-back; CPT; SST) and ICV (n-back; CPT; SST); *d*'s are taken as individual values, as they are assumed to reflect different cognitive processes (n-back: WM; CPT: sustained attention). Further predictors are  $N_{\text{corr}}$  (digit span; BTT), SST, CI and OE (SST) and LRC (CDT). Stepwise multiple regression analysis will be used, entering age and IQ at the first stage and the remaining predictors simultaneously at the second stage. Finally, we will explore if diagnostic group membership accounts for additional variation in the timing measures by implementing group in a third step. Latent class models will be performed by an external service provider. The calculation of the sample size contains an estimated dropout rate of 25%, leaving 17 subjects to be excluded listwise with no attenuation of power. A dropout can be defined this way as any set of incomplete data. If the number of missing values exceeds 17 persons, we plan on multiple imputations.

### Patients and public involvement

The study will be presented to the local ADHD competence network, consisting of experts, affected patients and their parents, where all participants will jointly develop ideas about patient involvement in the development of further recruitment strategies and in the development of the study flyer. Moreover, we will collect ideas concerning the presentation of the study results.

### Ethics and dissemination

The study will be conducted in accordance with the Declaration of Helsinki. Prior to study participation, all children and their parents will be informed about the aim of the study in a more general way as taking part in some experiments about concentration and time estimation. They will be provided with a detailed study information sheet and all points from the sheet are gone through



with them. The sheet is designed such that it is easily understood by younger probands. The children and their parents will be informed that they will be allowed—at any time—to discontinue their study participation without giving reasons, without incurring sanctions and other disadvantages as a result, and they will be informed about the applied data protection measures. Then, oral and written informed consent/assent will be collected from the parents and their children, respectively. If only the parent or the child, that is, not both, agreed to participate, the child will not be included in the study. At the end of the study, a detailed final discussion will be conducted with the parents and their children on the specific study aims.

As the proposed study uses only computer experiments and does not use burdening stimulus material, there is no health risk to the study participants. The two experimental sessions will take approximately 2 hours each. In order to avoid attention overload and demotivation, a relaxing break of about 20 min will be scheduled for both experimental sessions after half of the tasks have been solved. During the break, the children will be offered to play popular games, that is, table football or air hockey. The children will be looked after by the experimenter (doctoral student) who is always present during the experimental sessions, and they will be asked about their well-being after the experiments have been completed. Moreover, the physician on duty is present in the premises of the outpatient clinic and can be consulted, if necessary.

According to the Federal Data Protection Act, the data collected during this study will be stored in a pseudonymised manner. Each participant will receive a study code. Personal data will be stored in two separate databases: (a) the reference list which will be kept under lock and which contains names, birthdays, contact information and study code and (b) the experimental file which contains experimental data and study code. After termination of the study, the reference list will be deleted. The data will only be used for research purposes and communications and publications will not enable identification of individual participants. Data backup and storage orient itself along the Good Clinical Practice guidelines of the German Research Foundation (DFG) commission ‘Self-control in Science.’

Data from all experiments will be made available in the form of SPSS files and .csv files (exchange format) via the Open Science Framework (<https://osf.io/>) and will be additionally accessible via the first authors’ homepage on Researchgate (<http://www.researchgate.net>) after publication. The data will be stored for the duration of at least 10 years and according to the rules of data protection at the University of Rostock. The results of this study will be disseminated to researcher, clinician and patient communities in peer-reviewed journals and at scientific conferences, at a meeting of the local ADHD competence network, and on our web page which will summarise the study results in an easily comprehensible manner.

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