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Corresponding author:
Anthony C. Ruocco;
Email: anthony.ruocco@utoronto.ca

Pretreatment cognitive performance is associated with differential self-harm outcomes in 6 *v.* 12-months of dialectical behavior therapy for borderline personality disorder

Jenna M. Traynor[1,2,3*,4*], Shelley McMain[1], Alexander L. Chapman[5], Janice Kuo[6], Cathy Labrish[1] and Anthony C. Ruocco[1,2]

[1]Centre for Addiction and Mental Health, Toronto, ON, Canada; [2]Department of Psychology, University of Toronto Scarborough, Toronto, ON, Canada; [3]McLean Hospital, Belmont, MA, USA; [4]Department of Psychiatry, Harvard Medical School, Boston, MA, USA; [5]Department of Psychology, Simon Fraser University, Burnaby, BC, Canada and [6]Department of Psychology, PGSP-Stanford PsyD Consortium, Palo Alto University, Palo Alto, CA, USA

Abstract

Background. Recent findings suggest that brief dialectical behavior therapy (DBT) for borderline personality disorder is effective for reducing self-harm, but it remains unknown which patients are likely to improve in brief *v.* 12 months of DBT. Research is needed to identify patient characteristics that moderate outcomes. Here, we characterized changes in cognition across brief DBT (DBT-6) *v.* a standard 12-month course (DBT-12) and examined whether cognition predicted self-harm outcomes in each arm.

Methods. In this secondary analysis of 240 participants in the FASTER study (NCT02387736), cognitive measures were administered at pre-treatment, after 6 months, and at 12 months. Self-harm was assessed from pre-treatment to 2-year follow-up. Multilevel models characterized changes in cognition across treatment. Generalized estimating equations examined whether pre-treatment cognitive performance predicted self-harm outcomes in each arm.

Results. Cognitive performance improved in both arms after 6 months of treatment, with no between-arm differences at 12-months. Pre-treatment inhibitory control was associated with different self-harm outcomes in DBT-6 *v.* DBT-12. For participants with average inhibitory control, self-harm outcomes were significantly better when assigned to DBT-12, relative to DBT-6, at 9–18 months after initiating treatment. In contrast, participants with poor inhibitory control showed better self-harm outcomes when assigned to brief DBT-6 *v.* DBT-12, at 12–24 months after initiating treatment.

Conclusions. This work represents an initial step toward an improved understanding of patient profiles that are best suited to briefer *v.* standard 12 months of DBT, but observed effects should be replicated in a waitlist-controlled study to confirm that they were treatment-specific.

Background

Borderline personality disorder (BPD) is a serious psychiatric condition characterized by high rates of self-harm and suicide risk (Hawton, Zahl, & Weatherall, 2003; Paris & Zweig-Frank, 2001). Intentional, repetitive self-harm, with or without an intent to die, is a priority target in BPD treatments, including dialectical behavior therapy (DBT). Recent findings from a randomized-controlled trial (RCT) of 240 participants with BPD demonstrated that a brief, 6-month course of DBT for BPD is non-inferior to the standard 12 months of treatment for treating repetitive self-harm and other outcomes (McMain et al., 2022). Significant improvements in self-harm occurred in both treatment arms by 6 months and were sustained at 24-month follow-up (McMain et al., 2022). These results converge with a growing body of evidence which suggests that briefer forms of DBT for BPD are effective on a range of outcomes including self-harm (Keng et al., 2021; Westad, Hagen, Jonsbu, & Solem, 2021). By extension, lengthier treatments may not be necessary for all individuals with BPD (Griffiths et al., 2019).

However, there is considerable heterogeneity in BPD treatment response; approximately half of BPD patients are considered non-responders following DBT and other BPD interventions (Woodbridge, Townsend, Reis, Singh, & Grenyer, 2022). Furthermore, it remains unknown which BPD patients are likely to improve in briefer (e.g. 6 months) *v.* the more

standard 12 months of DBT. To tailor the length of treatment for different patients, research is needed to identify patient characteristics that moderate treatment outcomes.

Historically, research on moderators of self-harm outcomes in BPD patients has employed self-report questionnaires to measure symptom-level moderators, and findings are mixed. On one hand, some findings suggest that greater symptom severity at pre-treatment is associated with better self-harm outcomes in DBT and other interventions for self-harm (Adrian et al., 2019; Andover, Schatten, Holman, & Miller, 2020; Barnicot et al., 2012; Sahlin et al., 2019). Although, Bateman and Fonagy (2013) found no association between baseline BPD symptom severity and self-harm outcomes in mentalization-based therapy (MBT). Finally, McMain et al. (2018) examined associations between baseline severity markers and trajectories of self-harm outcomes in 180 BPD patients treated with DBT or general psychiatric management (GPM) and identified distinct trajectories. Specifically, patients with the lowest frequency of baseline self-harm showed a 'rapid and recovered' self-harm trajectory, whereas a second class of patients had slow yet sustained improvements in self-harm. Moreover, a third class with rapid but unsustained improvements, had the highest levels of baseline self-harm.

Taken together, the findings are inconclusive and the field may benefit from examining other types of moderators (e.g. cognitive moderators). Indeed, BPD is characterized by a range of cognitive deficits in the domains of impulsivity and attentional control (Albert et al., 2019; Koudys & Ruocco, 2021; Thomsen, Ruocco, Carcone, Mathiesen, & Simonsen, 2017a). Deficits in inhibitory control have also been associated with intentional self-harm in BPD (Drabble, Bowles, & Barker, 2014; LeGris, Links, van Reekum, Tannock, & Toplak, 2012).

Impulsivity and related cognitive dimensions can be assessed using performance-based tasks (e.g. continuous performance tests). Factor analytic findings provide strong evidence that performance-based measures assess unique dimensions (e.g. action impulsivity), relative to self-report measures of those constructs (e.g. trait impulsivity) (Cyders & Coskunpinar, 2011; Stahl et al., 2014). Performance-based measures therefore have the potential to assess different markers of functioning that may moderate self-harm outcomes in BPD.

In particular, continuous performance tests (CPTs; e.g. Conners, 2014) that require selective responses to target and non-target stimuli are valid measures of inhibitory and attentional control. Findings from CPT studies generally show impaired inhibitory control in BPD, as observed by elevated commission errors in adults with BPD or BPD traits (e.g. Feliu-Soler et al., 2013; Soler et al., 2012; van Dijk et al., 2014), although one study found no between-group differences in commission errors (Ferraz et al., 2009). Relatedly, many studies using variants of CPTs, such as stop signal tasks, have observed impairments in inhibitory control in BPD (Albert et al., 2019; McCloskey et al., 2009; Rentrop et al., 2008; Rubio et al., 2007; van Dijk et al., 2014), although many have found no impairment (Barker et al., 2015; Dinn et al., 2004; Hagenhoff et al., 2013; Jacob et al., 2010; Lampe et al., 2007). These mixed findings may reflect heterogeneity in cognitive functioning in BPD.

To date, only 2 BPD treatment studies have included performance-based cognitive measures. One study found improvements in sustained attention and perceptual reasoning in 18 patients with BPD who completed MBT, but not in untreated controls (Thomsen, Ruocco, Uliaszek, Mathiesen, & Simonsen, 2017b). Another study found improvements in inhibitory control, hit reaction time, and detectability on the Conners Continuous Performance Test-II in 40 BPD patients who completed GPM plus DBT mindfulness skills training, but not in 19 patients who received GPM alone (Soler et al., 2012). These findings suggest that, among BPD patients, cognition might improve with treatment, although the samples in these studies were small and require replication in larger samples.

Importantly, impulsivity-related deficits in inhibitory control have been associated with the frequency and lethality of intentional self-harm in BPD (Williams et al., 2015). Similarly, pre-treatment brain activation in inhibitory control-related frontal regions has been prospectively associated with self-harm improvements in DBT for BPD (Ruocco et al., 2016). Indeed, biomarker correlates of psychotherapy improvements in BPD converge on adaptive changes in inhibitory and attentional control-related brain function as potential mechanisms of change (Marceau, Meuldijk, Townsend, Solowij, & Grenyer, 2018). BPD treatment non-completion has also been linked to lower baseline attentional control (Fertuck et al., 2012).

Taken together, it is plausible that performance-based measures of impulsivity and related cognitive dimensions could provide unique prognostic information about individuals with BPD undergoing DBT. This is an understudied area with the potential to illuminate unidentified cognitive risk factors for unfavorable self-harm outcomes. However, no published study to our knowledge has examined cognition as a predictor of self-harm outcomes in BPD. Therefore, in this study, we examined whether performance on a well-established measure of inhibitory and attentional control (the CPT-3; Conners, 2014) predicted self-harm outcomes among BPD patients receiving comprehensive DBT. Relatedly, another important area investigated was whether cognitive performance differentially predicted self-harm outcomes in briefer or more standard length of treatment. In the present research, we wished to examine whether CPT-3 performance could identify patient profiles that are most suited to different lengths of DBT.

Study aims and hypotheses

The current study involved a secondary analysis of cognitive performance and self-harm data from the FASTER study (The **F**easibility of **a** **S**horter **T**reatment and **E**valuating **R**esponses; NCT02387736), a large multi-site RCT comparing the effectiveness of a brief, 6-month course of DBT for BPD (DBT-6) to a standard 12-month course of treatment (DBT-12). This secondary study had two primary aims. Aim 1 was to characterize changes in inhibitory control and attention across DBT-6 *v.* DBT-12. We hypothesized that improvements in cognition would be observed in both treatment arms by 6 months of treatment, but we expected that DBT-12 participants would continue to improve up to 12 months (i.e. treatment end point), whereas DBT-6 participants would display no further improvements after 6 months. Aim 2 was to examine whether cognition at pre-treatment could predict self-harm outcomes in DBT-6 *v.* DBT-12. Given that a certain level of inhibitory and attentional control functioning may be required to learn the novel and sometimes complex information in DBT (e.g. mindfulness skills training), we hypothesized that lower cognitive performance at pre-treatment would be associated with better self-injury outcomes in DBT-12 *v.* DBT-6 (i.e. reflecting that the most cognitively impaired patients at baseline would require a longer treatment to show self-injury improvements). In an exploratory manner, we also investigated the extent to which a performance-based

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Table 1. Participant demographics and clinical characteristics for all participants randomized

Baseline demographics and clinical characteristics	Length of treatment		Total sample ($n = 240$)
	12-months ($n = 120$)	6-months ($n = 120$)	
Mean (s.d.) age	27.3 (8.67)	28.3 (8.64)	27.75 (8.65)
Female	95 (79)	95 (79)	190 (79)
Marital status			
Married	22(18)	16 (13)	38 (16)
Separated, divorced, widowed	9 (8)	12 (10)	21 (9)
Never married	89 (74)	92 (77)	181 (75)
Education			
High school or less	29 (24)	33 (28)	62 (26)
Some post-secondary	41 (34)	37 (31)	78 (33)
Post-secondary	50 (42)	50 (42)	100 (42)
Employed	40 (33)	55 (46)	95 (40)
Income			
<$15 000	72 (60)	62 (52)	134 (56)
$15 000–$ 29 000	36 (30)	42 (35)	78 (33)
$30 000–$ 49 000	6 (5)	13 (11)	19 (8)
Current Comorbid Axis I Disorders			
Major depressive disorder	46 (38)	49 (41)	95 (40)
Panic disorder	35 (29)	36 (30)	71 (30)
Posttraumatic stress disorder	37 (31)	44 (37)	81 (34)
Any anxiety disorder	91 (76)	99 (83)	190 (79)
Any substance use disorder	46 (41)	47 (39)	96 (40)
Any eating disorder	18 (15)	32 (27)	50 (21)
Axis II cluster A diagnosis	15 (13)	10 (8)	25 (10)
Axis II cluster B diagnosis (excl. BPD)	12 (10)	12 (10)	24 (10)
Axis II cluster C diagnosis	29 (24)	45 (38)	74 (31)
Mean (s.d.) Axis I current disorders	2.85 (1.81)	2.94 (1.69)	2.90 (1.75)
Mean (s.d.) Axis I lifetime disorders	5.14 (2.29)	4.94 (2.46)	5.04 (2.38)
Mean (s.d.) Axis II disorders (excl. BPD)	0.53 (0.87)	0.63 (0.88)	0.58 (0.87)

measure of inhibitory and attentional control could provide prospective information about self-harm outcomes, compared to a measure of self-reported impulsivity.

Methods

Participants and study design

Data from the full FASTER study sample of 240 participants were analyzed. The trial was completed at the Centre for Addiction and Mental Health (CAMH) and Simon Fraser University (SFU) in Canada. The protocol was approved by the CAMH and SFU ethics boards and all participants provided written informed consent prior to participation. A description of the main study methods and results can be found in the original report (McMain et al., 2022). Demographics for all participants randomized are presented in Table 1. Participants were randomized to DBT-6 ($n = 120$, 79% female, mean age = 28.3) or DBT-12 ($n = 120$, 79% female, mean age = 27.3). Participants randomized to both treatment arms received comprehensive DBT, including weekly individual therapy, two weekly DBT skills groups, and on-call phone coaching with a DBT therapist. According to the standard, a participant was considered to have dropped out of treatment if they missed four consecutive individual or group sessions. All study therapists attended weekly DBT team consultations. Participants were followed from pretreatment to 2-year follow-up, and completed follow-up assessments every 3 months, including assessments of self-harm and self-reported impulsivity. A performance-based measure of inhibitory control and attention was administered at pretreatment, after 6 months of treatment, and at 12 months.

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Eligibility criteria

Eligibility assessments were completed by graduate- and postdoctoral-level assessors under the supervision of a licensed psychologist. Individuals who met the following criteria were eligible to participate: 18–60 years; a diagnosis of BPD according to the Diagnostic and Statistical Manual of Mental Disorder- Fourth Edition (DSM-IV; American Psychiatric Association, 1994); engaged in at least two incidents of intentional self-harm in the 5 years prior to study enrolment, including at least one incident in the 2 months preceding enrolment; proficient in English; and valid provincial health insurance. Individuals with the following exclusion criteria were not eligible: meeting DSM-IV criteria for bipolar I disorder, dementia, or a psychotic disorder; IQ $\leqslant$ 70; a serious physical health problem that required hospitalization over the next year; received $\geqslant$8 weeks of DBT in the preceding year; plans to move out of province during the trial.

Clinical and neurocognitive measures

Psychometric properties of measures are in Supplementary Material.

The International Personality Disorders Examination – BPD Section (IPDE-BPD; Loranger et al., 1994) was used to assess BPD. The Structured Clinical Interview for DSM-IV Axis I Disorders (SCID-1-IV; First, Gibbon, & Williams, 2002) and Axis II Disorders (SCID-II-IV; First, Gibbon, Williams, & Benjamin, 1997) were used to assess concurrent disorders.

Consistent with the main outcome paper (McMain et al., 2022), self-harm was queried with the Suicide Attempt Self-Injury Interview (SASII; Linehan, Comtois, Brown, Heard, & Wagner, 2006), a clinician-administered measure to assess the total aggregate incidents of intentional self-harm, with or without intent to die, across the 3 months preceding each assessment.

Self-reported impulsivity was assessed with the Barratt Impulsiveness Scale (BIS-11; Patton, Stanford, & Barratt, 1995). The BIS-11 contains 30 items rated on a scale from 0 ('rarely/never') to 4 ('almost always/always') and produces a total score out of 120 representing the severity of impulsive behaviors. A score of 72 suggests high impulsivity, whereas a score between 51 and 71 reflects impulsivity within a normal range (Stanford et al., 2009). Scores below 51 suggest an invalid response profile (Helfritz et al., 2006) or an over-controlled personality presentation. In the current study, pre-treatment BIS-11 scores demonstrated good internal consistency (Cronbach's alpha = 0.83).

Performance-based measures of inhibitory control and attention were assessed with the Conners Continuous Performance Test – 3rd Edition (CPT-3; Conners, 2014), a standardized, computer-administered task that requires selective responding to target and non-target stimuli. Participants were presented with letters of the alphabet and instructed to press a space bar when they saw any letter appear on the screen except the letter 'X,' in which case they were instructed to withhold their response. The speed of stimulus presentation and the interstimulus interval varied across the 10-min task, with non-target stimuli presented approximately 10% of the time. A description of each CPT-3 outcome variable is provided below. *T*-scores are based on CPT-3 normative data derived from the scores of individuals of the same age and gender of the participant. A *T*-score <60 indicates performance in the normal range, whereas a *T* score $\geqslant$60 reflects clinically elevated (i.e. impaired) performance.

Inhibitory control

Commissions: *T*-scores for total mean commissions (i.e. 'false-alarms', or pressing the space bar for non-target stimuli) reflects inhibitory control performance. Higher *T*-scores suggest greater difficulties inhibiting a prepotent response.

Impulsivity index: A separate 'impulsivity index' raw score was calculated using an equation from Soler et al. (2012). Compared to commissions, the impulsivity index takes into account hit reaction time, total commission errors, and total omission errors: [1/hit reaction time] * [omissions/commissions]. As the score is not a standardized CPT-3 scale, a normatively referenced *T*-score is not available. Higher scores indicate higher impulsivity.

Attention

Detectability (d′): *d′ T*-scores represent the ability to discriminate between target and non-target stimuli. Higher scores indicate more difficulty differentiating targets from non-targets.

Attentional consistency (hit reaction time – standard deviation): *T*-scores for hit reaction time – standard deviation (HRT-SD) measure the consistency of response speed to target stimuli across the task. Higher scores reflect greater inconsistency and less task engagement.

Vigilance (hit reaction time interstimulus interval change): *T*-scores for hit reaction time – interstimulus interval change (HRT-ISI) reflect the slope of change in HRT across the three ISIs in the CPT-3 task (i.e. 1, 2, and 4 s). A positive slope reflects decelerating HRTs at longer ISIs, whereas a negative slope reflects accelerating HRTs at longer ISIs. Higher scores represent a loss of vigilance in the context of changing task demands.

Analyses

An intent-to-treat analysis was used and included data from all 240 participants in the trial, including dropouts. Missing data increased over time as participants were lost to follow-up (online Supplementary Table S1). The results of analyses to explore patterns of missingness supported the assumption that data were missing at random (online Supplementary Material). As such, pairwise deletion was used to handle missing data.

Multilevel modeling: does cognitive performance and self-reported impulsivity improve in DBT-6 and DBT-12?

Multilevel models were created for each CPT-3 outcome variable using the 'nlme' package in R to investigate Aim 1, evaluating if cognitive performance and self-reported impulsivity change over treatment, and whether changes depend on treatment arm. A time by treatment arm interaction term was included in all models, and no significant interactions were found ($p > 0.05$). As such, all analyses modeled CPT-3 performance as a function of time plus treatment arm but did not include an interaction term. A Bonferroni statistical correction was applied, resulting in a significance threshold of $p < 0.003$. Post-hoc pairwise comparisons were examined for all participants collapsed across treatment arms. A family-wise statistical correction was applied to each post-hoc test, resulting in a significance threshold of $p < 0.017$. Details pertaining to the construction of each model and the calculation of statistical correction thresholds are in Supplementary Material.

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Generalized estimating equations: Is pre-treatment neurocognition associated with self-harm outcomes in DBT-6 and DBT-12?

Generalized estimating equations (GEEs) were created using the 'geeglm' package in R to investigate Aim 2, assessing whether CPT-3 performance at pretreatment was associated with the frequency of total self-harm across treatment and up to 2-year follow-up, and if associations depended on treatment arm.

To examine clinically meaningful cognitive predictors, the *T*-score for each CPT-3 variable was used in the GEE analyses. In each GEE model, CPT-3 *T*-scores were binarized according to standardized CPT-3 norms. Accordingly, a *T*-score <60 represents baseline cognitive performance in the normal range and $T \geqslant 60$ represents performance in a likely clinically impaired range (Conners, 2014). Regarding *T*-scores for commission errors, 161 participants fell in the normal range, and 59 participants in the clinically impaired range. For d′ *T*scores, 172 participants were in the normal range and 48 were in the clinically impaired range. Due to a restricted range of *T*-scores for the HRT-SD and HRT-ISI variables (most participants exhibited baseline performance in the normal range), these predictors were not examined. As normative data are not available for the impulsivity index, this variable was binarized according to the 50th percentile of the sample scores, resulting in 110 participants in the low impulsivity index group and 110 participants in the high impulsivity index group. Finally, pre-treatment BIS-11 scores were binarized according to published guidelines, whereby a score of ⩾72 suggested elevated self-reported impulsivity, and a score of 52–71 indicated self-reported impulsivity in the average range (Stanford et al., 2009).

An ANOVA of each GEE model examined the three-way interaction between pre-treatment cognitive performance, time, and treatment arm. A Bonferroni statistical correction was applied to all ANOVAs, resulting in a significance threshold of $p < 0.013$. Post-hoc pairwise comparisons explored differences in self-harm between DBT-6 and DBT-12 participants at each time point, using the Tukey's HSD adjustment for multiple comparisons (Tukey, 1953), which controls for the experiment-wise error rate, α_{EW} (Maxwell & Delaney, 2004). Details pertaining to the construction of GEE models are in Supplementary Material.

Results

Descriptive statistics and pre-treatment associations

Table 2 presents descriptive statistics for pre-treatment cognitive performance. There were no significant between-arm differences. A Pearson R correlation matrix of CPT-3 scores across assessment timepoints is in Supplementary Material (online Supplementary Table S2).

Aim 1: Does cognitive performance change during DBT, and do changes depend on treatment arm?

Inhibitory control

Commissions. A significant reduction in commissions was observed at the 6-month ($\beta = -2.73$ [95% CI −3.92 to −1.54], S.E. = 0.61, $t[315] = -4.49$, $p < 0.001$) and 12-month time points ($\beta = -3.13$ [95% CI −4.73 to −1.88], S.E. = 0.64, $t[315] = -4.92$, $p < 0.001$). There was no effect of treatment arm on reductions in commissions ($\beta = 1.50$ [95% CI −1.02 to 4.02], S.E. = 1.28, $t[235] = 1.17$, $p = 0.24$). Figure 1 displays pairwise comparisons collapsed across treatment arms showing a significant improvement in commissions at 6 months ($\beta = -2.73$, S.E. = 0.61, $z = -4.51$, $p < 0.001$) and 12 months ($\beta = -3.13$, S.E. = 0.63, $z = -4.94$, $p < 0.001$) relative to baseline. No improvement was observed between 6 and 12 months ($\beta = -0.39$, S.E. = 0.64, $z = -0.61$, $p = 0.81$).

Impulsivity index. Reductions in impulsivity index scores were observed at the 6-month ($\beta = -0.0008$ [95% CI −0.0016 to 0.0005], S.E. = 0.0004, $t[315] = -1.95$, $p = 0.05$) and 12-month time points ($\beta = -0.001$ [95% CI −0.002 to −0.0009], S.E. = 0.0005, $t[315] = -2.04$, $p = 0.04$), which were not significant at the corrected threshold ($p > 0.003$; Figure 1). There was no effect of treatment arm on improvements in the impulsivity index ($\beta = 0.001$ [95% CI −0.0005 to 0.04], S.E. = 0.0009, $t[235] = 1.30$, $p = 0.20$).

Attention

Detectability. A significant improvement in *d′* was observed at the 6-month ($\beta = -3.25$ [95% CI −4.51 to −1.99], S.E. = 0.64, $t[315] = -5.06$, $p < 0.001$) and 12-month time points ($\beta = -3.28$ [95% CI −4.60 to −1.97], S.E. = 0.67, $t[315] = -4.90$, $p < 0.001$). There was no effect of treatment arm on *d′* ($\beta = 0.87$ [95% CI −1.39 to 3.13], S.E. = 1.15, $t[235] = 0.76$, $p = 0.45$). Figure 1 shows pairwise comparisons collapsed across treatment arms demonstrating improvements in *d′* at 6-months ($\beta = -3.25$, S.E. = 0.64, $z = -5.07$, $p < 0.001$) and 12-months ($\beta = -3.28$, S.E. = 0.67, $z = -4.92$, $p < 0.001$) relative to baseline. No improvement in *d′* was observed between 6 and 12 months ($\beta = -0.04$, S.E. = 0.68, $z = -0.05$, $p = 0.99$).

Attentional consistency. The effect of time on HRT-SD *T*-scores was not significant at either the 6-month ($\beta = -1.11$ [95% CI −2.26 to 0.04], S.E. = 0.59, $t[315] = -1.89$, $p = 0.06$) or 12-month time points ($\beta = -1.05$ [95% CI −2.25 to 0.15], S.E. = 0.61, $t[315] = -1.71$, $p = 0.09$). There was no effect of treatment arm on HRT-SD *T*-scores ($\beta = 0.21$ [95% CI−1.99 to 2.41], S.E. = 1.12, $t[235] = 0.18$, $p = 0.85$).

Vigilance. The effect of time on HRT-ISI *T*-scores was not significant at the 6-month ($\beta = 0.72$ [95% CI −0.41 to 1.85], S.E. = 0.58, $t[315] = 1.25$, $p = 0.21$) or 12-month time points ($\beta = 0.99$ [95% CI −0.35 to 2.34], S.E. = 0.69, $t[315] = 1.45$, $p = 0.15$). There was no effect of treatment arm on HRT-ISI T-scores ($\beta = -0.17$ [95% CI −2.18 to 1.84], S.E. = 1.02, $t[235] = -0.17$, $p = 0.87$).

Exploratory aim: Does self-reported impulsiveness change during DBT and do changes depend on treatment arm?

Bis-11 scores

The effect of time on BIS scores was significant at the 6-month ($\beta = -3.17$ [95% CI −4.34 to −1.99], S.E. = 0.60, $t[376] = -4.49$, $p < 0.001$) and the 12-month time points ($\beta = -4.29$ [95% CI −5.47 to −3.06], S.E. = 0.64, $t[376] = -6.72$, $p < 0.001$). There was no effect of treatment arm on self-reported impulsivity ($\beta = 1.67$ [95% CI −1.08 to 4.37], S.E. = 1.28, $t[238] = 1.17$, $p = 0.24$). Figure 1 displays pairwise comparisons collapsed across treatment arms, showing a significant improvement in self-reported impulsivity at 6-months ($\beta = -3.17$, S.E. = 0.60, $z = -5.30$, $p < 0.001$), and at 12-months ($\beta = -4.27$, S.E. = 0.61, $z = -6.94$, $p < 0.001$), relative to baseline. No further improvements were observed between the 6- and 12-month timepoints ($\beta = -1.10$, S.E. = 0.63, $z = -1.75$, $p = 0.19$).

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Table 2. Descriptive statistics for pre-treatment neurocognition

Descriptive statistics for GEE predictor variables	Combined sample		Length of treatment: 12 months		Length of treatment: 6 months		
CPT-3 and BIS-11 scores at pre-treatment Mean (s.d.)	*T*	Raw	*T*	raw	*T*	raw	*T*-value, *p*-value
Commissions	52.63 (10.9)	31.45 (18.53)	51.89 (9.98)	30.21 (17.05)	53.41 (11.8)	32.76 (19.97)	$t = -1.52$, $p = 0.28$
Impulsivity index	–	0.02 (0.01)	–	0.02 (0.01)	–	0.02 (0.01)	$t = 0.00$, $p = 1.00$
Detectability (d')	51.35 (9.89)	−2.96 (0.88)	51.06 (9.18)	−2.99 (0.82)	51.65 (10.63)	−2.92 (0.94)	$t = -0.59$, $p = 0.66$
Hit reaction time – standard deviation	46.0 (9.59)	0.20 (0.05)	46.06 (8.92)	0.20 (0.05)	45.93 (10.3)	0.20 (0.06)	$t = 0.00$, $p = 1.00$
Hit reaction time – interstimulus interval change	50.06 (9.74)	0.05 (0.03)	50.47 (10.34)	0.05 (0.03)	49.63 (9.11)	0.05 (0.03)	$t = 0.59$, $p = 0.56$
BIS-11	–	78.8 (11.5)	–	79.9 (11.5)	–	77.8 (11.4)	$t = 1.42$, $p = 0.16$

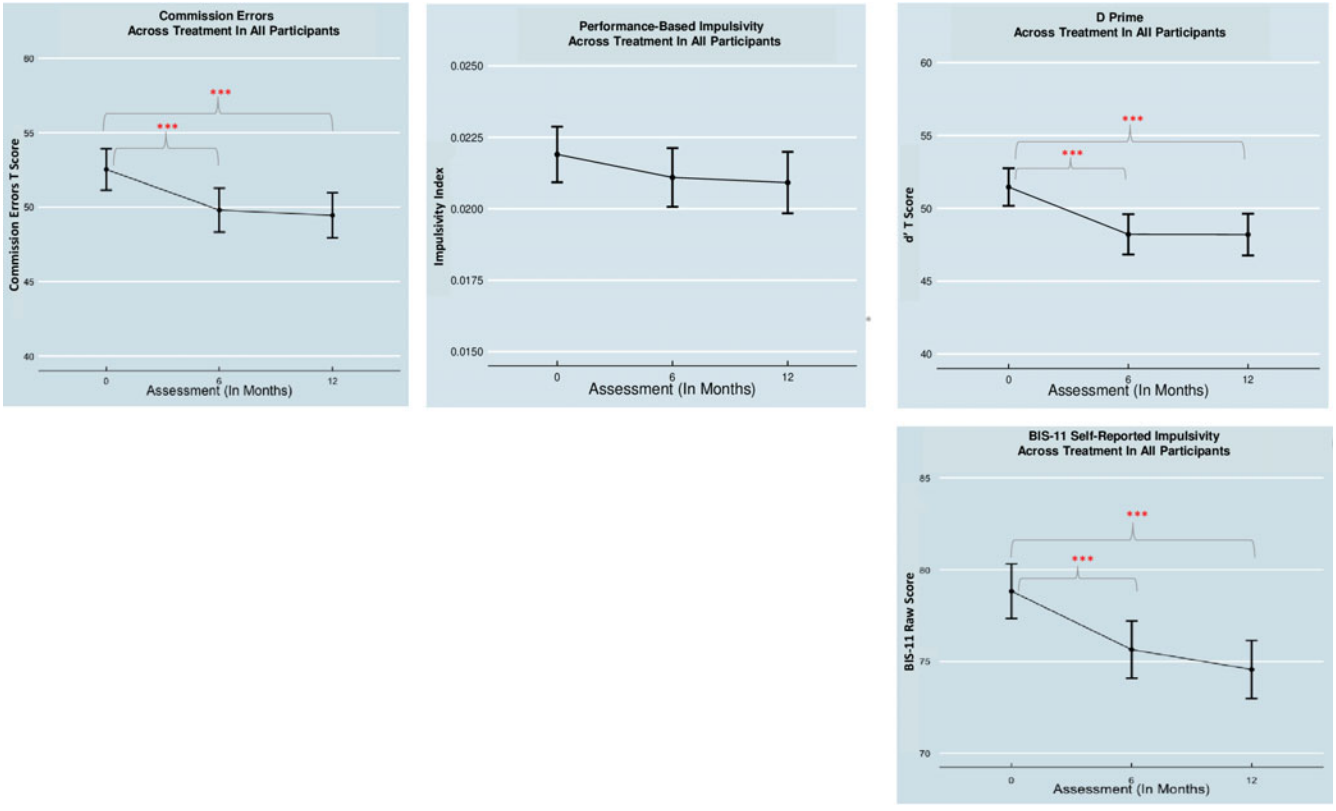

Figure 1. Neurocognitive performance across treatment, collapsed across arms for commissions (left top panel), impulsivity (middle top panel), d' (right top panel), and self-reported impulsivity (bottom right panel). ***$p < 0.001$. Asterisks indicate significance at the corrected alpha threshold.

Aim 2: Is pre-treatment cognition associated with self-harm outcomes, and do associations depend on treatment length?

Pre-treatment inhibitory control and self-harm outcomes

Commissions. A significant three-way interaction between pretreatment commissions, time, and treatment arm was found ($\chi^2 = 35.0$, $df = 8$, $p < 0.001$; Table 3), indicating that the association between pre-treatment commissions and self-harm outcomes *depended on treatment arm*. Figure 2a displays post-hoc pairwise comparisons for self-harm outcomes in each treatment arm up to the 2-year follow-up for participants with normal *v.* clinically impaired pre-treatment commissions. An examination of Fig. 2a

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Table 3. GEE analyses: significant three-way interactions between pre-treatment cognition, time, and treatment length

Source		*df*	χ^2	*p*-Value
Analysis of Commission errors *T* score	Pre-treatment commission errors	1	0.1	0.77
	Time	8	176.5	<0.001
	Treatment length	1	0.4	0.55
	Pre-treatment commission errors: time	8	13.0	0.11
	Pre-treatment commission errors: treatment length	1	1.4	0.24
	Time: treatment length	8	48.5	<0.001
	Pre-treatment commission errors: time: treatment length	8	35.0	**<0.001**
Analysis of Impulsivity Index		***df***	χ^2	***p*-Value**
	Pre-treatment impulsivity	1	0.3	0.59
	Time	8	297.3	<0.001
	Treatment length	1	0.2	0.63
	Pre-treatment impulsivity: time	8	6.4	0.60
	Pre-treatment impulsivity: treatment length	1	0.5	0.48
	Time: treatment length	8	30.3	<0.001
	Pre-treatment impulsivity: time: treatment length	8	41.1	**<0.001**
Analysis of BIS-11 impulsivity (self-report)		***df***	χ^2	***p*-Value**
	Pre-treatment BIS-11 score	1	0.3	0.61
	Time	8	187.0	<0.001
	Treatment length	1	0.7	0.42
	Pre-treatment BIS-11 score: time	8	8.5	0.39
	Pre-treatment BIS-11 score: treatment length	1	0.2	0.64
	Time: treatment length	8	33.9	<0.001
	Pre-treatment BIS-11 score: time: treatment length	**8**	**16.0**	**0.04**
Analysis of d' *T* score		***df***	χ^2	***p*-Value**
	Pre-treatment d'	1	0.6	0.45
	Time	8	173.9	<0.001
	Treatment length	1	0.4	0.51
	Pre-treatment d': time	8	9.0	0.34
	Pre-treatment d': treatment length	1	9.6	0.002
	Time: treatment length	8	54.3	<0.001
	Pre-treatment d': time: treatment length	**8**	**15.4**	**0.05**

reveals that participants with normal-range pre-treatment commissions displayed a lower frequency of self-harm when assigned to DBT-12 compared to DBT-6, during active treatment ($p < 0.001$ for between-arm contrasts at 9 and 12 months), and at 18-month follow up ($p < 0.05$). Although, by the 2-year follow-up, self-harm outcomes did not significantly differ between participants with normal commission scores assigned to either DBT-6 or DBT-12 ($p > 0.05$). On the other hand, participants falling within the clinically impaired range for commissions at pre-treatment displayed significantly lower frequencies of self-harm when assigned to DBT-6 *v.* DBT-12. In fact, significantly lower frequencies of self-harm in DBT-6 *v.* DBT-12 were observed during active treatment ($p < 0.05$ for between-arm contrasts at 6 and 12 months) and remained significant up to 2-year follow-up ($p < 0.05$ for between-arm contrasts at 15 and 18 months and $p < 0.001$ at 24 months). Taken together, poor inhibitory control at pre-treatment was associated with better self-harm outcomes, but only when assigned to brief *v.* standard length DBT.

Impulsivity index. A significant three-way interaction between pre-treatment impulsivity index, time, and treatment arm was observed ($\chi^2 = 41.1$, $df = 8$, $p < 0.001$; Table 3), suggesting that the association between impulsivity index at pretreatment and self-harm outcomes *depended on treatment arm*. Figure 2b displays post-hoc pairwise comparisons of self-harm outcomes in each treatment arm up to the 2-year follow-up in participants with low *v.* high pre-treatment impulsivity index scores. Examining Fig. 2b reveals that participants with low pre-treatment impulsivity index scores displayed a lower frequency of self-harm when assigned to DBT-12 *v.* DBT-6 (between-arm contrasts were significant by 6 months at a significance threshold of $p < 0.05$, and remained significant at 18 months at a threshold of $p < 0.01$). However, by the 2-year follow-up, self-harm outcomes did not significantly differ between DBT-6 and DBT-12 in participants with low baseline impulsivity ($p > 0.05$). In contrast, participants with high pre-treatment impulsivity index scores displayed a significantly lower frequency of self-harm when assigned to DBT-6 *v.* DBT-12, although these between-arm differences were only significant at long-term follow-up time points ($p < 0.01$ at 15 months and $p < 0.001$ at 24 months). Taken together, participants with high impulsivity at pre-treatment demonstrated significantly lower frequencies of self-harm at some long-term timepoints, but only when assigned to brief *v.* standard length DBT.

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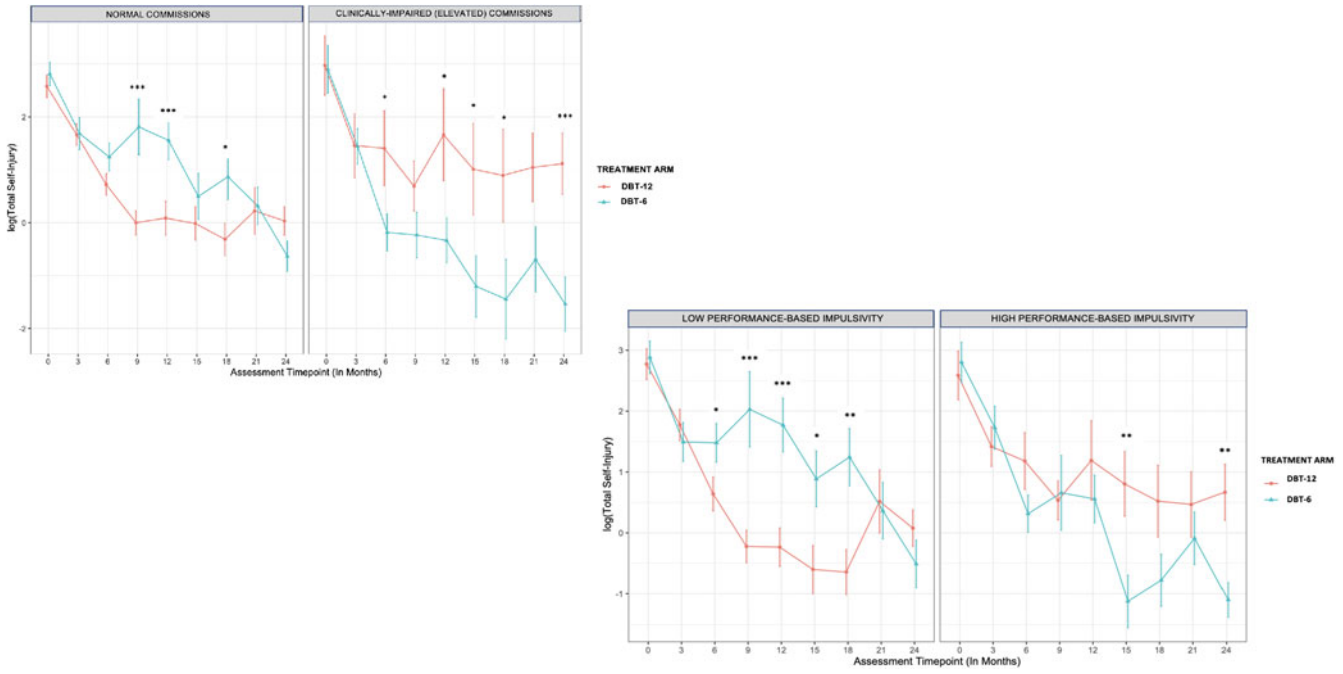

Figure 2. (a) Self-injury outcomes as a function of normal (left) or clinically impaired (right) pre-treatment inhibitory control performance. *$p < 0.05$, ***$p < 0.001$. (b) Self-injury outcomes as a function of low (left) or high (right) performance-based impulsivity at pre-treatment. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Pre-treatment detectability and self-injury outcomes

There was a marginal three-way interaction between pre-treatment d', time, and treatment arm ($\chi^2 = 15.4$, $df = 8$, $p = 0.05$) that was not statistically significant after correcting for multiple comparisons ($p > 0.013$; Table 3). Post-hoc comparisons were not examined due to the non-significant omnibus F-test.

Exploratory aim: pre-treatment self-reported impulsivity and self-injury outcomes

A three-way interaction between pre-treatment self-reported impulsivity on the BIS-11, time, and treatment arm ($\chi^2 = 16.0$, $df = 8$, $p = 0.04$) was not statistically significant after correcting for multiple comparisons ($p > 0.013$; Table 3). Post-hoc comparisons were not examined due to the non-significant omnibus F-test.

Discussion

There is a lack of research on changes in cognitive functioning during BPD treatments and on cognitive moderators of BPD treatment outcomes. The current findings suggest two things. First, they suggest that inhibitory control and attention may improve after at least 6 months of DBT for BPD, but due to the lack of a waitlist control arm, it is not possible to definitively conclude this. That is, it is possible that improvements in cognition could be due to practice effects on the CPT-3, instead of treatment-specific improvements. Three prior studies have reported on cognitive changes following specialist BPD therapy. Notably, our findings converge with Soler et al. (2012), who found improvements in detectability scores, in addition to inhibitory control and sustained attention, in participants with BPD who completed GPM + DBT mindfulness skills, but not GPM-alone, suggesting that DBT may impact attentional processes via the uptake of mindfulness skills. Soler et al. (2016) also found improvements in delay discounting (a component of impulsivity), but not on the CPT-II impulsivity index, in participants with BPD randomized to a mindfulness skills training group, relative to those randomized to interpersonal effectiveness skills training, which suggests that specific DBT skills may impact particular facets of impulsivity in BPD. On the other hand, Thomsen et al. (2017b) observed changes in attention and perceptual reasoning, but not inhibitory control, following 6 months of MBT for BPD, which contrasts with our findings of improved inhibitory control after 6 months of DBT. Future research may investigate whether there are changes in cognitive processes driven by the different treatment approaches of DBT and MBT. As DBT is a behaviorally rooted treatment, it is possible that it may exert a stronger influence on behavioral inhibition, whereas MBT targets social cognition (i.e. mentalizing) and may have a stronger impact on attention and perception.

Second, we also found that CPT-3 inhibitory control at pre-treatment was associated with different self-harm outcomes in DBT-6 *v.* DBT-12. Specifically, for participants with average inhibitory control at pre-treatment, self-harm outcomes were significantly better at 9–18 months into treatment, but only when assigned to DBT-12. Given that these between-arm differences did not emerge until 9 months into treatment, it is possible that participants with average inhibitory control may have benefited more from a longer (standard) 12-month course of DBT *v.* a brief course of DBT-6. As such, early desisting of DBT may not be appropriate in all cases and further study is needed in this area. Although, it is noteworthy that by the 2-year follow-up, self-harm in these participants did not differ in DBT-6 and DBT-12, suggesting that by 2 years, treatment length was not associated with self-harm outcomes *in participants with average inhibitory control,* In contrast, participants with clinically impaired inhibitory control at pre-treatment showed significantly lower rates of self-harm at post-treatment that were further potentiated up to 2-year follow-up, but only when assigned to the briefer DBT-6

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arm. Taken together, these findings suggest that, on average, DBT-6 may be superior to DBT-12 for reducing self-harm in participants with impaired inhibitory control, but not for participants with average inhibitory control. Importantly, these findings require replication in a clinical trial with a waitlist control group to conclude that improvements in self-harm were treatment-specific.

There are several reasons why participants with impaired inhibitory control may fare better in a shorter treatment, although future work is required to explore these possibilities. Response inhibition (a component of inhibitory control strongly associated with CPT-3 commissions) may be a non-specific pre-requisite cognitive ability for optimal outcomes in long-term psychotherapy. For example, impaired inhibitory control may translate to difficulty suppressing distractors to maintain attention and process novel information across a 12-month course of psychotherapy. As a result, a briefer treatment may have felt more tolerable for participants with impaired inhibitory control initiating DBT who have such difficulties. Similarly, cognitive impairment may be associated with feelings of lower self-efficacy or poor treatment expectancies to DBT-12 *v.* DBT-6, which may have impacted treatment engagement or skills acquisition. These hypotheses parallel findings from at least one prior study showing that better performance-based executive control at pre-treatment was predictive of more weeks in treatment (i.e. engagement) across self-harming patients with BPD who were completing 12-month treatments (Fertuck et al., 2012). Future RCTs should include participant experience measures to explore moderators of treatment response.

Moreover, it is important to highlight that there are diverse ways to measure dimensions of impulsivity (i.e. performance-based *v.* self-report measures). It is notable that prior research has mostly relied on self-report or demographic variables to predict treatment response. For example, one study could not identify differences in early and late self-harm responders to DBT when using such predictors (Westad et al., 2021). The lack of prognostic utility of such variables converges with our finding that trajectories of self-harm in DBT-6 *v.* DBT-12 could not be discerned using self-reported impulsivity on the BIS-11. One explanation for this finding is that the BIS-11 measures trait impulsivity, which is elevated in BPD (Stanford et al., 2009) As such, BIS-11 scores in BPD samples may not possess enough variability to identify distinct subgroups for prediction. Indeed, approximately 73% of participants in the current study had pre-treatment BIS-11 scores in the elevated range (Stanford et al., 2009). In contrast, the CPT-3 assesses the ability to deliberately withhold a prepotent response (which falls in the domain of action impulsivity), and only about one-third of participants in the current study scored in the clinically elevated range. With this said, at least two studies have shown that subgrouping BPD patients based on profiles of self-reported executive function can lead to the identification of subgroup-specific symptom profiles (Hoermann, Clarkin, Hull, & Levy, 2005; Kalpakci, Ha, & Sharp, 2018) and the prognostic utility of these self-reported measures for predicting treatment outcomes may be investigated in the future.

Our study also has some notable strengths. This is the first study to examine performance-based cognitive predictors of self-injury outcomes in BPD treatment and to identify discernable patterns of treatment response based on pre-treatment cognitive performance. It is also the first study to examine how treatment length may interact with cognitive functioning to affect self-harm outcomes. Importantly, we employed a performance-based measure of attention and inhibitory control with standardized clinical cut-offs and clinically interpretable predictors of self-harm outcomes. Additionally, our sample of $N = 240$ was highly powered to detect effects among randomized participants, resulting in no between-arm differences in pre-treatment cognition or self-harm.

Clinical implications and limitations

Our findings preliminarily suggest that cognitive measures of impulsivity may have predictive utility for patients with BPD who are beginning DBT and challenge the assumption that more impaired patients require lengthy treatments to make self-harm gains. In fact, we found that brief DBT may be better suited for patients with impaired response inhibition at pre-treatment, although the limitations of our study preclude any definitive clinical implications. First, because we did not employ a waitlist control group, we cannot conclude that the observed cognitive or self-harm improvements were treatment-specific. Second, our analysis drew group-level conclusions, precluding personalized predictions of individual outcome trajectories. Finally, most participants in the trial were women, which reflect the large gender disparity in treatment-seeking patients with BPD. Future work should prioritize recruiting more gender-diverse samples into a waitlist-controlled randomized trial and may employ machine learning to examine whether CPT-3 performance can predict individual patient outcomes.

Conclusions

The current findings suggest that 6 months of DBT may be associated with improvements in inhibitory control and attention. Moreover, clinically impaired inhibitory control at pre-treatment was predictive of significantly better self-harm outcomes in brief *v.* standard DBT. This work represents an initial step toward an improved understanding of patient profiles that are best suited to briefer *v.* lengthier treatments for BPD. However, before clinical implications can be drawn from these findings, they require replication in a clinical trial with a waitlist control arm.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0033291723003197.

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Competing interests. Dr McMain received personal fees from reimbursement for giving seminars and workshops on dialectical behavior therapy (DBT) and is co-owner of a practice offering DBT. Dr Chapman received payment for providing seminars and workshops on DBT and royalties for books on DBT and is co-owner of a practice offering DBT. Dr Kuo receives payment for providing consultation and workshops on DBT and is co-owner of practices offering DBT and DBT training. The other authors do not have conflicts of interest to report.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

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