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Inhibitory Control in Youth with Tourette's Disorder, Attention-Deficit/Hyperactivity Disorder and their Combination and Predictors of Objective Tic Suppressibility

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Abstract

The present study investigated inhibitory control deficits in Tourette's Disorder (TD)-only, Attention Deficit/Hyperactivity Disorder (ADHD)-only, and TD+ADHD and explored the degree to which measures of inhibitory control, and tic and ADHD severity predicted objective tic suppressibility. Participants were youth ages 9 to 14 (M=11.15) with TD-only (n=24), TD+ADHD (n=19), ADHD-only (n=139), and typically-developing controls (n=59) drawn from a larger study. Groups were compared on computer-based and paper and pencil neurocognitive inhibitory control tasks. Among youth with TD, neurocognitive measures of inhibitory control, subjective tic-suppressibility (Premonitory Urge for Tics Scale, item 10), and ADHD symptom severity were evaluated as predictors of objective tic suppressibility (i.e., laboratory-based tic suppression task), controlling for total tic severity. There were significant group differences on Color-Word inhibition/switching performance, though post-hoc comparisons yielded no significant pairwise group contrasts. Subjective tic suppressibility was the only significant predictor of objective tic suppressibility. The evident intact neurocognitive inhibitory control among youth with TD suggests that individuals with TD may use compensatory neural mechanisms to support typical

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Author Contributions

Alexandra Sturm: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft. Emily J. Ricketts: Conceptualization, Methodology, Writing – original draft. Joseph F. McGuire: Conceptualization, Writing - review & editing. Juliette Lerner and SoJeong Lee: Data curation. Sandra K. Loo, James J. McGough, James McCracken, John Piacentini, Susanna Chang: Funding acquisition; Investigation, Supervision, Writing - review & editing. Douglas W. Woods: Data curation.

Conflicts of interest

The authors have no conflicts of interest to report.

speed and accuracy of response. The role of cognitive flexibility in mechanisms of tic suppression should also be further explored.

Keywords

tic disorder; attention-deficit/hyperactivity disorder; children and adolescents; inhibitory control; tic suppression

1. Introduction

Tourette's Disorder (TD) and Attention-Deficit/Hyperactivity Disorder (ADHD) are childhood-onset neuropsychiatric disorders both characterized by behavioral disinhibition (Martino, Madhusudan, Zis, & Cavana, 2013). TD is marked by repetitive, involuntary movements and vocalizations, while ADHD is characterized by a pattern of excessive or uninhibited motor or verbal activity and/or inattention (American Psychiatric Association, 2013). TD and ADHD are prevalent at rates of 0.5% and 5.3%, respectively (Polanczyk, Willcutt, Salum, Kieling, & Rohde, 2014; Scharf et al., 2014), and frequently co-occur, particularly in individuals with TD as approximately 50% of youth with TD also receive an ADHD diagnosis (Hirschtritt et al., 2015). Further, both conditions increase risk of significant functional impairment across a range of psychosocial domains (Himle et al, 2007), with their co-occurrence often exacerbating deficits for TD youth (Sukhodolsky et al, 2003).

Given the co-occurrence of TD and ADHD, a disorder characterized by difficulty with impulse control, it is unsurprising that impaired inhibitory control has emerged as the most notable executive function-related impairment among TD youth (Morand-Beaulieu et al., 2017). Executive function, or the higher order cognitive processes that enable goal-directed action and adaptive responses to ambiguous or novel situations, encompasses inhibitory control, cognitive flexibility, and working memory (Hughes, Graham, & Grayson, 2004). Inhibitory control has been implicated in the pathophysiology of both TD and ADHD, and findings have demonstrated clear deficits in inhibitory control in youth with ADHD relative to healthy controls (Best & Miller, 2010; Homack & Riccio, 2004; Wright et al., 2014). In contrast, studies of inhibitory control in youth with TD have yielded mixed results. Meta-analyses do reveal some impairment in inhibitory control in TD relative to healthy controls (Morand-Beaulieu et al., 2017). However, comparison between youth with TD and those with TD+ADHD reveal these deficits are often exacerbated, or fully explained by, a co-occurring ADHD diagnosis (Morand-Beaulieu et al., 2017). Additionally, very few studies examining inhibitory control in TD have appropriately accounted for the co-occurrence of ADHD, and also include wide age ranges that make it difficult to account for the role of developmental differences in executive function (Openneer et al., 2020).

Theoretical evidence also supports the role of inhibitory control in TD symptoms. For example, behavioral interventions for tics involve engagement in a competing response or tic blocking action, which serves to inhibit tic occurrence (i.e., habit reversal training; Woods et al., 2008) or suppression of tics, applied in exposure and response prevention for tics (Van de Griendt, Verdellen, van Dijk, & Verbraak, 2013). Both behavioral intervention

approaches, therefore, potentially rely on an individual's inhibitory control capacity for treatment efficacy. Indeed, poorer pre-treatment inhibitory control performance predicts lower reduction in tic severity across behavior therapy (McGuire et al., 2021). Despite the persuasiveness of the theoretical connection between inhibitory control, which is presumed to underlie TD symptoms and predict response to behavioral treatment, and tic suppressibility, a mechanism through which behavioral intervention is presumed to be effective, few studies have examined the relationship between the two constructs. Woods et al. (2008) found that impaired orientation to stimuli (i.e., errors of omission) during an inhibitory control task was associated with poorer ability to suppress tics during a separate experimental task, whereas impulsivity in response to stimuli (i.e., errors of commission) was not. Further, parent-reported youth attention problems were also associated with poorer tic suppressibility during an experimental paradigm (Himle & Woods, 2005). Nevertheless, research evaluating the differential impact of inhibitory control measures – namely experimental inhibitory control and behavioral impulsivity – and tic frequency on tic suppressibility is still limited.

The present study aimed to further understand the degree to which inhibitory control is related to TD, and its impact on voluntary tic inhibition via tic suppression, a potential mechanism of behavioral treatment response for TD. As there have been few direct comparisons of neurocognitive functioning across TD, ADHD, their co-occurrence, and healthy controls, the primary aim of the present study was to compare inhibitory control deficits in youth with TD, ADHD, TD+ADHD and a healthy comparison sample. Based on prior studies, we expected to find increased inhibitory control deficits in youth with TD relative to controls, and less impairment in inhibitory control relative to ADHD and TD+ADHD groups. Understanding differences in inhibitory control may inform treatment, as youth with TD and inhibitory control deficits may require adjunctive or tailored intervention. Due to the previously found links between inhibitory control and tic suppressibility, a secondary aim was to evaluate the degree to which measures of inhibitory control (i.e., neurocognitive inhibitory control, subjective tic suppressibility), tic severity, and ADHD symptom severity were related to objective tic suppressibility. Such knowledge would have implications for predicting which youth may be able to suppress tics, and potentially which youth may have more success during behavior therapy for tics.

2. Methods

2.1 Participants

Participants were 34 youth with TD-only, 19 with TD+ADHD, 139 with ADHD-only and 59 typically developing controls (TDC) aged 11.15 years, on average (see Table 1 for sample characteristics) drawn from the Translational Research to Enhance Cognitive Control program project studies, which investigated the effects of medication on inhibitory control in youth with ADHD (McCracken et al., 2016) and the effects of behavior therapy (i.e., Comprehensive Behavioral Intervention for Tics [CBIT]; Woods et al., 2008) on neurocognitive function in youth with TD (McGuire et al., 2021), both compared to a baseline-only TDC group. In order to be eligible for inclusion in the TDC group, participants needed to be aged 7 to 14 and have a full scale IQ greater than 70. TDC

participants were excluded if diagnosed with a psychiatric disorder, were currently taking a medication impacting the central nervous system, or were pregnant. Clinical group participants were recruited from specialty clinic patient flow, primary care physician referrals, radio and newspaper advertisements, advocacy and support organizations, and schools. In order to be eligible for participation in the TD treatment study, children needed to be aged 9 to 14 years, meet DSM-IV-TR criteria (American Psychiatric Association, 2000) for TD, chronic motor tic disorder or chronic vocal tic disorder, have a Yale Global Tic Severity Scale (YGTSS; Leckman, Riddle, Hardin, & Ort, 1989) total tic severity score greater than 14 for TD or greater than 9 for chronic motor or vocal tic disorder, have moderate or higher global severity (i.e., Clinical Global Impression-Severity scale [CGI-S; Guy, 1976] score ≥ 4), and have a full-scale IQ score greater than 80 (i.e., Wechsler Abbreviated Scale for Intelligence; Wechsler, 1999). Children with a diagnosis of PDD, mania, depression, psychotic disorder, substance abuse, or conduct disorder were excluded. In order to be eligible for participation in the ADHD treatment study, youth needed to be 7 to 14 years of age, meet DSM-IV-TR criteria for ADHD-Inattentive type, ADHD-Hyperactive type, or ADHD-Combined type, have a CGI-S score ≥ 4, and have a full-scale IQ score greater than 70. Children with a diagnosis of autism spectrum disorder, major depressive disorder, psychosis, bipolar disorder, or chronic tic disorder were excluded from the ADHD treatment study. To ensure consistency between the TD-only, TD+ADHD, ADHD-only, and TDC samples, only youth between the ages of 9 and 14 from the ADHD-only and TDC groups were included. Only baseline data were used for the purpose of the present study. Participants in the ADHD-only group who were currently treated using a psychostimulant or alpha agonist (N=13) were instructed to be medication free on the day of the neurocognitive assessment, while participants in the TD+ADHD (N=4), and TD-only (N=1) groups on a current course of psychotropic treatment were permitted to take psychotropic medication at the time of their assessment.

2.2 Measures

2.2.1 Clinical Measures

2.2.1.1 SWAN.: The Strengths and Weaknesses of ADHD and Normal Behavior (Swanson et al., 2006) is a 30-item parent-report measure assessing relative strengths and weaknesses regarding ADHD symptoms and yield inattention and hyperactivity subscale scores. Higher scores are indicative of better attention and reduced hyperactivity/impulsivity. The measure exhibits excellent internal consistency, moderate test-retest reliability, and support for convergent and discriminant validity in preschool children (Lakes, Swanson, & Riggs, 2011).

2.2.1.2 YGTSS.: The Yale Global Tic Severity Scale (Leckman et al., 1989) is a clinician-rated measure of tic symptoms in the past week, yielding separate scores for tic severity (motor and vocal) and tic-related impairment, each rated on a 0- to 50-point scale (Leckman et al., 1989). The YGTSS displays good to excellent internal consistency, good to excellent interrater reliability, fair to excellent test-retest reliability, good convergent validity and support for discriminant validity (Leckman et al., 1989; Storch et al., 2005).

2.2.1.3 PUTS: The Premonitory Urge for Tics Scale (PUTS; Woods et al., 2005) is a measure of severity of premonitory sensations or urges preceding tic occurrence. Only item 10, "I am able to stop my tics, even if only for a short period of time" was used in the present analyses and youth responded on a 4-point Likert scale (0=not at all true, 1=a little true, 2=pretty much true, 3=very much true; Woods et al., 2005). This item is not included in scoring of the PUTS measure. The PUTS exhibits good internal consistency and test-retest reliability, and support for concurrent and discriminant validity (Raines et al., 2018; Woods et al., 2005).

2.2.2 Tic Suppression Task

2.2.2.1 Tic Suppression Task: Participants completed a tic suppression paradigm (Himle & Woods, 2005; Woods & Himle, 2004), involving baseline (i.e., tic freely) and voluntary tic suppression conditions each lasting a duration of 5 minutes. Participants were assigned to a counterbalanced order of conditions – baseline (tic freely) and tic suppression – generated through randomization. During baseline, participants were instructed to tic as much or little as they needed to. During the tic suppression condition, participants were instructed to look straight ahead at a dot for 5 minutes and try not to tic. They were informed they could stop themselves from ticcing in any way that they wanted, as long as they refrained from leaving their chair or blocking their face or head with their hands. In both conditions, youth were instructed to remain seated in their chair and place their hands in their lap or on armrests. Sessions were video recorded and viewed separately by research assistants masked to condition. The research assistants familiarized themselves with operational definitions previously developed by the independent evaluator, and then recorded the occurrence of tics present in each condition by pressing a key. Instances of tic occurrence were tracked using Behavioral Observation Research Initiative Software version 7.9.7 (BORIS; Friard & Gamba, 2016). Interrater reliability of tic coding was calculated using intraclass correlation coefficient (ICC; two-way mixed effects, absolute agreement, average measures), yielding a value of .84, classified as good (Koo & Li, 2016).

2.2.3 Neurocognitive Measures

2.2.3.1 ANT.: The Attention Network Task (Eriksen & Eriksen, 1974) required subjects to respond by pressing the mouse button that corresponded to the direction (left or right) of an arrow in the center of a visual display with flanking congruent (same direction), incongruent (opposite direction) arrows, or dashes on both sides of the target arrow. The ANT incongruent accuracy score percentage correct was used as a measure of inhibitory control, where higher scores indicate greater accuracy.

2.2.3.2 SST.: The Stop-signal task (Logan, Cowan, & Davis, 1984) is a well-established measure of response inhibition, and required subjects to perform a choice response time task on each trial, with responses withheld if an auditory beep was heard. The mean stop-signal reaction time (SSRT) for inhibition, which is the amount of time needed to inhibit a response after presentation of the stop signal, was included as a measure of inhibitory control where lower scores indicate greater inhibitory control.

2.2.3.3 D-KEFS C-WIT.: The Delis-Kaplan Executive Function System Color-Word Interference Test (D-KEFS C-WIT) is a has four conditions, including color naming, word reading, inhibition (involving inhibition of reading aloud written color names, while instead stating conflicting ink color names), and inhibition/switching, which requires one to state the ink color, then shift to stating the written name of the color whenever a word is outlined in a box (Delis, Kaplan, & Kramer, 2001). Only inhibition/switching scaled scores were used in the present study as a measure of inhibitory control, where higher scores indicate greater inhibitory control. The D-KEFS has strong psychometric properties and normative data derived from a nationally representative sample.

2.2.3.4 Go/No-Go.: Go/No-Go is a test of sustained attention and inhibitory control (Conners, 1996) and during which letters A through Z appear on the screen one at a time and subjects are required to press the space bar when any letter ("Go" trial) except the target letter "X" appears ("No-Go" trial). The high presentation rate of "Go" trials (90%) compared to the low presentation of "No-Go" trials (10%) results in a prepotent response bias toward responding. False positive errors of commission, or the percentage of "No-Go" trials that were incorrectly classified as "Go" trials, was used in the present study as a measure of inhibitory control, where higher scores indicate more impaired inhibitory control.

2.3 Procedure

Institutional review board-approved parent and child consent (and assent for children aged 12 years and below) were obtained prior to completing study procedures. Families completed a screening assessment to evaluate study eligibility. Participants in the ADHD trial were recruited from January 2007 to July 2011 (NCT00429273), with 323 consented and screened and 212 randomized (McCracken et al., 2016). Participants in the TD trial were recruited from July 2007 to December 2011 (NCT00675675), with 86 screened and 53 randomized (McGuire et al., 2021). An independent evaluator (IE), who was a trained Masters-level clinical psychology graduate student extern or a supervising licensed psychologist, assessed for psychiatric diagnoses using a semi-structured diagnostic interview (Kiddie-Schedule for Affective Disorders and Schizophrenia-PL; Kaufman, Birmaher, Brent, Ryan, & Rao, 2000) and completed a clinician rating of global severity (Clinical Global Impression-Severity). At screening, the IE also rated tic severity (YGTSS) for children in the TD. Participants deemed eligible, returned for a baseline assessment 1–3 weeks later, during which the IE re-rated tic severity (YGTSS) to ensure stability of TD impairment. Youth with TD rated their own premonitory urge (to tic) severity (PUTS), and their parents rated youth ADHD symptoms (SWAN). Youth in the TD trial, completed the tic suppression task, and youth in both trials completed neurocognitive measures evaluating response inhibition (ANT, SST, DKEFS C-WIT, Go/No-Go). Tasks were administered by a post-baccalaureate research assistant, trained by a supervising psychologist, through an iterative process, whereby they first practiced administration of measures independently and with peers, followed by practice on the supervising psychologist, and then with a participant while being shadowed by the supervising psychologist. Observation with prompt feedback continued until post-baccalaureate research assistants reliably delivered the neurocognitive measures. The YGTSS was administered and CGI was rated by a supervising psychologist or Master's

level clinical psychology graduate student extern. Rater training consisted of review and rating of video recordings of three YGTSS and CGI videos followed by shadowing/co-rating with a supervising psychologist and finally conducting an interview with a supervising psychologist shadowing. Research assistants and clinical psychology graduate student externs received ongoing supervision in weekly meetings with the supervising psychologist.

2.3 Analyses

Diagnostic group comparisons on demographic variables of interest were conducted using one-way ANOVA for continuous variables (e.g., age, YGTSS total score) and likelihood ratio tests for categorical variables (e.g., gender, co-occurring diagnoses) and are reported in Table 1. In order to evaluate diagnostic group differences on measures of inhibitory control (i.e., ANT incongruent trials, Go-NoGo omissions, SST reaction time, and D-KEFS CWIT inhibition/switching), analysis of variance (ANOVA) tests were conducted using STATA version 15.1. Effect sizes (ω^2) were computed, where .01 corresponds to a small effect, .06 to a medium effect, and .14 to a large effect. Each measure of inhibitory control was used as an outcome in separate analyses, with diagnostic group (TD-only, TD+ADHD, ADHD-only, TDC) included as a predictor and chronological age as a covariate. Post-hoc comparisons (Tukey HSD) were used to probe diagnostic group differences given the presence of a significant main effect. Power analyses for the four-group comparisons were conducted using G*Power (Faul et al., 2007), where alpha (α) was set to .05, β was set to .80, with an effect size of .25, consistent with findings from prior studies of between-group differences in inhibitory control among TD and TDC youth (Morand-Beaulieu et al., 2017). Power analyses indicated a total sample size of N=180 (N=45 per group) would be required to detect between-group differences of moderate magnitude. Despite being underpowered for some between-group comparisons, we proceeded with analyses and acknowledge the potential impact of insufficient power in the Discussion.

To determine the effect of neurocognitive measures of inhibitory control, subjective tic-suppressibility (PUTS item 10), and ADHD symptoms (SWAN) on objective tic suppressibility, controlling for total tic severity (YGTSS) in youth with TD (i.e., the TD and TD+ADHD groups were combined), ordinary least squares regression was used. Objective tic suppressibility scores, derived from the tic suppression task, were calculated using the following formula [baseline tic frequency – suppression tic frequency)/BL tic frequency*100] that has been used in prior research (Conelea et al., 2018).

3. Results

3.1 Comparison of inhibitory control deficits across diagnostic groups

There was a significant main effect of diagnostic group $F(3,245)=5.19$, $p<.01$, $\omega^2=.05$, on ANT incongruent trial accuracy. Post-hoc comparisons revealed a significant differences between the TDC and ADHD diagnostic groups, such the TDC group scored significantly higher, on average, than ADHD-only group, and no other pairwise differences among the other diagnostic groups ($EMM_{TDC}=42.70$, SE=1.23; $EMM_{ADHD}=37.01$, SE=0.81; $EMM_{TD}=40.15$, SE=1.63; $EMM_{TD+ADHD}=39.42$, SE=2.16). There was a significant main effect of diagnostic group $F(3,245)=3.40$, $p<.05$, $\omega^2=.03$, on D-KEFS CWIT

inhibition/switching. However, post-hoc comparisons revealed no significant pairwise comparisons (EMM_{TDC}=11.04, SE=.34; EMM_{ADHD}=9.88, SE=.22; EMM_{TD}=10.87, SE=.44; $EMM_{TD+ADHD}$=10.34, SE=.60) and thus the main effect of diagnostic group was not interpreted. There was no significant main effect of diagnostic group on Go-NoGo commission errors $F(3,237)=1.25$, $p=.29$, $\omega^2=.003$, or Stop Signal Task SSRT $F(3,185)=1.03$, $p=.38$, $\omega^2=.0005$.

3.2 Neurocognitive correlates of objective tic suppressibility

Among all youth with TD (i.e., TD and TD+ADHD groups), there was a significant main effect of subjective tic suppressibility (PUTS Item 10; $p < .05$), but no main effect of neurocognitive measures of inhibitory control or ADHD symptoms (Table 2; $p > .05$) on objective tic suppressibility, controlling for total tic severity. Relative to youth who reported poor subjective tic suppressibility, 1 (not at all true), youth who provided ratings of 3 (pretty much true) or 4 (very much true) exhibited significantly fewer tics while trying to suppress during the tic suppression task.

4. Discussion

In the present study, we aimed to further understand the degree to which inhibitory control is related to TD, and its impact on voluntary tic inhibition via tic suppression, a potential mechanism of behavioral treatment response for TD. We found no significant differences between TD youth (TD, TD+ADHD) and their ADHD and neurotypical peers on common neurocognitive measures of inhibitory control, including ANT, SST, Go/No-Go, and D-KEFS Color-Word Interference Inhibition-Switching. In addition, neurocognitive measures and behavioral measures of inhibitory control (i.e., ADHD symptoms) bore no relationship with objective tic suppressibility by youth with TD (alone or in combination with ADHD). However, there was a significant relationship between subjective tic suppressibility and objective tic suppressibility in these youth.

The lack of inhibitory control deficits among youth with TD, with and without co-occurring ADHD, in the present study contribute further evidence to the equivocal findings of inhibitory control deficits across studies (Morand Beaulieu et al., 2017). Findings from the present study are somewhat inconsistent with the task-specific inhibitory control deficits found in a recent meta-analysis (Morand Beaulieu et al., 2017). While the absence of inhibitory control deficits on SST SSRT confirms prior work, the absence of deficits on Go/No-Go commission errors does not replicate meta-analytic findings demonstrating the presence of inhibitory control deficits on CPT commission errors among TD youth. The non-significant inhibitory deficit on the attention network task found in the present study further lends support to the intact response inhibition in youth with TD observed in the present sample. Researchers have theoretically divided inhibitory control tasks into those that primarily assess motor response inhibition (e.g., SST, Go-NoGo) and, separately, verbal response inhibition (e.g., D-KEFS CWIT; Hovik et al., 2016), indicating greater inhibitory control deficits on verbally-mediated tasks (Morand Bealieu et al., 2017). The present study revealed a significant, small-medium group effect on D-KEFS CWIT, but failed to demonstrate significant pairwise group comparisons. Though the present study was

underpowered to detect between-group differences of medium effect, trends in group means are consistent with prior studies, demonstrating deficits in performance for TD youth, and even greater impairment for youth with TD and co-occurring ADHD compared to healthy controls (Morand Bealieu et al., 2017).

Despite lack of demonstrable neurocognitive deficits in inhibitory control found in youth with TD in the present study, there is some support in the literature for deficits in inhibitory brain networks during completion of motor inhibition tasks in youth and adults with TD relative to healthy controls. These studies suggest that individuals with TD may use compensatory strategies to support accuracy (e.g., sacrificing speed for accuracy) or neural mechanisms to support both typical speed and accuracy of response (e.g., as evidenced by deficits in neural correlates of inhibitory control including event-related potentials obtained from EEG, and shortened cortical silent period, referring to disruption of voluntary muscle contraction during transcranial magnetic stimulation of the motor cortex) (Ganos et al., 2014; Moll et al., 2001; Morand Beaulieu et al., 2017; Schüller et al., 2018; Wolters, Ziemann, & Benecke, 2008). The necessity of compensatory strategy use may, in part, explain the sample specific findings across studies of inhibitory control as the majority of existing study samples are small and may fail to generalize to the larger population of TD youth.

With respect to evaluation of neurocognitive and behavioral inhibitory control and subjective tic suppressibility as predictors of objective tic suppressibility, the only significant predictor to emerge was subjective tic suppressibility, as measured by item 10 (“I am able to stop my tics, even if only for a short period of time”) from the PUTS. The present association found between subjective tic suppressibility and objective tic suppressibility contradicts prior aggregate analysis showing no relationship (Conelea et al., 2018). However, Conelea et al. (2018) tested for a linear relationship (i.e., Pearson correlation) between subjective tic suppressibility and objective tic suppressibility. In the present study, an effect of subjective tic suppressibility on objective tic suppressibility was observed for youth who endorsed that they were “pretty much” or “very much” able to suppress their tics, even for a short period of time *compared* to youth who reported no ability to suppress tics. Further, Conelea and colleagues (2018) had analyzed objective, reward-enhanced tic suppressibility (i.e., tic suppression conditions wherein subjects received points or tokens contingent upon periods of successful suppression). In contrast, objective tic suppressibility in the present analysis was based on a verbal prompt to suppress tics, with no contingent rewards given. This discrepancy in outcomes suggests that youth may actually display good insight into their own ability to suppress tics in more naturalistic contexts.

Contrary to our hypothesis, neither overall tic severity nor behavioral inhibitory control (inattention and hyperactivity symptoms) significantly predicted objective tic suppressibility. Findings regarding associations between these two clinical characteristics and tic suppressibility have been mixed, and may reflect differences in sample size, characteristics, and measures used across studies (Conelea et al., 2018; Himle & Woods., 2005, Woods et al., 2008). Moreover, neurocognitive measures of inhibitory control were not associated with tic suppressibility. Research examining the relationship between laboratory-based measures of inhibitory control and tic suppressibility is limited and mixed, reporting both significant

(Woods et al., 2008) and non-significant associations (Specht et al., 2014) between inhibitory control (i.e., increased errors of commission) and objective tic suppressibility. It is possible that neurocognitive tasks of inhibitory control and tic suppression may rely on distinct neural processes, as the actions involved differ in nature. For example, tasks of motor inhibition require quick inhibition, but the tic suppression paradigm requires sustained tic suppression over longer periods (Ganos et al., 2014).

The present study has several limitations. First, although youth with TD and ADHD stemmed from clinical trials run as part of a single center grant with shared assessment batteries, the trials entailed different treatments (i.e., behavior therapy for youth with TD vs. medication for youth with ADHD), and distinct protocols were in place for neuropsychological testing (i.e., youth with ADHD were instructed to refrain from taking medication during testing, whereas youth with TD, were allowed to take medication). Due to this heterogeneity between clinical groups, findings should be interpreted cautiously. Second, our TD samples are modest in size and the present study was underpowered to detect a medium effect. However, sample size was comparable, if not larger, than many previous studies examining similar constructs (Hovik et al., 2016; Sukhodolsky et al., 2003). Indeed, few studies have compared these four groups (Hovik et al., 2016), necessitating a need for further comparison in larger studies using rigorous methodology. Third, given that the inhibition/switching task evaluates both response inhibition and cognitive flexibility, and OCD is associated with deficits in cognitive flexibility, higher rates of OCD in youth with TD and TD plus ADHD relative to youth with ADHD may have skewed performance on the inhibition/switching task. Fourth, the single-item measure of subjective ability to suppress tics was not validated as a stand-alone item, although researchers recognize this item to be distinct from the remaining PUTS items (e.g., Conelea et al., 2018; Woods et al., 2005). Replication of the present findings is warranted to confirm these findings. Additionally, it is possible that increasing the neurocognitive task load may have resulted in larger between group differences in inhibitory control. In addition, future research in the area of compensation among youth with TS should consider the addition of measures that may reveal the relationship between cognitive effort and neurological correlations (i.e., EEG or fMRI) to identify compensatory circuit activity that may buttress cognitive functioning. Further, more research is needed to address the neural correlates of inhibitory control and the degree to which clinical and neural characteristics cluster together to predict tic suppressibility. Future work should continue to explore the utility of subjective tic suppressibility in predicting objective tic suppressibility and response to behavior therapy.

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Highlights

- The inhibitory control of youth with Tourette's Disorder (TD)-only, ADHD-only, TD+ADHD, and no diagnosis was compared.
- Inhibitory control, and tic and ADHD severity were evaluated as predictors of objective tic suppressibility.
- TD youth, with and without ADHD, did not demonstrate significant impairment in inhibitory control.
- Subjective tic suppressibility was the only significant predictor of objective tic suppressibility in TD youth.

Table 1.

Sample characteristics

Variable	TD	TD+ADHD	ADHD	TDC	F/X^2
N	34	19	139	59	
Age	11.02 (1.59)	10.77 (1.70)	11.14 (1.67)	11.65 (1.71)	p=0.12
FSIQ	106.47 (11.33)	109.06 (14.63)	100.85 (14.10)	107.12 (14.11)	p<.05
Gender, N(%) Male	22 (65)	16 (84)	93 (67)	35 (59)	p=.22
Ethnicity, N (%) Non-Hispanic White	23 (67.6)	9 (47.4)	71 (51.1)	29 (49.2)	p=.18
YGTSS Total	25.15 (5.18)	27 (5.73)			p=.24
SWAN Inattentive	29.03 (10.24)	20.5 (9.23)	13.98 (7.1)	36.75 (9.35)	p<.01
SWAN H/I	29.97 (9.05)	20.26 (6.42)	21.79 (10.74)	37.81 (9.88)	p<.01
Diagnoses					
Anxiety	14 (41.2)	12 (63.2)	39 (28.1)	1 (1.7)	p<.01
Depression	1 (2.9)	0 (0)	7 (5.0)	0 (0)	P=.51
OCD	9 (27.3)	7 (36.8)	2 (1.4)	0 (0)	p<.01

Note. TD = Tourette's Disorder; ADHD = Attention-deficit/Hyperactivity Disorder; TDC = typically developing controls; YGTSS = Yale Global Tic Severity Scale; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Rating Scale; H/I = Hyperactivity/Impulsivity; OCD = Obsessive-Compulsive Disorder.

Table 2.

Linear regression analyses of measures of neurocognitive inhibitory control, and subjective tic suppressibility, ADHD symptoms and tic severity predicting objective tic suppressibility.

Objective Tic Suppressibility				
	Coef.	SE	*t*	*p*
YGTSS Total Score	−0.01	0.04	−0.22	0.83
D-KEFS CWIT				
Inhibition/Switching	−0.07	0.07	−0.93	0.38
Go-NoGo commission errors	−0.01	0.03	−0.26	0.80
SST SSRT	0.001	0.002	0.63	0.55
ANT incongruent accuracy	−0.01	0.02	−0.84	0.42
SWAN hyperactivity/impulsivity	0.05	0.03	2.02	0.08
PUTS Item 10				
2	0.50	0.78	0.65	0.54
3	2.47	0.72	3.42	0.01
4	1.70	0.75	2.25	0.05
constant	−1.50	1.78	−0.84	0.42
	df	*F*	*p*	
PUTS10	3	5.62	0.023	

Note. YGTSS = Yale Global Tic Severity Scale; D-KEFS = Delis Kaplan Executive Function System; CPT = Go-No/Go; SST = Stop Signal Task; ANT = Attention Network Task; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Rating Scale; PUTS = Premonitory Urge for Tics Scale.