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Attention regulation in women with ADHD and women with bipolar disorder: An ex-Gaussian approach

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ABSTRACT

Attention-deficit/hyperactivity disorder (ADHD) and bipolar disorder (BD) show certain overlapping features, such as increased reaction time variability. Here, we tested whether more detailed ex-Gaussian reaction time distribution measures identify shared or disorder-specific impairments in ADHD and BD. The total assessed sample consisted of 60 women (20 each in ADHD, BD and control groups). We compared the groups on ex-Gaussian measures of mu, sigma, and tau from a flanker task (congruent and incongruent conditions), an oddball task, and a four-choice reaction time task (baseline and fast-incentive conditions of the 'fast task'). The ex-Gaussian measures mu and sigma reflect the speed and variability of typical responses, while tau captures variability in infrequent slow responses. Compared to controls, both ADHD and BD groups showed significantly increased tau in the fast task baseline condition. Participants with BD further showed a significantly increased sigma compared to ADHD and control groups in the flanker task incongruent condition. Our findings indicate that the ex-Gaussian approach is informative in detecting shared and disorder-specific cognitive impairments in ADHD and BD that may represent objective markers of these two disorders.

1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) and bipolar disorder (BD) are common psychiatric conditions in adults, affecting 2–4% and 1–2% of the worldwide population, respectively (Merikangas et al., 2011; Willcutt, 2012). Cross-disorder comparisons point to a degree of symptomatic overlap, such as in restlessness, accelerated speech, inability to maintain concentration and distractibility, which can lead to difficulties in the differentiation of the two disorders (Asherson et al., 2014; Kitsune et al., 2016). Cognitive measures may aid in the identification of impairments underlying both overlapping and disorder-specific symptoms.

One of the most consistently reported cognitive impairments in individuals with ADHD, across many cognitive tasks, is increased reaction time variability (RTV) (Kofler et al., 2013; Kuntsi and Klein, 2012), which is commonly measured with the standard deviation of reaction times (SD-RT) and has been linked to the neural mechanisms underlying attention allocation (Cheung et al., 2017). A number of studies have also reported increased RTV in adults with BD, compared to controls (Brotman et al., 2009; Gallagher et al., 2015; Moss et al.,

2016). In a direct comparison of adults with ADHD and adults with BD, we recently reported that both clinical groups, compared to controls, showed increased RTV on a four-choice RT task (the 'fast task') (Michelini et al., 2018). Yet, during a cued continuous performance task (CPT-OX), only the BD group showed a significantly increased RTV, while the ADHD group showed a marginal difference (Michelini et al., 2016). No impairments in RTV emerged in either clinical group during an arrow flanker task (Carruthers et al., under review). Overall, we detected shared impairments in participants with ADHD and those with BD when performing a less cognitively engaging task (the fast task), whereas in a more cognitively demanding task (CPT-OX) impairments emerged more clearly in the BD group. This suggests that the increased RTV in the clinical groups might be related to task differences (e.g. cognitive demand and event rates).

Despite high RTV being a common finding in ADHD, it is indeed an impairment that shows some malleability: incentives and faster event rates can lead to a greater improvement in RTV in children and adolescents with ADHD than in controls (Kofler et al., 2013; Kuntsi et al., 2013; Slusarek et al., 2001; Tye et al., 2016). Evidence of RTV malleability in individuals with BD is still scarce. In our recent study on

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adults, although RTV significantly improved from a baseline to a faster and rewarded condition of the fast task both in adults with ADHD and with BD, the improvement was not greater in ADHD or BD participants compared to controls (Michellini et al., 2018).

While the majority of the studies have investigated reaction times (RTs) using the mean (MRT) and standard deviation, which represent global indices to assess response speed and variability in task performance, RTs can be further decomposed into more detailed measures using ex-Gaussian models (Luce, 1991). The ex-Gaussian approach decomposes the RT distribution into a normal (Gaussian) component and an exponential (ex-Gaussian) component, with the latter reflecting the positive skew generally observed in RT distributions (Hervey et al., 2006). In this way, ex-Gaussian analyses allow us to derive three summary parameters: μ (the mean of the Gaussian component), σ (the SD of the Gaussian component) and τ (the variability of the exponential component) (Hervey et al., 2006; Luce, 1991). The distribution of faster responses is indexed by μ and σ , while the infrequent, slow RTs, which lengthen the positive tail of the distribution, are indexed by τ (Leth-Steensen et al., 2000; Luce, 1991; Vaurio et al., 2009). Overall, μ and σ can be defined as speed and variability of typical responses, and τ as the infrequent slow responses, with the latter representing a more detailed measure to investigate lapses of attention.

Using the ex-Gaussian approach, studies using different sustained attention tasks have reported increased τ in children, adolescents and adults with ADHD compared to controls (Gmehlin et al., 2014; Hervey et al., 2006; Lee et al., 2015; Leth-Steensen et al., 2000; Vaurio et al., 2009; Wolfers et al., 2015). Only one study did not observe increased τ in ADHD children compared to controls (Geurts et al., 2008); however, the two-choice RT task lasting 3 min used in this study may have been too short to detect τ . For σ and μ , the findings are less consistent, with some studies reporting increased σ (Buzy et al., 2009; Gmehlin et al., 2014; Hervey et al., 2006; Vaurio et al., 2009) or decreased μ (Hervey et al., 2006; Lee et al., 2015; Wolfers et al., 2015) in participants with ADHD compared to controls, while other studies have failed to find case-control differences in σ (Epstein et al., 2011; Lee et al., 2015; Leth-Steensen et al., 2000) and μ (Epstein et al., 2011; Lee et al., 2015; Leth-Steensen et al., 2000; Vaurio et al., 2009). These inconsistent results may relate to task differences, for example in cognitive demand (Hervey et al., 2006; Vaurio et al., 2009). Overall, the findings suggest that the increased SD-RT usually observed in individuals with ADHD is mostly explained by the infrequent slow responses measured with τ . This aligns with the effect sizes reported in a recent meta-analysis, which were significantly bigger for τ compared to σ , but not different between SD-RT and τ (Kofler et al., 2013).

Fewer studies have examined the ex-Gaussian measures in relation to BD. One study indicated increased τ on a sustained attention task in adults with BD, compared to controls, during the euthymic phase, and increased τ and σ during the depressive phase (Gallagher et al., 2015). However, in another study, euthymic participants with BD had increased σ , but not τ , compared to controls, while performing a version of the CPT with high event rate and low target frequency that is considered to be more cognitive demanding (Moss et al., 2016). The inconsistent results between these two studies can be explained by differences in experimental conditions (Moss et al., 2016). Overall, whereas the studies on ADHD suggests that τ is the most sensitive measure to capture case-control differences, the studies available on BD suggest that increased τ may be limited to certain cognitive tasks only. The ex-Gaussian approach, by isolating RTs into different components, can help in the identification of more detailed processes underlying cognitive performance.

Given the overlap of increased RTV, measured with SD-RT, between ADHD and BD while performing some tasks but not others (Michellini et al., 2016, 2018; Carruthers et al., under review), we now aim to investigate whether more detailed ex-Gaussian measures help in

better delineating shared or disorder-specific impairments between ADHD and BD. In order to investigate the specificity of these impairments to different tasks and task conditions, we use data from three different cognitive tasks (the flanker task, an auditory oddball task, and the fast task). We used an all-female sample to match the groups on gender; ADHD and BD in adults shows a relatively equal sex ratio (Das et al., 2012; Pini et al., 2005).

Although we focus on 'pure' groups of adults with ADHD or BD (who do not have comorbid ADHD and BD), the possibility remains of subthreshold symptoms of the other disorder; to address this, we additionally examine whether the shared cognitive impairments observed in adults with ADHD and adults with BD may be explained by subthreshold symptoms of the other disorder. For this study, we will consider shared impairments those impairments that are present in both clinical groups compared to controls, and disorder-specific impairments those that are present only in one of the two clinical groups, compared to controls, and that distinguish between the clinical groups.

2. Materials and methods

2.1. Sample

The total assessed sample consisted of 60 adult women (20 with ADHD, 20 with BD and 20 controls) aged between 20 and 52 years. Mean age and IQ did not differ by group (see supplementary material, Table S1). Participants with ADHD were recruited from the National Adult ADHD Clinic at the Maudsley Hospital, where any female cases meeting inclusion criteria were considered for potential inclusion in the study. Participants with BD were recruited from the Maudsley Psychosis Clinic from a sample that had previously taken part in another study (Hosang et al., 2012). Controls were recruited from the Mindsearch volunteer database maintained by the Institute of Psychiatry, Psychology and Neuroscience, King's College London, and randomly selected from all those meeting recruitment criteria for this study.

Diagnosis in the clinical groups was confirmed by checking medical records for details of diagnosis and psychiatric history, following DSM-IV criteria. Exclusion criteria for all groups were drug or alcohol dependency in the last 6 months, autism, epilepsy, neurological disorders, brain injury, past ECT treatment, current involvement in another research trial likely to alter symptom severity, pregnancy or a limited proficiency in English language. Individuals with ADHD and individuals with BD with a reported comorbidity of both ADHD and BD were also excluded. Individuals with BD group who were experiencing a manic episode at the time of the assessment were excluded; only participants who were euthymic at the time of participation were included in the BD group. Control participants who reported a history of psychiatric disorders or who were taking psychiatric medication, were excluded from the study. Comorbidity in the clinical groups and lack of psychiatric disorders in the control group were further assessed through gold-standard clinical evaluations when participants took part in this study. An ADHD diagnosis was excluded in the BD group after conducting the Diagnostic Interview for Adult ADHD (DIVA v. 2.0; (Ramos-Quiroga et al., 2016) and the self-rated 18-item Barkley Adult ADHD rating scale (BAARS-IV) (Barkley, Murphy, 2006). BD diagnosis was excluded in the ADHD group by checking for a history of past episodes of depression or hypomania/mania and evaluating current mood symptoms using the Altman Self-Rating Mania Scale (ASRM) (Altman et al., 1997) and the Beck Depression Inventory (BDI) (Beck et al., 1996), and current and lifetime history of mania using the Young Mania Rating Scale (YMRS) (Young et al., 1978).

Participants in the ADHD group had a current combined-type diagnosis or an inattentive-type diagnosis with sufficient symptoms of hyperactivity-impulsivity in childhood to meet a childhood combined-type diagnosis, reflecting the typical adult ADHD clinical population (Asherson et al., 2014). Participants in the BD group had a diagnosis of BD Type I, having experienced at least one manic episode lasting 1

week or more in the past, but were euthymic at the time of the assessments. Full information on clinical profiles of ADHD and BD on all clinical measures can be found in [Kitsune et al. \(2016\)](#), except for the BAARS-IV total scores, which are reported in supplementary material (Table S2). Briefly, the ADHD and BD groups did not differ from each other and from controls on mania symptoms (mania symptoms according to the ASRM: mean = 4.63, SD = 3.98 in the ADHD group; mean = 4.95, SD = 5.03 in the BD group; mean = 2.42, SD = 2.09 in the control group). Depression symptoms were significantly higher in the ADHD and BD groups compared to controls, with no difference between the two clinical groups (symptoms of depression according to the BDI: mean = 17.50, SD = 15.54 in the ADHD group; mean = 11.90, SD = 11.11 in the BD group; mean = 4.35, SD = 4.03 in the control group). More information on the clinical measures used for this sample is reported in supplementary material.

2.2. Procedure

Participants attended a single 4.5-h research session (including breaks) for cognitive-EEG assessment, IQ assessment and clinical interviews. All participants were asked to refrain from caffeinated drinks and nicotine 2 h before assessments. Participants with ADHD were asked to stop taking any stimulant medication prescribed for their ADHD 48 h prior to the assessment. On the day of the assessments, all ADHD participants who were taking stimulant medication ($n = 13$) confirmed that they had stopped medication in the preceding 48 h. For ethical reasons, participants were not asked to stop taking mood stabilizers (70% of the BD group), anti-psychotic medication (40% of the BD group) or anti-depressants (7% of the ADHD group and 25% of the BD group) they had been prescribed. Ethical approval for the study was granted by the Camberwell St Giles Research Ethics Committee (approval number 11/LO/0438) and all participants provided informed consent.

2.3. Arrow flanker task

The task was an adaptation of the Eriksen flanker paradigm designed to increase cognitive load used in previous studies ([Albrecht et al., 2008](#); [McLoughlin et al., 2014, 2009](#)). In each trial, a central black fixation mark was replaced by a target arrow (a black 18-mm equilateral triangle). Participants had to indicate whether the arrow pointed toward the left or right by pressing corresponding response buttons with their left or right index fingers. Two flanker arrows identical in shape and size to the target appeared 22 mm above and below the centre of the target arrow 100 ms prior to each target arrow. Both flankers pointed in either the same (congruent) or opposite (incongruent) direction to the target. As such, conflict monitoring is maximal during the incongruent condition. When the target appeared, both target and flankers remained on the screen for a further 150 ms, with a new trial being presented every 1650 ms. Two hundred congruent and 200 incongruent trials were arranged in 10 blocks of 40 trials over 13 min.

2.4. Auditory oddball task

Participants completed an auditory novelty oddball task adapted from [Laurens et al. \(2005\)](#). The task had a total duration of 12 min and consisted of 300 frequent non-target stimuli (1000 Hz tone), 50 infrequent target stimuli (1500 Hz tones) and 50 infrequent, unique, non-repeating novel stimuli, which included digital noises (whistles, buzzes and trills). The non-target, target and novel stimuli were presented with a probability level of 0.75, 0.125, and 0.125. All stimuli had a duration of 200 ms, with 5 ms rise / 10 ms fall, and were separated with a random inter-trial interval of between 1000–1500 ms (average 1250 ms). The order of presentation was pseudorandom, while ensuring that no two low probability stimuli (target or novel) occurred

consecutively. Stimuli were presented in eight blocks of 50 stimuli, with a short rest period between each block. Total task duration was approximately 12 min. Presentation of stimuli was via headphones at 90 dB sound pressure level. During recording participants were asked to sit still with their eyes-open and focused on a static fixation mark on a screen directly in front of them. Participants responded to targets by pressing a button with the thumb of their dominant hand. They were instructed to respond as quickly as possible to target stimuli, and not to respond to the infrequent novel and frequent non-target stimuli. Prior to recording, participants familiarised with the paradigm using a 35-s practice session to ensure comprehension. Responses to target stimuli within 100–1000 ms from onset were counted as correct response; failure to respond within this time window was registered as an omission error.

2.5. Fast task

The fast task is a computerized four-choice RT task which measures performances under a slow-unrewarded and a fast-incentive condition ([Andreou et al., 2007](#); [Kuntsi et al., 2006](#)). In both conditions speed and accuracy were emphasized equally. The baseline (slow unrewarded) condition followed a standard warned four choice reaction-time task. A warning signal (four empty circles, arranged side by side) first appeared on the screen. At the end of the fore-period lasting 8 s (presentation interval for the warning signal), the circle designated as the target signal for that trial was filled (coloured) in. The participant 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. If the participant did not respond within 10 s, the trial terminated. First, a practice session was administered, during which the participant had to respond correctly to five consecutive trials. The baseline condition consisted of 72 trials. To investigate the extent to which a response style characterized by slow and variable speed of responding may be reduced, the task includes a comparison condition that uses a fast event rate (fore-period of 1 s) and incentives. This condition started immediately after the baseline condition and consisted of 80 trials, with a fixed inter-trial interval of 2.5 s following the response. The participants were told to respond as quickly as possible to each target, in order to win smiley faces and earn real prizes at the end. Participants won a smiley face for responding faster than their own MRT during the baseline (first) condition consecutively for three trials. The smiley faces appeared below the circles in the middle of the screen and were updated continuously. The fast-incentive condition was always administered after the baseline condition and, as such, did not involve a similar learning phase. Participants earned £5 in cash after the task battery.

2.6. Task performance parameters

We applied ex-Gaussian deconvolution to RT data employing a maximum-likelihood algorithm ([Heathcote et al., 2004](#)) implemented in the QMPE software (<http://newcl.org/software/qmpe.htm>). This algorithm measures the mean of the normal component of the RT distribution (μ) and divides the SD-RT into its normal (σ) and exponential (τ) components. Only participants with accurate and plausible responses (> 150 ms) ([Adamo et al., 2018](#)), and who responded correctly in at least 40 trials in each task were included to ensure the correct extraction of the ex-Gaussian measures ([Heathcote et al., 2002](#)). To account for positive skewness, we applied appropriate transformations to all measures in each task prior to analyses. In the flanker task and in the oddball task we used a logarithm transformation for all variables; in the fast task we used a logarithm transformation for μ and τ and a square root transformation for σ . For the oddball task, in addition to the ex-Gaussian variables, we report results also for MRT and RTV as these have not been reported

previously, unlike for the other two tasks (Carruthers et al., under review; Michelini et al., 2018).

2.7. Statistical analyses

In the arrow flanker task and in the fast task ex-Gaussian variables were investigated using random intercept linear models (i.e. multilevel regression models). Main effects of group (ADHD vs BD vs control), condition (baseline vs fast-incentive in the fast task, and congruent vs incongruent in the arrow flanker task), and group-by-condition interactions were examined. Significant ($p < 0.05$) main group effects were followed up with post-hoc comparisons between groups separately in the baseline and fast-incentive conditions of the fast task, and in the congruent and incongruent conditions of the flanker task. Additional post-hoc tests were run for measures showing a significant ($p < 0.05$) group-by-condition interaction, to examine differences between conditions within each group and differences between groups in the change between conditions (with difference scores). In the oddball task we used linear regressions to assess the main effect of group and between-group post-hoc comparisons on ex-Gaussian parameters. For all between-group comparisons, we report both p-values and Cohen's d effect sizes, calculated using the difference in the means divided by the pooled standard deviation, where $d \geq 0.20$ constitutes a small effect, $d \geq 0.50$ a medium effect and $d \geq 0.80$ a large effect. All statistical analyses were run in Stata 14 (Stata Corp, College Station, TX, USA). As this is an exploratory study, with modest sample sizes and non-independent variables derived from the same RT data, multiple-testing corrections were not applied, in line with previous publications on this sample (see also Michelini et al., 2016, 2018). Three participants were excluded from the fast task: one from the ADHD group (data on the fast-incentive condition were missing due to technical issues during the testing session), one from the control group, and one from the BD group due to the presence of outlier data (> 3.5 SD) in the baseline condition. Three participants of the BD group were excluded from the oddball task, and two participants of the ADHD group were excluded from the arrow flanker task due to lack of sufficient correct responses to fit the ex-Gaussian model. The remaining sample for each task consisted of (i) 19 participants with ADHD, 19 participants with BD and 19 controls for the fast task, (ii) 20 participants with ADHD, 17 participants with BD and 20 controls for the oddball task, and (iii) 18 participants with ADHD, 20 participants with BD and 20 controls for the arrow flanker task.

We re-ran between-group comparisons for those measures that showed both ADHD-control and BD-control differences, covarying for current self-report total symptoms of ADHD (BAARS-IV) in the BD-control comparison and for current self-report symptoms of mania (ASRM) and depression (BDI) in the ADHD-control comparison.

3. Results

Means and standard deviations for cognitive variables of each group are summarised in supplementary material (Table S3).

3.1. Arrow flanker task

Mu and tau showed significant main effects of condition (both $p < 0.001$), but no main effects of group ($p = 0.52$ and $p = 0.43$, respectively), or group by condition interaction ($p = 0.21$ and $p = 0.27$, respectively); therefore, we did not perform post hoc analyses for these variables.

Sigma showed significant main effects of group ($p = 0.04$) and condition ($p < 0.001$), but no group by condition interaction ($p = 0.10$). Post hoc tests showed a significantly higher sigma in the BD group compared to the ADHD and control groups, and a significantly increased sigma in the BD group compared to controls, in the incongruent condition (Table 1). No differences in sigma were found between

the ADHD and control groups.

3.2. Oddball task

Given that the oddball task is a task with only one condition, we only tested the main effect of group for this task. No significant main effects of group emerged for MRT ($p = 0.98$), SD-RT ($p = 0.24$), mu ($p = 0.90$) or tau ($p = 0.46$); therefore, post hoc analyses were not performed for these variables.

Sigma showed a significant main effect of group ($p = 0.03$). Post hoc analyses revealed a significantly increased sigma in the ADHD group compared to controls (Table 1). No significant differences emerged between the BD and control groups, or between the ADHD and BD groups (Table 1).

3.3. Fast task

Mu showed a significant main effect of condition ($p < 0.001$) and a group by condition interaction ($p = 0.04$), but no main effect of group ($p = 0.23$). Post hoc tests in the fast-incentive condition showed a significantly increased mu in the BD group, compared to controls, but no significant differences in the ADHD group compared to controls, and between the ADHD and BD groups (Table 1). All three groups showed a within-group decrease in mu from the baseline to the fast-incentive condition (Table S4). No significant differences emerged between groups in the degree of change between conditions (Table S4).

Sigma showed a significant main effect of condition ($p < 0.001$), but no significant main effects of group ($p = 0.52$) or group by condition interaction ($p = 0.25$); therefore, we did not perform post hoc group comparisons for this variable.

Significant main effects of group ($p = 0.01$) and condition ($p < 0.001$), but not of group by condition interaction ($p = 0.62$), emerged for tau. Post hoc tests showed significantly increased tau in the baseline condition in the ADHD group compared to controls, and in the BD group compared to the control group, but no differences between the two clinical groups (Table 1). A significantly increased tau emerged in the fast incentive condition in the ADHD group compared to controls (Table 1). No differences in the fast-incentive condition emerged in tau between the BD and control groups, or between the ADHD and the BD groups.

3.4. Analyses controlling for symptoms of ADHD or BD

As the only shared impairment between ADHD and BD (compared to controls) was increased tau in the baseline condition of the fast task, we re-ran post-hoc comparisons, first, between ADHD and control groups covarying for symptoms of mania and depression: all results remained unchanged ($p = 0.01$, $d = 0.91$ and $p = 0.04$, $d = 0.68$, respectively). Second, we re-ran the BD-control group comparison covarying for ADHD symptoms. Also, in this case, the significance of the results did not change ($p = 0.03$, $d = 0.62$).

4. Discussion

Using the detailed ex-Gaussian approach, we performed a precise analysis of the nature of previously reported reaction time impairments that are shared between ADHD and BD, or that are unique to either disorder. With data from three cognitive tasks, covering a total of five task conditions, we found a shared impairment between ADHD and BD groups in occasional lapses of attention observed as rare, ultra-slow responses (tau) in the slow-unrewarded condition of the fast-task, and a BD-specific impairment in the variability of typical RT responses (sigma) in the incongruent condition of the arrow flanker task.

We previously reported, in the same sample, a shared impairment between the ADHD and BD groups that was captured by the overall RT variability measure, SD-RT, while performing the fast task

Table 1
Group comparisons on cognitive measures in the arrow flanker, oddball and fast tasks.

Tasks	Measures	ADHD vs BD		ADHD vs Control		BD vs Control	
		<i>d</i> (95% CI)	<i>p</i>	<i>d</i> (95% CI)	<i>p</i>	<i>d</i> (95% CI)	<i>p</i>
Arrow flanker task	Sigma congruent	0.02 (−0.61; 0.66)	0.94	0.46 (−0.18; 1.10)	0.23	0.42 (−0.20; 1.05)	0.25
	Sigma incongruent	<i>0.57 (0.08; 1.21)</i>	0.03*	0.23 (−0.40; 0.87)	0.42	<i>0.75 (0.10; 1.39)</i>	0.01**
Oddball task	Sigma	0.38 (−0.28; 1.02)	0.17	<i>0.75 (0.11; 1.39)</i>	0.02*	0.36 (−0.29; 1.02)	0.48
Fast task	Mu baseline	0.07 (−0.56; 0.70)	0.77	0.02 (−0.62; 0.65)	0.96	0.07 (−0.57; 0.69)	0.82
	Mu fast-incentive	0.48 (−0.17; 1.12)	0.18	<i>0.64 (−0.01; 1.28)</i>	0.15	1.02 (0.33; 1.69)	0.01**
	Tau baseline	0.31 (−0.33; 0.95)	0.27	0.92 (0.23; 1.57)	0.01**	<i>0.72 (0.06; 1.37;)</i>	0.02*
	Tau fast-incentive	0.24 (−0.39; 0.88)	0.33	<i>0.74 (0.08; 1.39)</i>	0.02*	<i>0.52 (−0.13; 1.16)</i>	0.16

95% CI, 95% confidence intervals around *d* estimates; ADHD, attention-deficit/hyperactivity disorder; BD, bipolar disorder; *d*, Cohen's *d*.

** $p \leq 0.01$.

* $p \leq 0.05$. Bold = large effect size ($d \geq 0.80$); Italics = medium effects size ($d \geq 0.50$). Note: between group comparisons are reported only when the main group effect is significant in the main analysis.

(Michelini et al., 2018). Applying the ex-Gaussian approach to the same task, we show that the impairment shared between the disorders is specifically related to the rare lapses of attention indexed with tau, but not to the speed or variability of typical responses (mu or sigma). The shared impairment in tau (with medium-to-large effect sizes) emerged only in the baseline condition of the fast task and not in the fast-incentive condition, where increased tau was observed in the ADHD group only, suggesting that this shared impairment might be more prominent in the slow-unrewarded condition. However, since for tau the group-by-condition interaction was non-significant, and the non-significant BD-control difference in the fast-incentive condition showed a medium effect size, we cannot exclude a possible lack of power in detecting an impairment also in the BD group in the fast-incentive condition.

In the arrow flanker task – specifically the incongruent condition of the task – we found a disorder-specific impairment in sigma in participants with BD compared to both ADHD and control groups (with medium effect size), indicating an impairment in the regulation of attention in this task condition. This evidence may suggest a BD-specific impairment when high cognitive control is needed, in line with previous evidence showing that participants with BD have increased sigma, but not tau, compared to controls when performing a task with more effortful processing (Moss et al., 2016). However, the group-by-condition interaction in the arrow flanker task was not significant, possibly because of lack of power due to the modest sample size. If future studies replicate our finding that the impairment in sigma is specific to BD and not observed in individuals with ADHD, this cognitive characteristic may aid in the differentiation of the two disorders.

We additionally examined if the shared impairments observed in the baseline condition of the fast task of increased tau in ADHD and BD, compared to controls, could be explained by symptoms of ADHD or BD. When we repeated our analyses on the shared impairments covarying for symptoms of ADHD in the BD and control groups, and for symptoms of mania and depression in the ADHD and control groups, our results did not change. This pattern suggests that the attentional lapses observed in this sample in both ADHD and BD may not be explained by symptoms of the other disorder.

The oddball task did not reveal either shared or disorder-specific impairments for any of the variables. The ADHD group differed from controls on sigma on this task, but as no difference emerged between the clinical groups for this variable, it did not fulfil our criteria for a disorder-specific impairment. Overall, our results suggest that the choice of a task is an important consideration for future studies on ex-Gaussian measures, as the tasks and conditions varied in their sensitivity to group differences.

Certain limitations should be considered while interpreting our findings. First, although between-group differences emerged with medium-to large effect sizes in this sample, larger studies are needed to confirm our results. Second, our study was conducted in a

homogeneous all-female sample; and future studies are required to confirm the generalisability of our findings to adult male participants. Third, potential effects of medications must be considered on our results. Whereas participants with ADHD were asked to discontinue their stimulant medication 48 h before the assessment, participants with BD could not be asked to suspend mood-stabilizing, anti-psychotic or antidepressant medications for ethical reasons. Some studies have reported no change in cognitive performance in participants who were taking mood stabilisers (López-Jaramillo et al., 2010), or antipsychotics (Bora, 2018; Torres et al., 2010), while other studies have reported a positive association between cognitive impairments and type and dose of mood stabilisers (Pachet and Wisniewski, 2003) or antipsychotics (Arts et al., 2013; Torrent et al., 2011). As we observed significant impairments in both clinical groups compared to controls, specific confounding medication effects of mood stabilisers and antipsychotics are unlikely in this study; yet we could not directly investigate this due to the limited number of participants within each medication subgroup. Fourth, the adult participants in the clinical groups recruited for this study had slightly higher than expected IQs, which did not differ from average IQ scores in the control group. Future replication in samples with a wider range of IQs is required in order to generalise these findings to more typical clinical populations. Fifth, we did not obtain data on past psychosis in our participants with BD. Given previous evidence showing that a history of psychosis can result in more impaired or different patterns of cognitive performances in participants with BD (Bora et al., 2007; Martínez-Aran et al., 2008; Selva et al., 2007; Shin et al., 2016), future studies are needed to test the generalisability of the results to BD with psychotic features. Lastly, multiple testing corrections were not applied in this exploratory study; while the effect sizes for the main findings were, promisingly, medium-to-large, our results await replication in future larger-scale studies.

Overall, our results suggest that a fine-grained approach, such as the ex-Gaussian approach employed here across multiple tasks and conditions, is informative in elucidating overlap and specificity in cognitive impairments observed in ADHD and BD. The shared and BD-specific impairment that we identified, with moderate to large effect sizes, are potential objective cognitive markers that now await replication in future studies with larger sample sizes

CRediT authorship contribution statement

Isabella Vainieri: Conceptualization, Data curation, Investigation, Methodology, Formal analysis, Writing - original draft. **Nicoletta Adamo:** Conceptualization, Data curation, Methodology. **Giorgia Michelini:** Conceptualization, Formal analysis, Methodology, Funding acquisition. **Viryana Kitsune:** Conceptualization, Data curation, Funding acquisition. **Philip Asherson:** Conceptualization, Investigation, Funding acquisition. **Jonna Kuntsi:** Conceptualization, Methodology, Funding acquisition, Investigation, Supervision, Writing -

review & editing.

Declaration of Competing Interest

Professor Jonna Kuntsi has given talks at educational events sponsored by Medice; all funds are received by King's College London and used for studies of ADHD. Prof Philip Asherson has received funding for research by Vifor Pharma and has given sponsored talks and been an advisor for Shire, Janssen-Cilag, Eli-Lilly, Flynn Pharma and Pfizer, regarding the diagnosis and treatment of ADHD. All funds are received by King's College London and used for studies of ADHD. The other authors report no conflicts of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.psychres.2019.112729](https://doi.org/10.1016/j.psychres.2019.112729).

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