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Task-Switching Inefficiencies in Currently Ill, but not Remitted Anorexia Nervosa

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Abstract

Objective: Models of anorexia nervosa (AN) posit that set-shifting deficits may contribute to behavioral inflexibility and extreme dietary restriction. Findings from neurocognitive studies of set-shifting in AN have been somewhat mixed, perhaps due to the use of tasks that cannot distinguish shifting from other processes (i.e., learning). To more precisely characterize cognitive flexibility and selectively assess this process independent of rule learning and feedback sensitivity, we examined task-switching ability in AN.

Method: Women ill with AN, subthreshold AN, or atypical AN (IAN; $n = 40$), women remitted from AN (RAN; $n = 24$), and age-matched healthy control women (CW; $n = 42$) completed a computerized cued color-shape task-switching paradigm. Groups were compared on mix costs (reflecting global cognitive control) and switch costs (reflecting transient cognitive control).

Results: Although mix costs were equivalent across groups, switch costs were more pronounced in the IAN group, as indicated by a group-by-trial type interaction for reaction times on stay and switch trials.

Discussion: Findings indicate that IAN, but not RAN, have difficulty flexibly switching between cognitive task sets, and suggest that prior findings of set-shifting deficits in AN may reflect difficulty with cognitive flexibility independent of learning deficits. As such, task-switching may represent a promising adjunctive treatment target.

Keywords

anorexia nervosa; cognitive flexibility; task switching; executive function

Deficits in cognitive flexibility are theorized to contribute to the prototypically constrained, over-controlled, and rigid presentation commonly observed in patients with anorexia nervosa (AN) and to maintain its core cognitive and behavioral symptoms (Treasure & Schmidt, 2013). Set-shifting (i.e., ability to switch between tasks or modify behavior in response to

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

changing rules) is an aspect of cognitive flexibility that has been widely investigated in AN (Wu et al., 2014). However, to better characterize and specifically target cognitive inflexibility in AN, two key issues require clarification. First, findings of cognitive flexibility deficits in remitted AN samples are somewhat inconsistent (e.g., (Roberts, Tchanturia, & Treasure, 2010)), raising questions about the chronicity of these deficits. Second, tasks typically used to evaluate set-shifting in AN (e.g., the Wisconsin Card Sorting Test; (Tchanturia et al., 2012)) require integration of feedback to guide future decisions; therefore, the tasks cannot distinguish efficient switching from learning and potentially reward and punishment sensitivity, all of which are known to be altered in AN (Foerde & Steinglass, 2017; Harrison, O'Brien, Lopez, & Treasure, 2010; M. Shott et al., 2012; Tchanturia et al., 2007). Therefore, assessments across stages of illness and independent of feedback sensitivity and learning are needed.

Task-switching paradigms are a standard method of selectively assessing cognitive control and flexibility (Koch, Poljac, Muller, & Kiesel, 2018), and although widely used within the cognitive psychology field, have yet to be applied to eating disorders. In a typical task-switching experiment, subjects perform two or more simple tasks based on a set of stimuli, with each task requiring attention to, and classification of, a different stimulus feature (e.g., shape or color). Generally, responses are slower and less accurate on trials where the individual must switch between different tasks (‘switch’ trials) than on trials where the task is repeated (‘stay’ trials), reflecting a cognitive cost known as a *switch cost*. Switch costs are thought to reflect moment-to-moment, or “transient,” cognitive control mechanisms that are engaged when shifting attention between stimulus features, inhibiting prior task-sets, and activating the required task-set (Monsell, 2003). In addition, responses on task-repetition trials are slower and less accurate in blocks that require switching between tasks (‘stay’ trials) compared to task-repetition trials in blocks that involve just one task (‘single’ trials). This performance cost is called a *mix cost*. Because the only difference between these task-repetition trials is the context, mix costs are thought to reflect more global cognitive control mechanisms that monitor task-related cues, maintain competing goals, and keep track of potential conflicts between abstract task rules (Shahar & Meiran, 2015). Notably, neuroimaging studies have identified separate, dissociable networks associated with task switching versus mixing (Braver, Reynolds, & Donaldson, 2003).

We used a task-switching paradigm, the Cued Color-Shape Switching task (CCSST), to test the hypothesis that individuals currently ill with AN, subthreshold AN, or atypical AN (IAN) and remitted from AN (RAN) would demonstrate difficulties with task-switching ability compared to healthy control women (CW). Given a large body of neurocognitive research suggesting that cognitive control dysfunction may persist after AN remission, as well as data indicating that even unaffected sisters of individuals with AN show cognitive inflexibility (Ritschel et al., 2017; Roberts et al., 2010), we specifically predicted that both IAN and RAN would show increased mix and switch costs relative to CW.

Methods

Participants

IAN participants were patients at the University of California, San Diego (UCSD) Eating Disorders Center for Treatment and Research. Using an unstandardized, semi-structured interview at treatment admission, program psychiatrists assigned diagnoses of a current "AN-spectrum" disorder (AN, according to 2010 draft criteria for the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5)* (Hebebrand & Bulik, 2011), including atypical or subthreshold AN (body mass index range in this group: 13.9 - 23.8 kg/m^2; see Supplement)), and psychiatric comorbidities. RAN participants were recruited nationally as part of a larger study, and control women (CW) were recruited from the San Diego community. Eating disorder history and current and past psychiatric diagnoses in RAN and CW were assessed by trained staff using a modified version of the Structured Clinical Interview for *DSM-IV-TR* Module H (First, Spitzer, Gibbon, & Williams, 2002) and the Mini International Neuropsychiatric Interview (Sheehan et al., 1998), respectively (see Supplement for further information). Remission in the RAN group was defined by maintenance of more than 85% ideal body weight, regular menstrual cycles, and no eating disorder behaviors for the 12 months before participation.

Procedure

On average, IAN participants (see Table 1) completed the CCSST 34.2 days after treatment admission. All other participants completed the neurocognitive task within 2 weeks of completing the eligibility semi-structured interviews. Weight and height were measured via digital scale and stadiometer, respectively, within 2 days of study completion (for IAN) or during the task visit (for CW and RAN). Participants provided informed consent, and this research was approved by the UCSD Human Research Protection Program.

Cued Color-Shape Switching Task (CCSST)

Participants completed a computerized CCSST ((Weissberger, Wierenga, MW, & Gollan, 2012); Figure 1A) to examine task mixing and switching independent of learning. On color trials, a rainbow bar cued participants to press a button indicating the stimulus' color (red or green), and on shape trials, a series of black shapes cued participants to press a button indicating the stimulus' shape (triangle or circle). The cue, stimulus, and a button mappings legend remained on the screen until the subject responded or 2000ms passed. Participants completed two single-task blocks in which the trial type (color, shape) remained the same across all trials ("single trials"), followed by four mixed-task blocks (in which half of the trials were sequential trials of the same type and did not require task-switching ("stay trials"), and half were sequential trials of different types (e.g., color followed by shape; "switch trials")), followed by two single-task blocks. The order of color versus shape was counterbalanced for the single-task blocks. This sandwich block design enabled comparison of 40 switch trials, 40 stay trials, and 80 single-task trials (40 color and 40 shape), and reduces the influence of order effects on single and mixed block performance (Rubin & Meiran, 2005). Stimuli were presented using PsyScope X software on a 17-inch MacBook laptop (Cohen, MacWhinney, Flatt, & Provost, 1993).

Statistical Analysis

Error rates were calculated to gauge successful completion of the task. Response times (RTs) for incorrect responses were excluded from RT analyses (559 trials, 3.3% of responses). As previously described (Weissberger et al., 2012), outlier RTs (299 total trials) were trimmed for individual participants by excluding any response more than three standard deviations from the individual's mean RT. Consistent with prior studies (Weissberger et al., 2012), this procedure eliminated 1.6% of responses.

We report separate analyses of 1) mix costs, which contrast non-switch (stay) trials within mixed-task blocks with non-switch (single) trials in single-task blocks, and 2) switch costs, which contrast stay (non-switch) with switch trials in mixed-task blocks. We conducted 3 x 2 repeated-measures ANOVAs with diagnostic group as a between-subjects variable (IAN, RAN, CW), and RT for each trial type (stay and single trials for mix costs; stay and switch trials for switch costs) as within-subject variables. Analyses were repeated with accuracy rates for each trial type as within-subject variables. Alpha was set at 0.025 to adjust for multiple comparisons.

Exploratory Huber robust regressions within group examined associations of lowest lifetime body mass index (BMI) and current BMI with mix costs (RTs of stay trials in mixed blocks minus RTs of single trials in single blocks) and switch costs (RTs of switch trials in mixed blocks minus RTs of stay trials in mixed blocks). Alpha was set at 0.004 to adjust for multiple comparisons.

Sensitivity analyses examined the potential impact of current and past comorbidities, AN subtype, and group differences in age (see Supplement).

Results

Sample Characteristics

After excluding one RAN participant who responded incorrectly on over 50% of trials, our final sample included 42 CW, 40 IAN, and 24 RAN. Participant characteristics are reported in Table 1 and in the Supplement.

Group Differences in Task Switching—Mean RTs and error rates for single, stay, and switch trials, as well as mix and switch costs for each group are reported in Table S2.

Color-Shape Mixing

RTs.—All participants responded more quickly on the single trials in single-task blocks than on stay trials in the mixed blocks, $F(1,103)=76.040$, $p<0.001$, $\eta_p^2=0.425$. The interaction between group and trial type was not statistically significant ($p=0.175$), nor was the main effect of group ($p=0.159$).

Errors.—All participants made more errors during mixed-block stay trials than single trials, $F(1,103)=6.273$, $p=0.014$, $\eta_p^2=0.057$. Differences in accuracy between single and stay trials did not differ by group ($p=0.989$), and there was not a statistically significant main effect of group ($p=0.792$).

Color-Shape Switching

RTs.—All participants responded more quickly on stay than on switch trials in mixed blocks, $F(1,103)=72.899$, $p<0.001$, $\eta_p^2=0.414$; this effect was moderated by group, $F(2,103)=3.996$, $p=0.022$, $\eta_p^2=0.072$. The IAN group showed the most pronounced difference between stay and switch trials (Figure 1B).

Errors.—All participants were less accurate during mixed-block switch compared to stay trials, $F(1,103)=55.355$, $p<0.001$, $\eta_p^2=0.350$; there was no statistically significant interaction of group and trial type ($p=0.527$) or main effect of group ($p=0.567$).

Exploratory Clinical Associations and Sensitivity Analyses

No mix or switch costs associations with current or lowest past BMI survived correction for multiple comparisons (Table S3, Figure S1). Sensitivity analyses suggested that task-switching impairments in IAN were robust to group differences in age, and AN subtype and lifetime comorbidities did not appreciably impact our results (Tables S4, S5).

Discussion

This study assessed cognitive flexibility independent of learning and feedback sensitivity in symptomatic and remitted AN. As switch costs were more pronounced in our heterogeneous sample of IAN, our findings support a large body of research on set-shifting deficits in AN (Wu et al., 2014). However, mix costs were equivalent across groups, suggesting that set-shifting deficits in AN may be circumscribed to efficiently switching between tasks on a trial-by-trial basis, while global cognitive control is intact (e.g., goal maintenance, conflict processing).

Notably, our RAN group did not demonstrate elevated switch costs. Prior studies exploring set-shifting in recovered samples have used several tasks (e.g., trail making, CatBat) and have primarily focused on weight-restored (versus fully remitted) individuals, yielding mixed results (e.g., Jones, Duncan, Brouwers, & Mirsky, 1991; Tchanturia, Morris, Surguladze, & Treasure, 2002). Current or very recent chronic restrictive eating may have contributed to altered task-switching observed only in the IAN group. Supporting this possibility, acute fasting increases shifting costs in healthy individuals (Bolton, Burgess, Gilbert, & Serpell, 2014). Future longitudinal studies are needed to examine whether set-shifting is enhanced after remission or predicts better outcome. Moreover, as our and others' data (M. F. Shott, JV et al., 2012; Tchanturia et al., 2011) suggest no association between task-measured cognitive inflexibility and BMI or AN symptoms, future research should examine whether measures of eating disorder symptom-specific inflexibility (e.g., the Eating Disorder Flexibility Index Questionnaire (Dahlgren, Hage, Wonderlich, & Stedal, 2019) or diet variety scores) better capture task switching-related symptoms.

Study limitations should be acknowledged. The generalizability of our findings is limited by our modestly-sized, treatment-seeking samples of adult women, and the potential roles of current comorbid disorders and medications in our IAN sample cannot be conclusively determined. Structured research interviews established past AN diagnoses in RAN participants, but semi-structured clinical interviews established IAN diagnoses. As our IAN

sample included full and subthreshold AN, future studies should examine switch and mix costs in a homogenous sample who meet full criteria for the disorder. Group differences in switch costs were robust to group differences in age, but future research should focus on the impact of neurodevelopment on cognitive flexibility in AN. Additionally, although the CCSST measures task-switching independent of feedback sensitivity or learning, the task requires both attentional shifts (turning focus away from one set of features and onto another), as well as response shifts e.g., pressing different buttons for different cues; (Ravizza, 2008). Longitudinal administration of comprehensive set-shifting task batteries in combination with behavioral measures (e.g., test meals, ecological momentary assessment) in large samples would help to identify even more precise deficits that characterize AN and clarify contributions of comorbidities to task-switching alterations.

Despite these limitations, results were robust to group differences in age and have implications for future research. Neuroimaging studies of healthy individuals implicate the lateral prefrontal cortex (PFC), anterior cingulate, parietal cortex, and caudate in successful task switching (Braver et al., 2003; Hyafil, Summerfield, & Koechlin, 2009), and switch costs are associated with increased PFC activation (Jimura & Braver, 2009). Given that studies using symptom-specific tasks have implicated this frontostriatal circuitry (e.g., (Foerde, Steinglass, Shohamy, & Walsh, 2015)), future research should examine whether frontostriatal, and particularly PFC, dysfunction promotes generalized task-switching impairments in AN. Group differences in switch costs were not detected in analyses excluding IAN participants with comorbid anxiety disorders. Although this may be related to reduced power, and research to date has not suggested task-switching deficits in anxiety disorders compared to non-psychiatric controls, there may be state-specific alterations associated with anxiety that are driven by repetitive negative thinking (e.g., worry) that impair task switching (Derakshan, Smyth, & Eysenck, 2009; Paulus, 2015). As such, interventions targeting task-switching may be best suited to individuals with AN and comorbid anxiety, and targeting anxiety using other empirically-supported interventions could decrease difficulties with task switching. Overall, interventions that address behavioral flexibility, such as cognitive remediation therapy (Tchanturia, Giombini, Leppanen, & Kinnaird, 2017), Radically Open Dialectical Behavior Therapy (Lynch, Gray, Hempel, Titley, & O'Mahen, 2013; Lynch, Hempel, & Dunkley, 2015), the Maudsley Model of Anorexia Nervosa Treatment for Adults (Schmidt, Wade, & Treasure, 2014), and Temperament Based Treatment (Wierenga et al., 2018), may be important in targeting task-switching deficits in IAN.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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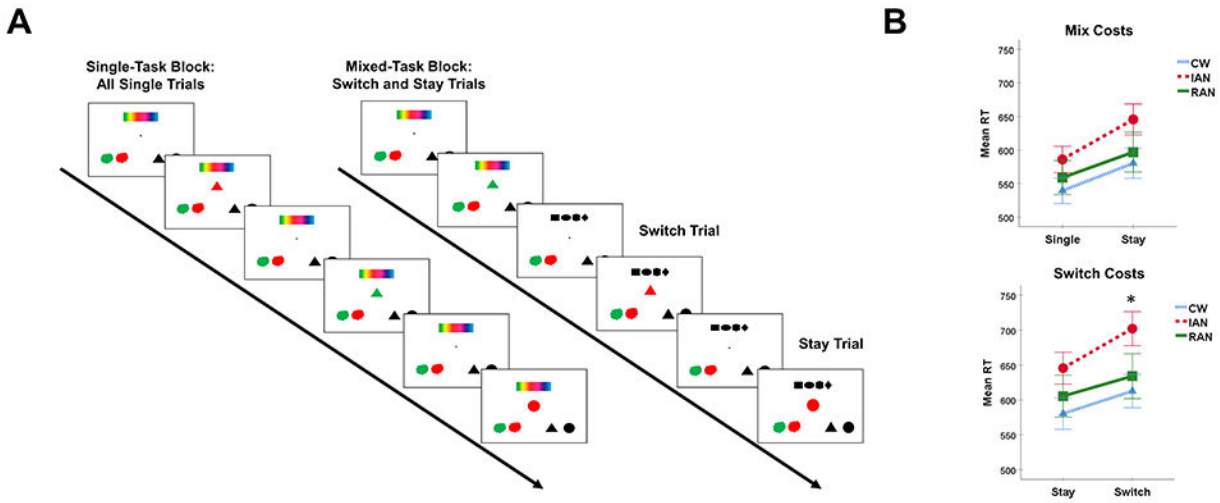

Figure 1.

A) Cued Color-Shape Switching Task. Participants completed a cued color-shape switching task (Weissberger et al., 2012) comprised of two single-task blocks, in which the task remained the same across all trials (e.g., indicate color of the stimuli, with order of color and shape tasks counterbalanced across subjects), followed by four mixed-task blocks, in which half of the trials were sequential trials of the same type and did not require task-switching ("stay trials"), and half were sequential trials of different types (e.g., color followed by shape; "switch trials"), followed by two more single-task blocks (with color and shape presented in the opposite order of the first two blocks). In cued task-switching paradigms, switching costs capture the change in reaction time (RT) and accuracy from task-repetition ('stay') trials to task-switch ('switch') trials in the context of task blocks that involve switching between tasks. These costs are thought to reflect the influence of the increased cognitive demand of immediate, "transient," or "local" task changes from not switching to switching. Mixing costs capture the change in RT and accuracy when comparing two types of task repetition trials--specifically, when comparing task repetition trials from task blocks that do not involve task switching ('single' trials) to task repetition trials from task blocks that involve task switching ('stay' trials). In mixing costs, the only difference between the two trial types is contextual. As a result, these costs are thought to reflect more "global" aspects of control, and have been shown specifically to represent cognitive conflict-related processing related to which task rule is required. **B) Color-Shape Mix and Switch Costs across Groups.** A group x trial-type interaction was detected only for switch costs analyses ($p=0.022$), and indicated that the IAN group showed the most exaggerated time (RT) difference between stay and switch trials.

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Table 1.

Participant Characteristics

	IAN (*n* = 40)		RAN (*n* = 24)		CW (*n* = 42)		Analysis	
	M	***SD***	***M***	***SD***	***M***	***SD***	***F or X²***	***p***
Age (years)	24.3	7.4	25.6	5.9	22.0	3.0	3.462	0.035
Current BMI (kg/m^2)	19.4	2.0	21.0	1.5	21.3	1.5	14.880	< 0.001
Lowest BMI (kg/m^2)	16.3	2.2	14.4	2.1	19.4	1.2	66.157	< 0.001
Education (years)	14.2	2.3	15.5	2.0	14.9	1.3	3.301	0.041
Binge-eating/purging subtype (%)	45%		37.5%				0.346	0.556
Race and Ethnicity							29.256	< 0.001
Hispanic White	10.3%		12.5%		19.0%			
Non-Hispanic White	76.9%		79.2%		38.1%			
Non-Hispanic Asian	5.1%		8.3%		35.7%			
Non-Hispanic Black	0%		0%		7.1%			
Non-Hispanic Other Ethnicity	7.7%		0%		0%			
Current Comorbidities								
MDD (%)	37.5%		-		-			
PTSD (%)	25.0%		-		-			
Any anxiety disorder (GAD, SAD, Panic)	32.5%		-		-			
Substance use disorder	10.0%		-		-			
Alcohol use disorder	7.5%		-		-			

IAN = participants ill with anorexia nervosa; RAN = participants remitted from anorexia nervosa; CW = healthy control participants; BMI = body mass index; MDD = major depressive disorder; PTSD = post-traumatic stress disorder; GAD = generalized anxiety disorder; SAD = social anxiety disorder; SSRI = selective serotonin reuptake inhibitor. Remission for RAN participants was defined as in prior studies (Bailer et al., 2005; Wierenga et al., 2015): maintenance of > 85% ideal body weight, regular menstrual cycles, and no eating disorder behaviors for 12 months before participation. Exclusion criteria included other current DSM-IV axis I diagnosis for RAN and CW participants, and a history of any eating disorder for CW participants. Two IAN participants reported a history of attention deficit hyperactivity disorder. No participants were diagnosed with obsessive-compulsive disorder, bipolar disorder, or psychotic disorders.