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Why cognitive performance in ADHD may not reveal true potential: Findings from a large population-based sample

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Abstract

Focusing on symptoms of attention deficit hyperactivity disorder (ADHD) in a sample obtained from the general population, we aimed to investigate the effects of incentives and event rate on reaction time (RT) performance and response inhibition. We assessed 1,156 children, at a mean age of 8 years, on their performance on an inhibition task and a RT task under different experimental conditions that manipulated event rate and incentives. Children with high ADHD symptoms (ADHD-H) showed cognitive performance deficits only under some of the experimental conditions, compared to a control group. The fast-incentive condition of the RT task succeeded in normalising the RT variability, as well as the slow overall speed, in the ADHD-H group. Analyses on ADHD symptom scores as a quantitative trait in the total sample were overall consistent with these findings. The findings suggest that at least some cognitive performance deficits in children with high ADHD symptoms do not reflect stable cognitive deficits. The degree to which cognitive impairments in ADHD can be modulated by energetic or motivational factors has important implications for clinical and educational interventions.

Keywords

attention deficit hyperactivity disorder; reaction times; response time; inhibition; attention; incentives

INTRODUCTION

Studies of the cognitive profile in attention deficit hyperactivity disorder (ADHD) indicate poor performance across multiple executive, as well as non-executive, domains (Kuntsi et al., 2006a; Willcutt et al.,2005). Yet there is inconsistency in findings across studies. Rather than considering the inconsistency as 'noise', the factors underlying it may inform us on the underlying processes.

A recent, detailed investigation confirmed earlier observations that the largest differences in comparisons between children with ADHD and control children across several commonly used cognitive tasks emerge for reaction time (RT) variability (Klein et al.,2006). In some studies this emerged initially as a 'side' finding, when other cognitive variables failed to distinguish between the groups (Kuntsi et al., 2001; Kuntsi & Stevenson, 2001). The strength and

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consistency of the association have, however, placed RT variability firmly on the scientific agenda. The proposed underlying causes for RT variability in ADHD continue to be debated (Bellgrove et al., 2005; Castellanos & Tannock, 2002; Castellanos et al., 2005; Kuntsi et al., 2006a), but several of the models require further development to include explicit, testable predictions that enable them to be properly proved or falsified.

Based on predictions emerging from theories of a deficit in the regulation of energetic state in ADHD (Sergeant, 2005; van der Meere, 2002), we recently investigated the extent to which RT variability can be 'normalised' in ADHD using a simple RT task unaffected by more complex cognitive demands—referred to as the 'fast task' (Andreou et al., 2007). We showed that under a condition with a fast event rate and incentives, the ADHD group improved significantly more than the control group in both speed and RT variability. Yet the performance of the ADHD group did not completely reach the level of the control group in the fast-incentive condition, suggesting that neither the manipulations of event rate or incentives were fully successful in optimising the energetic state of the participants with ADHD or that additional processes may be involved.

ADHD is also linked to performance deficits on inhibitory control tasks (Willcutt et al., 2005). However, several authors have questioned the primacy of an inhibition deficit in ADHD as the underlying mechanism for the observed difference in performance. Recent meta-analyses indicate that poor performance in ADHD on the stop task, which involves the suppression of an ongoing response, is not due to real differences in the inhibition measure of stopping speed between ADHD and control groups, but reflects differences in children's mean RT to go-stimuli (Alderson et al., 2007; Lijffijt et al., 2005). A carefully controlled cognitive experiment indicated poor overall performance in a combined continuous performance test–go/no-go task in young children at risk for ADHD, but no evidence of a deficit specific to either inhibitory control or sustained attention (Berwid et al., 2005). Electrophysiological data further indicate that inhibitory control difficulties in ADHD are accompanied by altered response preparation and execution processes in children (Banaschewski et al., 2004; Brandeis et al., 1998; Pliszka et al., 2000; van Leeuwen et al., 1998) and adults (McLoughlin et al., under review), which may indicate a more general state or response regulation problem (Banaschewski et al., 2004).

The primacy of an inhibition deficit in ADHD has been further studied using event rate and incentive manipulations. In two studies an apparent response inhibition deficit in ADHD 'disappeared' following the introduction of incentives (Konrad et al., 2000; Slusarek et al., 2001); yet this is not consistently found and, in general, study results appear highly sensitive to task parameters (Luman et al., 2005). Using event rate manipulations, some studies report no inhibition deficit in ADHD under any event rate, whereas other studies find ADHD-control differences only in a slow condition or, conversely, only in a fast condition (van der Meere, 2002; Wiersema et al., 2006). The effects of such manipulations on RT performance, when measured by the stop and go/no-go tasks, also vary across studies, emphasising both the sensitivity of ADHD performance to task parameters and the differential sensitivity of different aspects of task performance to the same task manipulation. For example, a fast event rate may lead to improved speed but worse inhibition performance. Yet a key finding emerges: children with ADHD do not show a stable inhibition deficit across varying task conditions.

The cognitive studies on ADHD commonly focus on clinically diagnosed ADHD. Given that selection biases may influence the composition of clinic-based samples, a complementary approach that focuses on ADHD symptoms in a sample obtained from the general population is required for a detailed understanding of the underlying processes. Such an approach is especially common in quantitative genetic research that assumes a liability threshold model, in which ADHD symptoms are continuously distributed throughout the population, with the 'extreme' group defined on the basis of a predetermined cut-off point on a quantitative scale. The underlying assumption is that multiple susceptibility factors (genes and environment) contribute to an underlying distribution of liability for the disorder. The evidence from quantitative genetic (twin and sibling) studies, as well as from epidemiological studies of environmental risk factors and prediction of adverse outcomes, is consistent with the hypothesis that ADHD represents the extreme of a quantitative trait in the population (Chen et al., 2008; van der Meere, 2002; Wiersema et al., 2006).

This study aimed to investigate the effects of incentives and event rate on RT performance and response inhibition by comparing the top 5% of the highest scoring individuals on ADHD symptoms from a large general population sample to the remainder of the sample. A 5% threshold was chosen to be comparable to estimated prevalence rates of ADHD in the UK of 4% for males and 1% for females (Ford et al., 2003), while also ensuring an adequate sample size for the analyses. Specifically, we investigated the extent to which RT variability, mean RT and inhibition performance can be normalised under conditions that aim to optimise the energetic state in ADHD. We have previously carried out a small-scale pilot investigation of the association between ADHD symptom scores in the general population and performance on the fast task and a go/no-go task under different conditions (Kuntsi et al., 2005). Here we extend this research to a separate, large sample of 1,156 children aged 7 to 9 years, and we compare the top 5% of the highest-scoring individuals on the ADHD scale with the rest of the sample. We investigate the effects of event rate and incentives both separately (go/no-go task) and in combination (fast task). The latter approach specifically examines the extent to which a response style characterised by slow and variable speed of responding can be *maximally* reduced. In addition, we investigate associations with task performance for continuous ADHD symptom scores in the total sample.

METHODS

Sample and procedure

Participants are members of the Study of Activity and Impulsivity Levels in children (SAIL) (Kuntsi et al., 2006b), a study of a general population sample of twins at age 7 to 10 years. The sample was recruited from a birth cohort study, the Twins' Early Development Study (TEDS, Trouton et al., 2002), which had invited parents of all twins born in England and Wales during 1994-1996 to enroll. Zygosity was determined using a standard zygosity questionnaire that has been shown to have 95% accuracy (Price et al., 2000).

Families on the TEDS register were invited to take part if they fulfilled the following SAIL project inclusion criteria: twins' birthdates between 1st September 1995 and 31st December 1996; lived within a feasible travelling distance from the Research Centre; ethnic origin white European (to reduce population heterogeneity for molecular genetic studies); recent participation in TEDS, as indicated by return of questionnaires at either 4- or 7-year data collection point; no extreme pregnancy or perinatal difficulties or specific medical syndromes, chromosomal anomalies, or epilepsy; not participating in other current TEDS sub-studies; and not on stimulant or other neuropsychiatric medications.

Of the 1,230 suitable families contacted, 672 families agreed to participate, reflecting a participation rate of 55%. Thirty individual children were subsequently excluded because of IQ <70, epilepsy, autism, obsessive-compulsive disorder, or neurodevelopmental disorderillness during testing, or placement on stimulant medication for ADHD. For the current analyses, we only included participants from whom we had the ADHD ratings from parents and teachers, reflecting 82% of the total available SAIL sample. The final sample for the current analyses consisted of 1,156 children. The mean age was 8.79 (SD = 0.66). The children's IQs ranged from 70 to 158 (mean = 109.70, SD = 14.72). The sample was 50% male. Parents of all participants have given informed consent and the Institute of Psychiatry Ethical Committee approved the study.

The families visited the Research Centre for the assessments. Two testers assessed the twins simultaneously in separate testing rooms. The tasks were administered in a fixed order as part of a more extensive test session, which in total lasting approximately 2.5 h.

Measures

Wechsler Intelligence Scales for Children, Third Edition (WISC-III, (Wechsler, 1991)—The Vocabulary, Similarities, Picture Completion and Block Design subtests from the WISC-III were used to obtain an estimate of the child's IQ following procedures described by Sattler (Sattler, 1992).

***The Go/No-Go Task* (Borger & van der Meere, 2000; Kuntsi et al., 2005; van der Meere, et al., 1995)—**On each trial, one of two possible stimuli appeared for 300 ms in the middle of the computer screen. The child was instructed to respond only to the 'go' stimuli and to react as quickly as possible, but to maintain a high level of accuracy. The proportion of 'go' stimuli to 'no-go' stimuli was 4:1. The response variables were commission errors (an index of inhibition), mean RT to 'go' stimuli and standard deviation of the RTs. Omission errors were rare – mean in each condition 2-12% – and were therefore not included in analyses.

The children performed the task under three different conditions, matched for length of time on task. The fast condition consisted of 462 trials and had an inter-stimulus-interval (ISI) of 1 s. The ISI dropped to 8 s in the slow presentation condition, which consisted of 72 trials. The order of presentation of the slow and fast conditions was varied randomly across children.

The incentive condition was administered last, to ensure that the possibility of earning rewards would not adversively affect performance on the other conditions where rewards could not be earned. This condition is a modification of the incentive condition used in the study on the stop task by Slusarek et al. (2001). Each correct response to the letter X and each correct non-response to the letter O earned the child one point. The child lost one point for each omission error (failure to respond to X) and for each failure to respond within 2 s. Each commission error (incorrect response to O) led to the loss of five points. The points were shown in a box, immediately right of the screen centre, and were updated continuously throughout. The child started with 40 points, to avoid the possibility of a negative tally. The child was asked to try to win as many points as possible, and was told that the points will be exchanged for a real prize when the game ends. This condition consisted of 72 trials and had an ISI of 8 s. A practice session preceded each experimental condition.

***The Fast Task* (Andreou et al., 2007; Kuntsi et al., 2005; Kuntsi et al., 2006b)—**The baseline condition followed a standard warned four-choice RT, as outlined in Leth-Steensen et al. 2000). A warning signal (four empty circles, arranged side by side) first appeared on the screen. At the end of the fore period (presentation interval for the warning signal), the circle designated as the target signal for that trial was filled (coloured) in. The child was asked to make a compatible choice by pressing the response key that directly corresponded in position to the location of the target stimulus. Following a response, the stimuli disappeared from the screen and a fixed inter-trial interval of 2.5 s followed. Speed and accuracy were emphasised equally. If the child did not respond within 10 s, the trial terminated.

First a practice session was administered, during which the child had to respond correctly to five consecutive trials. The baseline condition, with a fore period of 8 s and consisting of 72 trials, then followed.

To investigate the extent to which a response style characterised by slow and variable speed of responding can be maximally reduced, the task includes a comparison condition that uses a fast event rate (1 s) and incentives. This condition started immediately after the baseline condition and consisted of 80 trials using the faster event rate conditions employed by Leth-Steensen et al. (2000). The children were told to respond really quickly one after another, to win smiley faces and earn real prizes in the end. The children won a smiley face for responding faster than their own mean RT during the baseline (first) condition consecutively for three trials. The baseline mean RT was calculated here based on the middle 94% of responses, therefore excluding extremely fast and extremely slow responses. The smiley faces appeared below the circles in the middle of the screen and were updated continuously.

The response variables were mean RT and standard deviation of the RTs, calculated for each condition based on correct responses only. For analyses that compared performance across the baseline and fast-incentive conditions, data from the second set of 30 trials of the baseline condition were used to provide a match on length of time on task with the fast-incentive condition (see Andreou et al., 2007), as data from a twin project suggest greater reliability and heritability for the second than first set of 30 trials (Kuntsi & Asherson, unpublished data). The fast-incentive condition is always administered after the baseline condition and, as such, does not involve a similar learning phase.

Rating scales—ADHD symptoms were measured using the Long Version of Conners' Parent Rating Scale (CPRS-R:L, Conners et al., 1998b) and the Long Version of Conners' Teacher Rating Scale (CTRS-R:L,Conners et al., 1998a). On both the parent and teacher Conners' scales, adding up the scores on the 9-item hyperactive-impulsive and 9-item inattentive DSM-IV symptoms subscales forms a total DSM-IV ADHD symptoms subscale. We created an ADHD composite score by adding up the scores on the parent and teacher DSM-IV ADHD symptoms subscales.

Analyses

We conducted analyses using STATA Statistical Software release 9.2 (Stata Corporation, College Station, TX, USA). As the sample consisted of twins, we used the cluster command to remove any effects of familial clustering. Analysis of untransformed data was justified by the large sample size, with central limit theorem showing that the large sample size means that normality assumptions will not be violated for parametric tests (Lumley et al., 2002), and the use of logistic regression for group comparisons. The advantage of this analytic approach over ANOVA or MANOVA is that it corrected for the non-independence of the data and maximised power. A further advantage of logistic regression is its insensitivity to unequal cell sizes (Tabachnick & Fidell, 2001). Age and sex were included as covariates in the partial correlation and regression analyses. Given the clear a priori hypotheses for the direction of group differences for each variable and the aim of replicating findings across several of the variables, exact p-values are presented. A False Discovery Rate (FDR) correction for multiple testing was additionally used (Benjamini et al., 2001) based on an alpha of $p<.05$. Those p-values that remained significant after this adjustment are indicated with an asterisk in Table 2.

In the categorical analyses that compared the two groups, we first examined each task condition separately. Group status was entered into the logistic model as response variable and cognitive performance variables [mean reaction time (MRT), SD of RTs, commission errors], age and sex as predictor variables. Next, we examined the extent of improvement across task conditions, both within each group and between the groups, to investigate whether children with high ADHD symptoms (ADHD-H group) improved more than the comparison group. For between-group improvement analyses we entered group status as the response variable in the logistic regression model and difference score (performance on the variable in baseline condition –

performance on the same variable in the comparison condition), along with age and sex, as the predictor variables. To ensure comparability across scores, odds ratios (OR's) are presented for standardised cognitive scores. Each OR can thus be interpreted as the increase in risk of being in the ADHD-H group associated with a change of 1 standard deviation in cognitive score. Standardised scores are calculated by rescaling the group score distribution such that it has a mean of 0 and an SD of 1. For within-group improvement analyses we used a linear regression with the xi: interaction expansion command within STATA.

RESULTS

Categorical analyses

The ADHD-H group was created by selecting the highest-scoring 5% on the ADHD composite score (n = 58). The rest of the sample formed the control group (n = 1,098). The groups matched well on age and IQ, but there was an excess of boys in the ADHD-H group (Table 1). Examination of this sex difference revealed that the mean difference between males and females was significantly greater in the highest (5th) quintile of the distribution of ADHD composite scores compared to the rest of the sample, t(601) = −2.51, p=0.01, or compared to the 4th quintile, t(348) = −4.38, p<0.001.

The fast task analyses indicated that the ADHD-H group, compared to the control group, had slower MRT and greater SD of RTs in the baseline condition (both for all trials and 30 trials), whereas the groups did not differ in the fast-incentive condition (Table 2 and Figure 1). The within-group analyses indicated that both groups improved significantly both for MRT [ADHD-H t(606) = 10.73, p=.003; control t(606) = 10.30 p<.001] and SD of RTs [ADHD-H t(606) = 5.07, p<.001; control t(606) = 4.39, p<.001] from the baseline to the fast-incentive condition, with the between-group analyses showing that the improvement was significantly greater for the ADHD-H group (Table 2).

In the go/no-go task analyses, significant group differences emerged for MRT in fast and slow conditions, for SD of RTs in each of the conditions, and for commission errors in fast and incentive conditions (Table 2). The within-group analyses indicated that both groups improved significantly from slow to fast condition both for MRT [ADHD-H t(609) = 5.92, p<.001; control t(609) = 5.79 p<.001] and SD of RTs [ADHD-H t(609) = 3.32, p=.001; control t(609) = 2.87, p=.004], but not for commission errors [ADHD-H t(609) = 0.72, p=.47; control t(609) = 1.09, p=.27]. Both groups similarly improved significantly from slow to incentive condition for MRT [ADHD-H t(606) = 5.17, p<.001; control t(606) = 4.17 p<.001] and SD of RTs [ADHD-H t(606) = 3.71, p<.001; control t(606) = 3.03, p=.003], but not for commission errors [ADHD-H t(606) = 1.22, p=.22; control t(606) = 1.69, p=.09]. Between fast and incentive conditions, only the control group improved significantly for MRT [ADHD-H t(608) = −1.72, p=.09; control t(608) = −2.42, p=.02] and neither group for SD of RTs [ADHD-H t(608) = 0.95, p=.34; control t(606) = 0.52, p=.60] or for commission errors [ADHD-H t(608) = 0.65, p=.52; control t(608) = 0.73, p=.46]. All significant p-values remained significant at the alpha level of p<.05 after FDR correction for multiple testing (Benjamini et al., 2001), run separately for both sets of within-group analyses. The between-group comparisons for difference scores indicated greater improvement in the ADHD-H group than the control group for MRT from the slow to the incentive condition and from the fast to the incentive condition; and for SD of RTs from slow to the incentive condition (Table 2). Greater improvement across conditions was not observed for commission errors.

As combining data across theoretically-related measures improves reliability (Kuntsi et al., 2006b), we conducted additional analyses on RT data combined across the two tasks to investigate whether such composite scores best distinguish between the groups. For the go/no-go task our *a priori* prediction for largest ADHD-control group differences on RT data was for the slow condition, but the data indicated good group discrimination on RT data also for the fast condition. We therefore created RT composite scores in two ways: (1) combining data from fast task baseline condition and go/no-go task slow condition; (2) combining data from fast task baseline condition and go/no-go task fast condition. The odds ratios for the composite scores were of similar magnitude as those for the individual variables that best discriminated between the groups (Table 2).

The pattern and significance of the results were similar when additional analyses were carried out on data from boys only (data not shown). Additional analyses were also conducted to examine speed-accuracy trade off by obtaining correlations between MRT and commission errors. For both groups, the correlations were in the range of −0.34 – −0.50 ($p<0.01$) for the slow and incentive conditions. This indicates an association between fast speed and more errors, and hence speed-accuracy trade off. For the fast condition there was no association between MRT and commission errors for the ADHD-H group ($r = 0.06$, ns) and a correlation of −0.16 ($p<0.01$) for the control group.

Dimensional analyses

To study the association between the continuous dimension of ADHD symptom scores and cognitive performance, we obtained Pearson correlations between the ADHD composite score and each of the cognitive variables, controlling for age and sex (Table 3). The correlations were 0.2 – 0.3 (effect sizes of 0.4 – 0.5) for the variables most strongly associated with the ADHD composite score, with the highest correlation obtained for SD of RTs when combined across fast task baseline condition and go/no-go task slow condition. We carried out additional analyses controlling for IQ, but this did not change the pattern of findings (data not shown).

DISCUSSION

Cognitive deficits in ADHD have sometimes been characterised as having a “now you see it, now you don’t” quality to them. Studies that have included within-task manipulations, such as varied event rate and incentives, have investigated the stability of cognitive impairments in ADHD. In a study of clinic-referred participants with a research diagnosis of DSM-IV combined type ADHD, we previously demonstrated greater improvement in RT variability in a condition of the fast task with a fast event rate and incentives (Andreou et al., 2007). Here, using the same RT task in a large sample of children, we showed that RT variability normalised in the fast-incentive condition in children who represented the highest-scoring 5% on an ADHD composite rating scale score. The finding applied also to speed of responding (mean RT). The go/no-go data similarly suggested that slow speed is not a stable characteristic of children with high levels of ADHD symptoms, since the groups differed in mean RT in the slow and fast event rate conditions but were indistinguishable in the incentive condition. For both mean RT and RT variability, incentives led to significantly greater improvements in the ADHD-H compared to the control group and hence were more effective than a fast event rate.

Overall, the fast task was more effective than the go/no-go task in normalising the RT variability in the children with high levels of ADHD symptoms. This may reflect one or both of two key differences between the tasks: (1) the fast task focuses on the combined effects of incentives and fast event rate, whereas in the go/no-go task the effects of each are studied individually, and (2) in the fast task the aspect of performance that is rewarded is reduced RT variability, whereas in the go/no-go task accuracy is rewarded.

For commission errors in the go/no-go task, the groups differed significantly in the fast and incentive conditions, but not in the slow condition. While this appears to suggest a lack of a stable inhibition deficit in the ADHD-H group, we also note that neither group improved significantly across the conditions, which calls for some caution in the interpretation of the results. Further, the pattern of response inhibition performance (commission errors) across conditions did not confirm our expectations that group differences would be the most pronounced in the slow condition and that the ADHD-H group would show relatively greater improvement than controls from the slow to the fast and incentive conditions. Our results failed to replicate previous findings using the stop task on clinically diagnosed samples in which ADHD-control differences in response inhibition disappeared in an incentive condition (Konrad et al., 2000; Slusarek et al., 2001). These findings add to the previous research that indicates highly mixed findings from studies of event rate using inhibition tasks (van der Meere, 2002; Wiersema et al., 2006). The go/no-go task is one of the most popular tasks in ADHD research, but findings obtained depend crucially on the exact task parameters, highlighting the complexity of tasks that involve multiple cognitive demands. The task requires the child to be both fast and accurate, but we showed that the speed-accuracy trade-off did not remain stable across task conditions and groups. For example, incentives led to faster speed in the ADHD-H group, but not to a similar improvement in the percentage of commission errors, suggesting that the higher speed set a limit on any incentive-induced improvement in accuracy.

Findings from the analysis of the continuous ADHD symptom scores in the total sample were overall consistent with those obtained in the categorical (group) analyses. The correlations for key task variables were significant but somewhat lower than the highest correlations obtained with teacher-rated ADHD symptom scores in a previous small-scale preliminary investigation (Kuntsi et al., 2005). Among the highest correlations with the ADHD composite score in the current study was that obtained for the RT variability composite score ($r = 0.3$; effect size 0.5), calculated by summing up fast task baseline and go/no-go task slow condition data.

The composition of the ADHD-H group, defined as the top scoring 5% on the ADHD composite score, indicated a marked excess of boys (91%), replicating the well documented finding of gender imbalance in clinical ADHD samples (Ford et al., 2003). Analyses on a boys-only sample indicated largely similar findings as for the whole sample, with theoretical conclusions remaining the same.

The 5% threshold for the ADHD-H group was based on both prevalence rate and statistical power considerations. It is beyond the scope of the present study to examine effects of different possible cut-offs, but we acknowledge this as a limitation of the current study and as a worthwhile future topic of investigation. The applicability of the findings across a wider age range – beyond ages 7-10 as studied here – also needs to be established in future research.

Overall, two main findings emerged from this study. First, children representing the top-scoring 5% on an ADHD composite score showed poor inhibition and reaction time performance under some of the experimental conditions, replicating previous findings with clinically diagnosed samples on aspects of cognitive processing affected in ADHD. Second, these performance deficits, particularly on mean RT and RT variability, may not reflect stable cognitive deficits, as there were no group differences in some of the comparison conditions. This is consistent with predictions based on theories of a deficit in the regulation of energetic state in ADHD (Sergeant, 2005; van der Meere, 2002). It is not clear how alternative theoretical accounts of RT variability, such as the temporal processing/time estimation deficit hypothesis (Castellanos et al., 2002), would account for the overall pattern of findings, particularly the greater improvement in RT variability in the high-ADHD group when both incentives and faster event rate were combined (or with incentives rather than a fast event rate, when studied separately in the go/no-go task). Yet we did not set out specifically to test predictions of competing hypotheses for RT variability here and this requires further research.

In recent years the association between RT variability and ADHD has become one of the key topics in cognitive research on ADHD (Bellgrove et al., 2005; Castellanos et al., 2005; Klein et al., 2006). Without experimental manipulations or other theory-driven probing of the underlying mechanisms, RT variability itself is a non-specific finding that may reflect multiple potential causes. The finding here that RT variability (as well as mean RT) normalised in children with high ADHD symptoms under a fast-incentive condition extends our previous finding with a clinically diagnosed ADHD group, where RT variability improved more among the ADHD than control group, but did not completely normalise (Andreou et al., 2007). Clinic-referred individuals with ADHD diagnoses may either have impairments beyond those directly linked to their behavioural symptoms, or their behavioural symptoms – and associated cognitive or energetic deficits – may be more severe than those observed in children representing the highest-scoring 5% on an ADHD composite score. The specificity of the improvement in RT variability in ADHD also requires further study in relation to disorders that frequently co-occur with ADHD, as well as other disorders where RT variability may be observed.

A recent electrophysiological study reported an association between increased theta power, associated with cortical underarousal, and RT variability (Loo & Smalley, 2008), which is also consistent with the hypothesis that RT variability may index lapses in attention due to an energetic state that is non-optimal for task performance. The proposal that energetic processes are affected in ADHD links with findings that indicate how the mesolimbic dopamine system is involved in behavioural activation and effort-related processes (Salamone et al., 2007). Salamone et al. conclude in their review that "*nucleus accumbens dopamine regulates response speed and the exertion of effort in reinforcer-seeking behaviour, and participates with other brain areas in the regulation of decisions based upon effort expenditure*" (p. 475). Such neuroscience research will inform the further development of models of ADHD.

The degree to which cognitive impairments in ADHD can be modulated by energetic or motivational factors has important implications for clinical and educational interventions. In addition to highlighting the importance of using such energetic or motivational factors in helping children with ADHD stay focused, a further implication is the need to avoid labelling children with ADHD as 'low ability' where tasks may not have revealed their true ability. Further investigation of the factors that help children with ADHD achieve their potential seems a key priority.

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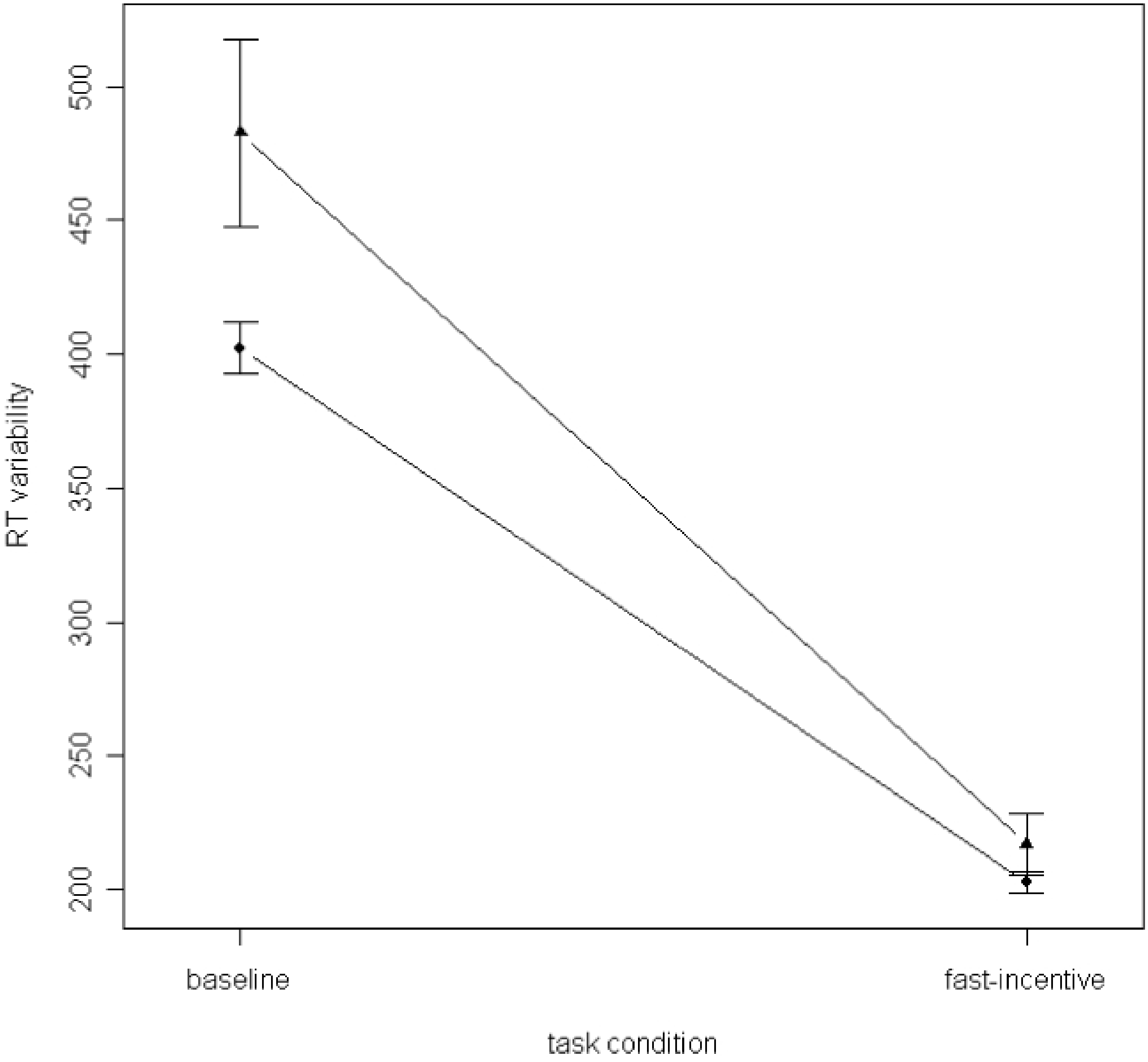

Figure 1.

Reaction time variability (SD of RTs) in baseline and fast-incentive conditions of the fast task (with standard errors): ADHD-H (-▲-) and control (-●-) groups. Note: Data presented on raw data; age and sex not controlled for.

Table 1

Sample characteristics: ADHD-H and control groups

	ADHD-H (N=58)	Control (N=1098)	Group comparison statistic
Age	8.79 (0.66)	8.79 (0.66)	$t_{(1154)} = .00$; $p>.99$
% male	91.38	48.09	$X^2 = 41.30$; $p<.001$
Full scale IQ	108.31 (14.72)	109.77 (14.72)	$t_{(1154)} = .74$; $p=.46$
Parent Conners': total DSM-IV ADHD symptoms subscale	33.05 (8.56)	10.91 (8.04)	$t_{(1154)} = 20.37$; $p<.001$
Teacher Conners': total DSM-IV ADHD symptoms subscale	30.33 (9.82)	7.12 (7.38)	$t_{(1154)} = 22.90$; $p<.001$

Table 2

Means (and standard deviations) and between-group comparisons on the fast task and go/no-go task variables, controlling for age and sex

	Mean (SD) *				
	ADHD-H (n=52– 57)	**Control (n=1043–1092)**	**z[b]**	**P**	**Odds ratio[a]**
Fast task					
Baseline (all trials)					
MRT	1018. 25 (259.03)	942.76 (232.55)	3.07	.002*	1.49
SD of RTs	494.63 (272.32)	403.73 (273.94)	3.05	.002*	1.37
Baseline (30 trials)					
MRT	1091.76 (300.34)	1007.12 (268.96)	3.19	.001*	1.47
SD of RTs	482.68 (257.99)	402.25 (316.12)	2.97	.003*	1.32
Fast-incentive					
MRT	653.17 (143.64)	648.13 (161.92)	0.47	.64	1.07
SD of RTs	216.99 (84.76)	202.61 (133.59)	0.78	.44	1.06
Difference score (baseline – fast-incentive)					
MRT	438.59 (251.73)	359.14 (202.98)	3.54	<.001*	1.54
SD of RTs	265.69 (234.89)	198.76 (293.55)	2.82	.01*	1.30
Go/no-go task					
Slow					
MRT	616.13 (179.49)	584.38 (129.02)	2.42	.02*	1.36
SD of RTs	311.04 (232.44)	219.26 (143.83)	3.77	<.001*	1.51
Commission errors	64.36 (20.58)	54.52 (23.12)	1.54	.12	1.26
Fast					
Mean RT	434.44 (71.95)	420.86 (62.52)	2.79	.01*	1.50
SD of RTs	202.23 (69.04)	159.64 (56.89)	4.61	<.001*	1.70
Commission errors	61.80 (14.48)	50.86 (16.36)	3.45	.001*	1.66
Incentive					

	Mean (SD) *				
	ADHD-H (n=52– 57)	**Control (n=1043–1092)**	**Z[b]**	**P**	**Odds ratio[a]**
MRT	533.73 (94.72)	555.16 (112.84)	−.31	.76	0.96
SD of RTs	173.18 (87.37)	144.08 (71.08)	2.43	.02*	1.25
Commission errors	42.02 (19.07)	31.36 (20.69)	3.06	.002*	1.46
Difference score (slow – fast)					
MRT	183.13 (159.41)	163.62 (106.76)	1.43	.15	1.21
SD of RTs	109.07 (224.18)	59.88 (138.29)	2.01	.04	1.30
Commission errors	2.36 (19.78)	3.67 (20.16)	−1.15	.25	0.86
Difference score (slow – incentive)					
MRT	90.11 (157.46)	29.18 (93.51)	3.54	<.001*	1.57
SD of RTs	141.78 (230.19)	75.19 (142.52)	2.58	.01*	1.34
Commission errors	21.85 (24.24)	23.17 (21.35)	−1.10	.27	0.85
Difference score (fast – incentive)					
MRT	−97.98 (87.09)	−134.02 (96.52)	1.97	.05	1.41
SD of RTs	30.77 (107.31)	15.82 (79.29)	0.94	.35	1.18
Commission errors	19.74 (23.95)	19.48 (19.18)	−0.13	.90	0.98
Combined data					
Fast task baseline + go/no-go slow					
MRT	1620.19 (395.78)	1521.81 (309.42)	2.82	.01*	1.51
SD of RTs	781.01 (405.75)	615.91 (342.91)	3.78	<.001*	1.54
Fast task baseline + go/no-go fast					
MRT	1450.25 (296.86)	1361.04 (268.27)	3.35	.001*	1.59
SD of RTs	696.43 (294.57)	560.55 (290.36)	4.16	<.001*	1.55

* Indicates p-values that remain significant at p<.05 after False Discovery Rate correction for multiple testing (Benjamini et al., 2001)

[a] Means and standard deviations calculated from raw data

[b] Odds ratio calculated from standardised cognitive score and represents the increase in risk associated with a 1 standard deviation change in cognitive score

[c] Odds ratio test statistic

Table 3

Association between ADHD composite score and fast task and go/no-go task variables: partial correlations controlling for age and sex, with associated effect sizes (d)

	ADHD composite score	
	Partial r	**d**
Fast task		
Baseline (all trials)		
MRT	.21**	0.4
SD of RTs	.22**	0.5
Baseline (30 trials)		
MRT	.20**	0.4
SD of RTs	.17**	0.3
Fast-incentive		
MRT	.11**	0.2
SD of RTs	.11**	0.2
Difference score (baseline – fast-incentive)		
MRT	.17**	0.3
SD of RTs	.14**	0.3
Go/no-go		
Slow		
MRT	.15**	0.3
SD of RTs	.23**	0.5
Commission errors	.08**	0.2
Fast		
MRT	.13**	0.3
SD of RTs	.20**	0.5
Commission errors	.15**	0.3
Incentive		
MRT	.04	0.1
SD of RTs	.13**	0.3
Commission errors	.13**	0.3
Difference score (slow – fast)		
MRT	.11**	0.2
SD of RTs	.16**	0.3
Commission errors	.03	0.1
Difference score (slow – incentive)		
MRT	.17**	0.3
SD of RTs	.17**	0.3

	ADHD composite score	
	Partial r	**d**
Commission errors	.04	0.1
Difference score (fast – incentive)		
MRT	.03	0.1
SD of RTs	.03	0.1
Commission errors	.00	0.0
Combined data		
Fast task baseline + go/no-go slow		
MRT	.21**	0.4
SD of RTs	.26**	0.5
Fast task baseline + go/no-go fast		
MRT	.21**	0.4
SD of RTs	.24**	0.5

** p<=.01