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Increased tactile sensitivity and deficient feed-forward inhibition in pathological hair pulling and skin picking

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ABSTRACT

An increasing body of evidence has linked pathological body-focused repetitive behaviors (BFRBs) to excessive sensory sensitivity and difficulty modulating sensory inputs. Likewise, neurobiological evidence points to deficits in feed-forward inhibition and sensory habituation in conditions with similar symptomatology. There is currently little evidence regarding potential physiological sensory abnormalities in BFRBs. The current study compared 46 adults with pathological hair pulling and/or skin picking to 46 age-matched healthy control participants on a series of self-report measures and objective psychophysical tests of neurophysiological sensory functions. Persons in the BFRB group reported increased scores on the Sensory Gating Inventory ($U = 320.50$, $p < .001$) and all of its subscales (all p-values $< .001$), reflecting abnormal sensory experiences. The BFRB group also showed decreased tactile thresholds (increased sensitivity) ($F[1, 76] = 10.65$, $p = .002$, $\eta_p^2 = .12$) and deficient feed-forward inhibition ($F[1, 76] = 5.18$, $p = .026$, $\eta_p^2 = .064$), but no abnormalities in quickly-adapting sensory habituation were detected on an amplitude discrimination task. Performance on objective psychophysical tests was not associated with self-reported sensory gating symptoms or symptom severity. Implications of these results for the pathophysiology of BFRBs and related disorders are discussed.

1. Introduction

Pathological body-focused repetitive behaviors (BFRBs) such as trichotillomania (i.e., hair pulling) and skin picking involve compulsive, self-defacing symptoms that are difficult to manage (Grant, Stein, Woods, & Keuthen, 2012). Consequences of these conditions include hair loss, skin lesions, and significant psychosocial impairment (Tucker, Woods, Flessner, Franklin, & Franklin, 2011; Weingarden & Renshaw, 2015; Woods et al., 2006).

BFRBs have traditionally been considered disorders of poor behavioral inhibition (Grant, Chamberlain et al., 2014), but there is increased recognition of associated non-motor features that underlie symptoms (Roberts, O'Connor, & Belanger, 2013). Pulling and picking appear to be maintained via automatic sensory reinforcement (Miltenberger, Long, Rapp, Lumley, & Elliot, 1998; Rapp, Milternberger, Galensky, Ellingson, & Long, 1999) and produce short-term reductions in tension/stress (Diefenbach, Mouton-Odum, & Stanley, 2002; Snorrason, Smari, & Olafsson, 2010; Roberts et al., 2013, 2015). Further, many affected persons report somatic urges/cravings to engage in symptoms (Madjar & Sripada, 2016; Snorrason, Olafsson, Houghton, Woods, & Lee, 2015).

Currently, the sensory mechanisms involved in BFRBs are not well-understood. Abnormalities in pain thresholds have not been detected (Christenson et al., 1994; Deshpande, Metter, Ling, Conwit, & Ferrucci, 2008; Grant, Redden, & Chamberlain, 2017; Grant & Stein, 2014), and gross somatosensory functioning (i.e., proprioception, tactile form recognition) appears to be intact (Stanley, Hannay, & Breckenridge, 1997). Nevertheless, those with BFRBs consistently self-report that they are abnormally sensitive to sensory inputs. Affected persons have described greater frequencies of interoceptive sensations (Teng, Woods, Twohig, & Marcks, 2002), heightened levels of sensory intolerance (Falkenstein, Conelea, Garner, & Haaga, 2018), and increased perceptual sensitivity (Houghton, Alexander, Bauer, & Woods, 2018). From these data, it is presently unclear whether sensory abnormalities in BFRBs are related to peripheral sensory nervous function or somatosensory cortical activity.

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The notion that perceptual anomalies, namely heightened sensitivity, are associated with repetitive behaviors is supported by findings in conditions with similar phenomenology. Tics and compulsive rituals characterize Tourette's Disorder and Obsessive-Compulsive Disorder (OCD), and affected persons reported generalized sensory intolerance and perceptual inundation (Belluscio, Jin, Watters, Lee, & Hallett, 2011; Sutherland Owens, Miguel, & Swerdlow, 2011; Taylor, Conelea, McKay, Crowe, & Abramowitz, 2014). Further, Autism Spectrum Disorders, which are often characterized by repetitive and stereotypic behaviors, are frequently associated with sensory hyper-sensitivity and a tendency to become overwhelmed by complex and intense stimuli (Rogers & Ozonoff, 2005). Like BFRBs, tics and compulsions are often instigated by somatosensory urges (da Silva Prado et al., 2008; Ferrao et al., 2012; Eddy & Cavanna, 2014; Houghton, Capriotti, Conelea, & Woods, 2014), and sensory hyper-sensitivity in Autism has repeatedly been found to be positively correlated with repetitive behavior symptom severity (Baranek, Foster, & Berkson, 1997; Boyd et al., 2010; Gabriels et al., 2008). This is important because Tourette's, OCD, and Autism may have overlapping etiology between themselves and BFRBs, as evidence points to high comorbidity rates between these conditions (Baron-Cohen, Scahill, Izaguirre, Hornsey, & Robertson, 1999; Greenberg et al., 2018; Hirschtritt et al., 2015; Leyfer et al., 2006; Simonoff et al., 2008; Snorrason, Belleau, & Woods, 2012) and similar neuroanatomical abnormalities (Albin & Mink, 2006; Delmonte, Gallagher, O'Hanlon, McGrath, & Balsters, 2013; Roos, Fouche, Stein, & Lochner, 2013; Roos, Grant, Fouche, Stein, & Lochner, 2015; Saxena & Rauch, 2000).

Despite evidence linking similar classes of repetitive and compulsive behaviors to sensory hyper-sensitivity and excessive perceptual inundation, the underlying pathophysiology of this process in BFRBs is not well-understood. The only existing physiological research has shown that patients with pathological skin picking have increased disgust reactions and heightened interoceptive cortical activity when shown pictures of skin irregularities (Schienle, Übel, & Wabnegger, 2018a), and greater somatosensory cortex activation (relative to healthy controls) in response to scratching as opposed to pleasant touch (Schienle, Übel, & Wabnegger, 2018b). These findings point to increased sensory neural activity in skin picking, but what produces this heightened sensory cue reactivity is unknown. Answers to this question could come from a growing body of evidence that points to deficits in sensory inhibition and habituation in Tourette's Disorder, OCD, and Autism. Research has found evidence of deficient feed-forward inhibition (Güçlü et al., 2015; Puts et al., 2015, 2014) and sensory gating (Orekhova et al., 2008; Rossi et al., 2005; Sutherland Owens et al., 2011), which involve GABAergic sensory filtering mechanisms (McCormick & Bal, 1994; Swadlow, 2003). Likewise, these studies found evidence of poor sensory adaptation, which is crucial for habituation (Tannan, Whitsel, & Tommerdahl, 2006, 2007, 2008). Evidence in regard to detection thresholds is mixed, with evidence pointing to either reduced or normal tactile sensitivity in Tourette's Disorder and OCD (Belluscio et al., 2011; Güçlü et al., 2015; Puts et al., 2015; Schunke et al., 2015) and highly variable results in Autism (Haigh, 2018; Marco, Hinkley, Hills, & Nagarajan, 2011). Thus, additional research is needed to determine sensory thresholds in repetitive behavior disorders, which could provide insight into whether sensory abnormalities in these conditions are due to peripheral perceptual abnormalities or dysfunctional central sensory processing mechanisms. Still, the current evidence indicates that persons with Tourette's, OCD, and Autism receive excess cortical sensory input through poor central inhibition and habituation.

The peripheral and cortical dynamics of sensory processing can be measured non-invasively using behavioral psychophysics. Demonstrated by Puts, Edden, Wodka, Mostofsky, and Tommerdahl (2013), vibratory tactile stimulation paradigms can be used to assess basic reaction time, detection thresholds, feed-forward inhibition, and lateral inhibition (Puts et al., 2013; Tannan, Simmons, Dennis, & Tommerdahl, 2007; Tommerdahl, Tannan, Cascio, Baranek, & Whitsel, 2007). As such, we utilized such a psychophysics battery to measure these constructs in body-focused repetitive behavior disorders. Understanding whether these sensory processing abnormalities are present in BFRBs would have several important implications. Not only would such findings link self-report data to objective physiological performance, but such research would suggest a shared endophenotype between seemingly related conditions. As such, the current study had several purposes. First, we sought to extend prior research on self-reported sensory abnormalities in BFRBs by measuring patients' experiences related to sensory habituation, sensory thresholds, and sensory inhibition. We predicted that persons with BFRBs would report deficiencies in sensory gating. Second, we investigated these same constructs using objective psychophysics, but made no explicit predictions because of the mixed findings from similar conditions. Third, we explored whether any objective deficits in sensory functions correlated with self-reported sensory abnormalities and BFRB symptom severity.

2. Method

2.1. Participants

Recruitment occurred from November 2016 until June 2017. Participants with BFRBs were recruited from a large public university (Texas A&M University; TAMU) and from a BFRB specialty clinic in a major metropolitan area. Within the university, email advertisements were distributed through a general campus listserv. At the BFRB specialty clinic, flyers describing the study were placed in the waiting room, and staff psychologists provided eligible participants brief information about the study. Healthy control subjects were recruited solely from the university listserv. The study protocol lasted approximately 1 h, and participants were compensated with $15. All but one participant were recruited from TAMU, and the participant recruited at the BFRB specialty clinic was run through the study by the same experimenter as all other participants. Institutional review board approval at Texas A&M was obtained prior to study initiation. All participants provided informed consent and all procedures conformed to the ethical guidelines of the Declaration of Helsinki.

Inclusion criteria for participants with BFRBs consisted of (1) age $\geq$ 18 and $\leq$ 65 and (2) meeting DSM-5 criteria for Trichotillomania or Excoriation Disorder. Exclusion criteria consisted of (1) diagnosis of Autism, a Psychotic disorder, or a major neurological disorder and (2) currently taking medications with GABAergic properties (e.g., anti-epileptics and benzodiazepines). Healthy control participants were subjected to the same inclusion and exclusion criteria as participants in the BFRB group but were also excluded if they met criteria for any psychiatric disorder except alcohol or substance abuse. Alcohol or substance abuse was allowed in the healthy control group based on evidence that college students (which our sample primarily consisted of) drink and use substances more often than non-college-attending peers but have comparable substance-related problems (Slutske, 2005). Because there is significant evidence of age-related changes in the tactile sensory system (Stevens, 1992, pp. P35–P40; Gescheider, Bolanowski, Hall, Hoffman, & Verrillo, 1994; Deshpande, Metter, Ling, Conwit, & Ferrucci, 2008; Zhang, Francisco, Holden, Dennis, & Tommerdahl, 2011), the BFRB and healthy control groups were age-matched.

A total of 46 participants with BFRBs, as well as an age-matched sample of 46 healthy control subjects, participated. This sample size was derived from an a priori power analysis utilizing results from studies utilizing the same measures of objective sensory functions in patients with OCD and Tourette's Disorder as compared to healthy controls (Güçlü et al., 2015; Puts et al., 2015). To estimate power, the smallest effect sizes found in those studies were used (f = 0.34, 0.36). Power level (β) was set at 0.80 and α was set at 0.05. The power analysis revealed that at least 35 participants were needed in each group, and we elected to over-sample in order to add power to the

study. The age range of participants was 18–47 (M = 24.86, SD = 7.97). The BFRB group was primarily composed of persons with Excoriation Disorder (n = 36), and a smaller number of participants were diagnosed with Trichotillomania (n = 7) or both conditions (n = 3).

2.2. Measures

Psychiatric diagnoses and symptoms. The *MINI International Neuropsychiatric Interview* (Sheehan et al., 1998) is a structured, clinician-rated diagnostic interview that assesses for common psychiatric conditions. Studies that have validated the MINI have found it to possess good psychometric properties (Lecrubier et al., 1997; Sheehan et al., 1997, 1998).

The *Habit Disorder Interview (HDI)* was developed by the authors and has been used in previous research on a clinical population of persons with BFRBs (Alexander, Houghton, Bauer, Lench, & Woods, 2018; Houghton et al., 2018). The HDI is a structured diagnostic assessment consisting of items derived from DSM-5 criteria for Trichotillomania and Excoriation Disorder. No psychometric data are available on the HDI.

The *Massachusetts General Hospital Hairpulling Scale (MGH-HPS*; Keuthen et al., 1995) is a 7-item self-report questionnaire of hair pulling severity. The total score ranges from 0 to 28. The MGH-HPS has consistently demonstrated strong reliability (r = 0.97; Keuthen et al., 1995; O'Sullivan et al., 1995), as well as acceptable validity (O'Sullivan et al., 1995).

The *Skin Picking Scale (SPS;* Keuthen et al., 2001) is a 6-item self-report questionnaire of skin picking severity. Total scores range from 0 to 24. The SPS has demonstrated moderate internal consistency, good convergent and divergent validity, and good predictive validity (Keuthen et al., 2001).

Self-reported sensory abnormalities. The *Sensory Gating Inventory (SGI*; Hetrick, Erickson, & Smith, 2012) is a self-report measure of difficulties related to sensory thresholds, sensory habituation, and perceptual inundation. There are 4 subscales derived from factor analysis: Perceptual Modulation, Distractibility, Over-Inclusion, and Fatigue and Stress Vulnerability. *Perceptual Modulation* reflects difficulty with habituating to stimuli and feelings of perceptual inundation. *Distractibility* reflects trouble with focusing attention on a single stimulus and becoming distracted via competing sensory inputs. *Over-inclusion* reflects a low threshold of perception (i.e., hyperawareness). Finally, *Fatigue and Stress Vulnerability* reflects a vulnerability to experiencing sensory phenomena, particularly when stressed or fatigued. A total severity score is comprised of the sum of all 36 items. The SGI has demonstrated strong reliability and validity (Hetrick et al., 2012).

Objective sensory abnormalities. The CM6 Vibrotactile Behavioral Battery (Puts et al., 2013) was used as the primary assessment of sensory neurophysiology. The CM6 is a small desktop-mounted device with two independently controlled vibrating nodes that stimulate the glabrous tissue of digits three and four of the left hand. The left hand is always used for the task, regardless of handedness. The technique has been validated in children and adults (Puts et al., 2013), as well as used to measure sensory phenomena in Tourette's Disorder (Puts et al., 2015), OCD (Güçlü et al., 2015), and Autism (Khan et al., 2015; Puts, Wodka, Tommerdal, Mostofsky, & Edden, 2014, 2017). Below, a description of the tasks involved in this battery are provided, and illustrations and task parameters (derived primarily from Puts et al., 2013) are described in Fig. 1 and Table 1, respectively.

Reaction time. The reaction time task requires participants to click a computer mouse with their opposite hand as soon as they detect a vibration on their testing hand. Reaction time measures serve to establish a baseline level of sensory function. Two conditions were used as reaction time tasks: a *Simple Reaction Time (sRT)* task, in which only one stimulus must be detected, and a *Choice Reaction Time (cRT)* task, in which the participant must not only respond to the stimulus but also indicate which finger was stimulated (i.e., D3 or D4).

Detection Threshold. The detection threshold tasks involve two paradigms in which participants press a computer mouse with their opposite hand as soon as they detect a vibratory stimulus on their testing hand. In the *Static Detection Threshold (sDT)* task, the amplitude of the vibratory stimulus is steadily decreased across trials from supra-threshold levels to sub-threshold levels in a staircase reversal method, and the level at which an individual can reliably detect the stimulus becomes that individual's detection threshold. Parameters for the sDT task slightly deviated from those in Puts et al. (2013), in that the total number of trials was shortened from 24 to 20, as it was determined that reliable detection thresholds could be derived with fewer trials. In the *Dynamic Detection Threshold (dDT)* task, each test stimulus is initiated with a sub-threshold stimulus, which steady increases in amplitude and activates feed-forward inhibition processes, thus raising detection thresholds. After a variable delay,[1] stimuli started at 0 μm and were ramped up at a rate of 2μm/s. If feed-forward inhibition processes are intact, one should observe an increase in *dynamic* detection threshold as compared to the *static* detection threshold.

Amplitude Discrimination. The amplitude discrimination tasks involved three paradigms in which individuals must determine which of two simultaneously presented vibratory stimuli was stronger. In the 'without adaptation' condition (*Simultaneous Amplitude Discrimination [simAD]*), the difference between two simultaneously applied stimuli amplitudes decreases across trials until a reliable difference limen of discrimination is established. The standard stimulus amplitude was 200 μm and the initial comparison stimulus amplitude was set to 400 μm.[2] The comparison stimulus was adjusted by 20 μm after each trial. The simAD task reflects individuals' ability to detect subtle differences in intensity between two simultaneously delivered stimuli, which involves attentional and perceptual factors as well as lateral inhibition. In the '*Single-Site Adaptation' (SSA)* condition, one of the two stimuli is preceded by a stimulus that participants are told to ignore, which disrupts lateral inhibition and raises the amplitude discrimination threshold. This effect is reversed when both digits receive an adapting stimulus. Indeed, in the 'Dual-Site Adaptation' (DSA) condition, both of the two stimuli are preceded by stimuli (200 μm, 25Hz, 500ms) that participants are told to ignore. The application of dual adapting stimuli has been found to improve amplitude discrimination in healthy individuals (Tannan et al., 2007) but not individuals with ASD (Tommerdahl et al., 2007).

Performance or fatigue effects. The simple reaction time task was administered again at the conclusion of the battery in order to measure the influence of performance or fatigue effects. An increase in reaction time was operationalized as an indicator of fatigue, whereas a decrease in reaction time was operationalized as an indicator of performance effects.

2.3. Procedure

After consenting to participate, potential participants were screened for inclusion/exclusion criteria using the MINI and HDI. If not excluded at that stage, participants completed several self-report measures of demographics, BFRB severity, and sensory gating. Next, the vibrotactile tasks were administered on the left hand.

[1] No training trials are conducted in dDT because it is impractical to train persons to respond to sub-threshold stimuli.

[2] Standard and comparison stimuli intensity have previously been set at 100 μm and 200 μm, respectively (Puts et al., 2013). However, a demonstration of Weber's law in Francisco, Tannan, Zhang, Holden, and Tommerdahl (2008) has shown that doubling the amplitudes of these stimuli does not effect outcomes.

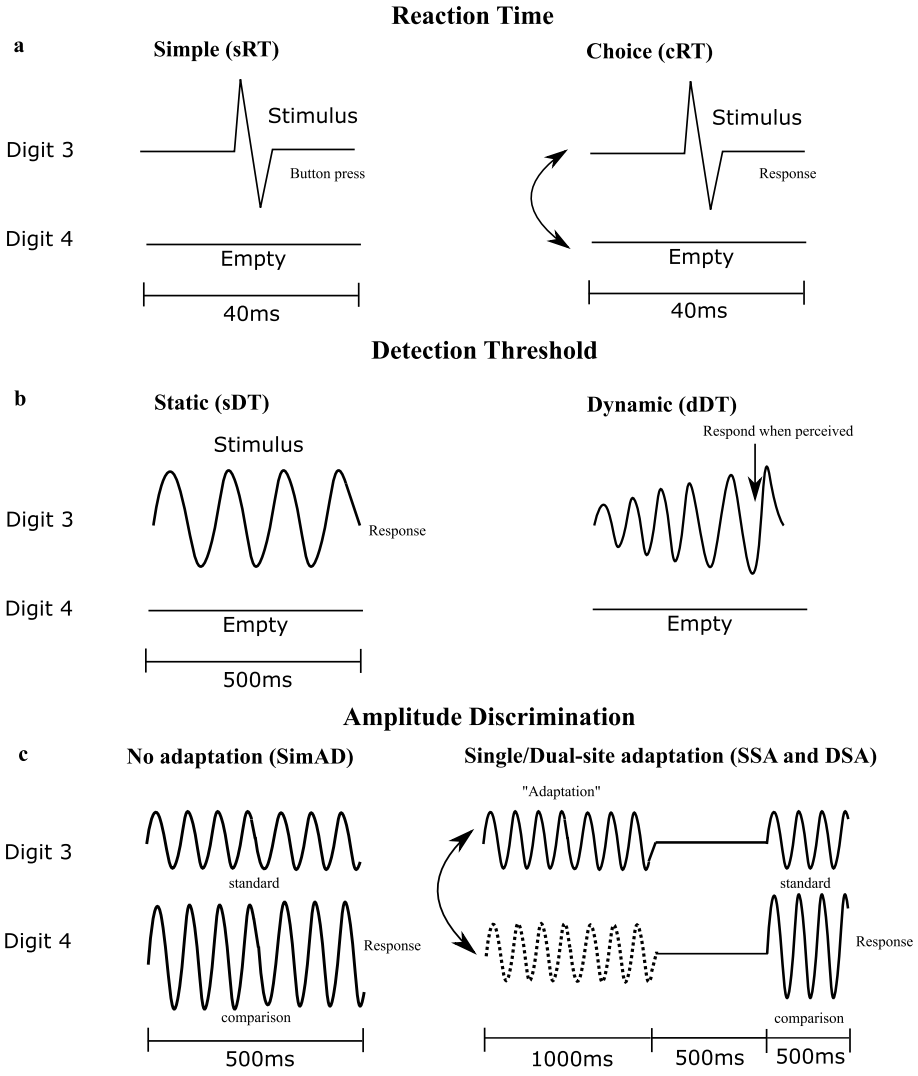

Fig. 1. Vibrotactile behavioral battery, trial examples.

Table 1
Vibrotactile task parameters.

Task	Digits	Number of Training Trials	Number of Test Trials	ITI	Amplitude	Frequency	Duration
Simple Reaction Time (sRT)	D3	1	10	5s	300 μm	25Hz	40ms
Choice Reaction Time (cRT)	Random	1	10	3s	300 μm	25Hz	40ms
Static Detection Treshold (sDT)	D3	3	20	5s	Variable	25Hz	40ms
Dynamic Detection Threshold (dDT)	D3	0	7	10s	Variable	25Hz	Variable
Simultaneous Amplitude Discrimination (simAD)	D3 and D4	3	20	0–2500ms	Variable	25Hz	500ms
Single-Site Adaptation (SSA)	D3 and D4	3	20	0–2500ms	Variable	25Hz	500ms
Dual-Site Adaptation (DSA)	D3 and D4	3	20	0–2500ms	Variable	25Hz	500ms

ITI = Inter-trial interval.

2.4. Statistical analyses

Prior to analyses, variables which could theoretically confound results were tested as potential covariates using paired-samples *t*-tests, independent-samples *t*-tests, and chi-square tests of independence. The BFRB group and control group were compared on variables that could influence outcome (gender and age), and potential changes in performance over time were also examined (fatigue or performance effects). There were no differences between the BFRB group and healthy control group with regard to gender (X^2 = 2.33, p = .13) or age ($t(90)$ = 0.01, p = .99). As such, gender and age were not introduced into any subsequent analyses as a covariate. There was also no difference in fatigue/performance between groups on the vibrotactile battery ($t(90)$ = -.38, p = .71), but both groups showed evidence of performance effects over time ($t(45)$ = 5.92, $p < .001$; $t(45)$ = 6.57, $p < .001$). Accordingly, differences in performance across time (post-battery reaction time – pre-battery reaction time) on the Simple Reaction Time tasks were entered as covariates into all analyses except the first tests of Simple Reaction Time and Choice Reaction Time. Thus, all parametric tests using generalized linear models were covaried for differences in performance using ANCOVA.

Prior to examining group differences on dependent variables, data were examined to ensure they met assumptions of parametric statistics (*t*-tests and ANCOVA) using Shapiro-Wilks tests of normality, Levene's

test of equality of variances, and Mauchly's test of sphericity. If assumptions were violated, non-parametric tests were used. Because the validity of *t*-tests is vulnerable to violations of normality (Erceg-Hurn & Mirosevich, 2008) while ANCOVA is robust to this assumption violation (Schmider, Ziegler, Danay, Beyer, & Bühner, 2010), Mann-Whitney U tests and Wilcoxon Signed Ranks tests were substituted when non-normality was detected for between-groups and within-subjects *t*-tests, respectively. When violations of heteroscedasticity were found, ANCOVA tests were interpreted through Greenhouse-Geisser corrections.

Given that tests of self-report data on the sensory gating inventory involved multiple comparisons, a Bonferroni correction was applied ($\alpha = .005$). Because each group of vibrotactile tasks involved two or three conditions (i.e., static vs. dynamic detection threshold), a series of factorial ANCOVAs (task condition x group, covarying for potential confounding variables) were used to test main effects of task condition, experimental group, and interactions between task condition and group. Additionally, post-hoc tests using estimated marginal means and Fisher's least significant difference confidence intervals were employed to examine significant interaction effects in more detail. All tests were two-tailed and *p*-values were set at .05. Furthermore, in order to test whether task performance was associated with self-reported symptoms related to sensory gating and symptom severity, those variables were regressed upon the differences in performance between task conditions using a series of linear regressions. Regression tests were also two-tailed, but a Bonferroni correction for multiple comparisons was applied ($\alpha = .003$). Only participants with Trichotillomania and/or Excoriation Disorder were included in regressions predicting variables associated with BFRBs.

3. Results

3.1. Participant characteristics

A full description of demographic information between groups can be found in Table 2. Participants in the BFRB group presented with significant frequencies of comorbid psychopathology. Several participants in the healthy control group met criteria for substance (marijuana) or alcohol abuse, but claimed to have not consumed substances recently (i.e., in the 24 h prior to participation) and did not appear to be intoxicated or suffering from withdrawal symptoms. For those in the BFRB group, the average scores on the MGH-HPS and SPSS (See Table 3) indicate that the sample consisted primarily of participants with moderate hair pulling and/or skin picking severity.

3.2. Self-report data

Consistent with predictions, there were numerous differences on self-reported sensory gating (See Table 3). Participants with BFRBs reported greater abnormal experiences on all subscales and the total score of the Sensory Gating Inventory.

3.3. Reaction time and basic sensorimotor function

See Fig. 2 for descriptive statistics regarding outcome variables. There were no baseline differences between groups on either the sRT ($Mdn_{BFRB} = 258.80$, $Mdn_{HC} = 250.70$; $U = 978.50$, $p = .55$, $r = .06$) or the cRT ($Mdn_{BFRB} = 435.60$, $Mdn_{HC} = 437.70$; $U = 1008.00$, $p = .70$, $r = .04$). ANCOVA revealed a large main effect of condition ($F[1, 90] = 339.99$, $p < .001$, $\eta_p^2 = .79$), suggesting that the increased attentional and sensorimotor demand of cRT as compared to sRT significantly affected reaction times in both groups. There was no main effect of group ($F[1, 90] = .07$, $p = .70$, $\eta_p^2 = .001$) and no task by group interaction ($F[1, 90] = .07$, $p = .79$, $\eta_p^2 = .001$). This suggests that the BFRB group did not show any greater change in reaction times between conditions. There were also no between groups differences in consistency or accuracy on SRT and CRT. There were no differences in the variability in reaction times on SRT between groups ($Mdn_{BFRB} = 23.00$, $Mdn_{HC} = 17.60$; $U = 996.50$, $p = .63$, $r = .05$), and there were no between groups differences in percent correct on CRT ($Mdn_{BFRB} = 90.00$, $Mdn_{HC} = 100.00$; $U = 857.00$, $p = .08$, $r = .18$). This suggests that persons with BFRBs have normally developed sensorimotor integration on tasks requiring quick motor reactions.

Table 2
Demographic Information and Psychiatric Comorbidity by Group.

	Clinical BFRBs	Healthy Controls
Gender		
Female	39 (84.8%)	33 (71.7%)
Male	7 (15.2%)	13 (28.3%)
Ethnicity		
Hispanic	9 (19.6%)	9 (19.6%)
Non-Hispanic	37 (80.4%)	37 (80.4%)
Race		
White	42 (91.3%)	34 (73.9%)
Asian	2 (4.3%)	10 (21.7%)
"Other"	1 (2.2%)	2 (4.3%)
Age: *M(SD)*	24.85 (8.05)	24.87 (7.97)
Current Psychiatric Diagnoses - Any	19 (41.2%)	4 (8.7%)
Major Depression	1 (2.2%)	0
Bipolar I	2 (4.3%)	0
Bipolar II	1 (2.2%)	0
Bipolar NOS	0	0
Panic Disorder	2 (4.3%)	0
Agoraphobia	6 (13.0%)	0
Social Phobia	3 (6.5%)	0
Obsessive-Compulsive Disorder	3 (6.5%)	0
Posttraumatic Stress Disorder	4 (8.7%)	0
Alcohol Dependence	1 (2.2%)	0
Alcohol Abuse	4 (8.7%)	3 (6.5%)
Substance Dependence	0	0
Substance Abuse	0	1 (2.2%)
Psychotic Disorder	0	0
Mood Disorder with Psychotic Features	0	0
Anorexia Nervosa	1 (2.2%)	0
Bulimia Nervosa	2 (4.3%)	0
Binge Eating Disorder	0	0
Generalized Anxiety Disorder	9 (19.6%)	0
Antisocial Personality Disorder	0	0
Multiple Current Psychiatric Diagnoses	12 (26.0%)	0

Note. One participant in the BFRB group did not provide their ethnicity.

3.4. Detection threshold

Due to a programming error, data from the sDT task were invalid for 6 participants in the BFRB group. As such, their data and the healthy controls with whom they were age-matched were excluded. Furthermore, due to technical failure during administration, 1 participant in the BFRB group and 1 participant in the healthy control group did not complete the dDT task, thus they were excluded along with their matched controls.

See Fig. 3 for descriptive statistics for detection threshold performances between groups. Participants in the BFRB group had lower detection thresholds on both the sDT task ($Mdn_{BFRB} = 7.80$, $Mdn_{HC} = 8.40$; $U = 583.50$, $p = .036$, $r = .23$) and the dDT task ($Mdn_{BFRB} = 8.10$, $Mdn_{HC} = 10.00$; $U = 457.00$, $p = .002$, $r = .34$). Likewise, there was a significant main effect of group ($F[1, 76] = 10.65$, $p = .002$, $\eta_p^2 = .12$). This suggests that persons with BFRBs have greater tactile sensitivity and lower overall detection thresholds.

There was also a significant main effect of condition ($F[1, 76] = 4.71$, $p = .033$, $\eta_p^2 = .058$) and a significant interaction between group and condition ($F[1, 76] = 5.18$, $p = .026$, $\eta_p^2 = .064$). As expected, the detection thresholds of persons in the healthy control group increased between the sDT and dDT task ($Z = -2.55$, $p = .011$, $r = .41$). However, the detection thresholds of persons in the BFRB group

Table 3
Group differences on behavioral data.

Scale	BFRB Mean (SD)	Healthy Control Mean (SD)	U	p-value	r
Massachusetts General Hospital Hairpulling Scale					
Total Score	15.31 (5.96)	-	-	-	-
Skin Picking Severity Scale					
Total Score	11.63 (5.09)	-	-	-	-
Sensory Gating Inventory					
Perceptual Modulation	35.57 (14.49)	22.61 (6.16)	467.50	< .001*	.48
Distractibility	28.07 (9.58)	17.36 (7.31)	408.00	< .001*	.52
Overinclusion	21.04 (7.74)	13.65 (5.39)	466.00	< .001*	.47
Fatigue/Stress Vulnerability	16.76 (5.58)	10.39 (4.28)	395.00	< .001*	.53
Total Score	101.66 (31.09)	64.16 (20.32)	320.50	< .001*	.58

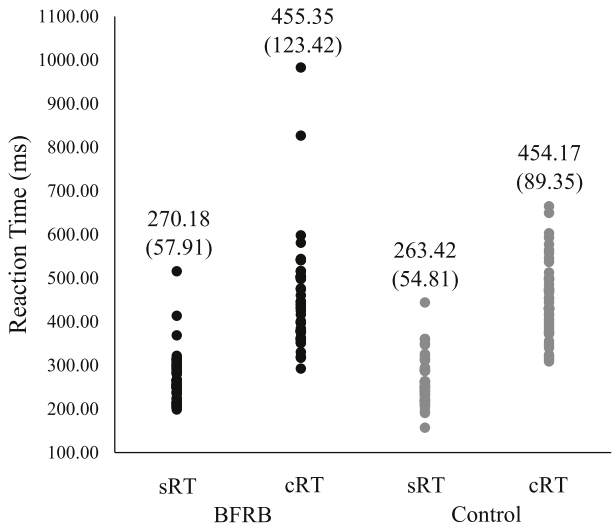

Fig. 2. Performance on Reaction Time Tasks Between Groups.

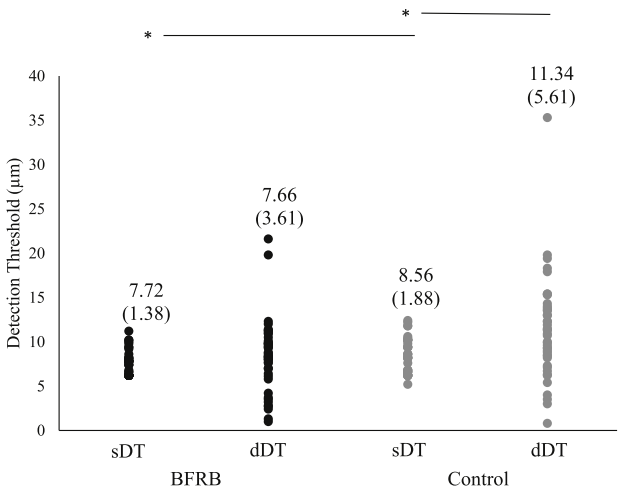

Fig. 3. *Performance on Detection Threshold Tasks between groups.*

showed no change between tasks (Z = -.34, p = .73, r = .05). Persons in the control group had larger mean differences between the dDT and the sDT task (M_{diff} = 2.37, SD = 5.61) than persons in the BFRB group (M_{diff} = -.06, SD = 3.61), and this difference was significant (U = 547.50, p = .033). To ensure that premature response tendencies (i.e., guessing) did not affect these results, an ANCOVA was again conducted with the percent correct on the dDT task also entered as a covariate. Accordingly, effect sizes increased substantially, and there was still a significant main effect of condition (F[1, 75] = 19.99, p < .001, η_p^2 = .21), a significant main effect of group (F[1, 75] = 13.94, p < .001, η_p^2 = .16), and a significant interaction between condition and group (F[1, 75] = 8.58, p = .004, η_p^2 = .103). These results support the hypothesis of faulty feed-forward inhibition in persons with BFRBs.

3.5. Amplitude discrimination

See Fig. 4 for descriptive statistics regarding performances on amplitude discrimination tasks between groups. There were no differences between groups on the simAD task (Mdn_{BFRB} = 68.00, Mdn_{HC} = 60.00; U = 930.50, p = .32, r = .06), SSA task (Mdn_{BFRB} = 116.00, Mdn_{HC} = 124.00; U = 961.00, p = .45, r = .04), or DSA task (Mdn_{BFRB} = 58.00, Mdn_{HC} = 46.00; U = 863.50, p = .13, r = .16). There was a main effect of condition (F[2, 180] = 56.01, p < .001, η_p^2 = .38), no main effect of group (F[1, 90] = .05, p = .83, η_p^2 = .001) and no interaction between group and condition (F[2, 180] = .77, p = .45, η_p^2 = .008). There was no evidence of a different increase in scores between simAD and SSA between groups (Mdn_{BFRB} = 41.50, Mdn_{HC} = 62.00; U = 952.50, p = .41, r = .09), and no evidence of a different decrease in scores between SSA and DSA (Mdn_{BFRB} = 65.50, Mdn_{HC} = 83.00; U = 927.50, p = .31, r = .11). Indeed, there were no larger differences between scores on the simAD task and SSA task between groups (U = 952.50, p = .41), nor variations in differences between scores on the simAD task and DSA task (U = 1039.00, p = .88). As such, these results do not suggest any abnormalities in lateral inhibition and/or dynamic sensory adaptation in BFRBs.

3.6. Association between performance and self-report

The only group differences that emerged from vibrotactile data between groups were that persons with BFRBs showed lower detection thresholds on sDT and faulty feed-forward inhibition as evidenced by an interaction between group and detection threshold tasks. As such,

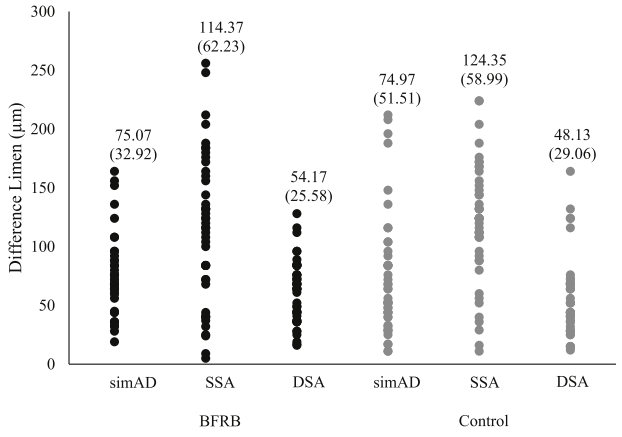

Fig. 4. Performance on Amplitude Discrimination Tasks between groups.

Table 4
Regression analyses predicting behavioral data from vibrotactile performance.

Outcome	Predictor					
	Detection Threshold			FFI		
	Beta	*t*-value	*p*-value	Beta	*t*-value	*p*-value
MGH-HPS	.10	.32	.76	.51	1.89	.088
SPS	.17	.97	.34	.40	2.48	.018
SGI – Perceptual Modulation	-.12	−1.08	.28	.07	.63	.53
SGI – Distractibility	-.14	−1.24	.22	.12	1.03	.31
SGI – Overinclusion	-.10	-.88	.39	.12	1.07	.29
SGI – Fatigue/Stress Vulnerability	-.31	−2.81	.006	.06	.51	.61
SGI – Total Score	-.15	−1.39	.17	-.04	-.22	.83

performance on the sDT task and the differences between sDT and dDT task were used as predictors in regression analyses predicting behavioral self-report data from vibrotactile data.

Marginal but non-significant relationships were observed when detection threshold predicted the Fatigue/Stress Vulnerability subscale of the Sensory Gating Inventory and when feed-forward inhibition predicted skin picking severity (See Table 4). These associations were significant at the .05 level but did not survive a bonferroni correction for multiple comparisons ($\alpha = .003$). As such, the hypothesis that performance on vibrotactile tasks would predict symptom severity and self-reports of sensory phenomena was not supported.

4. Discussion

Results of the current study suggest that individuals with BFRBs exhibit several sensory and perceptual abnormalities. Persons with BFRBs reported more frequent and intense experiences associated with deficient sensory gating as compared to healthy adults and showed decreased tactile detection thresholds and abnormal feed-forward inhibition, but no deficits in sensorimotor integration or quickly adapting lateral inhibition. In linking quantitative sensory abnormalities to phenomenology, regression analysis did not show strong, significant relationships between sensory abilities and self-reported symptoms.

The fact that the level of sensory processing dysfunction did not significantly correlate with disorder severity is not necessarily problematic. It may be that if increased sensitivity and deficient sensory inhibition increase the risk for developing a BFRB, but that other factors influence symptom severity. BFRB severity may fluctuate depending on numerous factors, as evidence indeed indicates that symptoms tend be chronic but highly variable (Bohne, Keuthen, & Wilhelm, 2005). However, sensory abnormalities could represent an underlying risk factor that predisposes individuals to engaging in BFRBs and similar compulsive, self-regulatory behaviors.

The findings from the current study are consistent with previous phenomenological research and support the view that there are important sensory features of the pathophysiology of BFRBs. Evidence indicates that deficient sensory inhibition is associated with a state of perpetual hyper-arousal (Clancy, Ding, Bernat, Schmidt, & Li, 2017; McGhie & Chapman, 1961). Indeed, some have argued that BFRBs are characterized by difficulties in maintaining perceptual homeostasis (e.g., Penzel, 2002). Penzel's account of BFRBs further states that due to such interoceptive discomfort, BFRBs are particularly functional because body areas with hair, skin, and nails are densely populated with sensory receptors and easily stimulated. Indeed, other self-cutaneous actions, such as scratching, self-grooming, or non-suicidal self-injury, can relieve tension in certain contexts such as stress or intense negative affect (Troisi, 2002; Selby, Nock, & Kranzler, 2014).

Yet, while the current results support the notion that hyper-sensitivity and poor sensory inhibition are associated with BFRBs, our findings differ from similar investigations on comparable conditions. While BFRBs, Tourette's Disorder, OCD, and ASD are associated with self-reported heightened self-reported sensitivity, the latter three conditions have shown mixed results on detection threshold tasks (Belluscio et al., 2011; Ganos et al., 2015; Güçlü et al., 2015; Marco et al., 2011; Puts et al., 2015; Schunke et al., 2015). One possible explanation of these findings is that sensory processing is disrupted in all of these conditions, but that learning histories shape affected persons' sensitization to specific types of stimuli. For instance, research has shown that persons with ASD show widely variable results regarding tactile sensitivity (Marco et al., 2011), suggesting there may be significant individual differences in tactile sensitivity. Further, individuals with BFRBs show reduced neural activation in response to pleasant touch vs. scratching (Schienle et al., 2018b), suggesting that while tactile thresholds may be lowered persons with BFRBs, affected persons are less sensitive to some forms of touch. BFRBs also do not appear to be associated with habituation deficits, despite reporting experiences related to such problems on the SGI. However, examination of the item content of the SGI reveals that some of the questions related to poor habituation could be frequently endorsed by someone with only low sensory thresholds, such as “Sometimes I notice background noises more than usual” (Hetrick et al., 2012). Intercorrelations between subscales of the SGI are indeed high, ranging from 19.4% to 43.6% of shared variance (Hetrick et al., 2012). According to this notion, perhaps BFRBs and similar conditions share some but not all neurophysiological sensory abnormalities, and they often report sensory experiences that are not directly linked to underlying sensory dysfunctions.

Despite the novelty and implications of these findings, the current study has several notable limitations. First, we recruited a restricted range of persons with BFRB severity, such that most had moderate BFRB severity and very few had severe BFRBs. No persons were included in the study with mild, subclinical BFRBs. This range restriction could have caused the marginally significant correlation between feed-forward inhibition and hair pulling severity. Yet, the limited number of persons with TTM in the sample also make any comparisons between TTM severity and other variables poorly powered to detect significance. Indeed, it would have been ideal to collect a sample consisting equally of persons with skin picking and hair pulling, but due to random chance we recruited more persons with skin picking. Thus, we cannot conclude as to whether the results of the current study were more relevant to skin picking than hair pulling. However, given the high degree of similarity between these conditions (Albin & Mink, 2006; Delmonte et al., 2013; Roos et al., 2013, 2015; Saxena & Rauch, 2000), this is a modest limitation. A second limitation is that our power analysis did not assume that Bonferroni corrections would be made in regression analyses, suggesting that our study could have been underpowered to detect small but potentially important correlations. Finally, while we excluded participants for a diagnosis of Autism, for which an extensive body of literature has documented sensory abnormalities (Ward, 2018), we did not exclude participants for OCD and Tourette's disorder, which could potentially confound our results. However, no tics were observed in participants and only 3 persons in the BFRB group were diagnosed with OCD. Another limitation is that the sample of persons with BFRBs showed high rates of comorbidity with other psychiatric disorders. Thus, while we attempted to control for the presence of comorbid psychopathology, we cannot rule out the potential influence of other conditions on our dependent variables.

This study represents the first account of physiological sensory abnormalities in BFRBs and provides and important link between BFRBs and related conditions. Research on primary sensory features of psychiatric disorders is still in early stages, but future research should focus on sensory and perceptual factors that may drive symptom performance. In particular, developmental and longitudinal research is needed to determine how such phenomena develop over time and covary with disorder onset. For instance, our theoretical rationale in the current study was that sensory phenomena may underlie BFRB symptom development, but it is also possible that BFRB symptoms lead

to the development of sensory abnormalities.

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Conflicts of interest

Dr. Houghton reports no conflicts of interest. Dr. Woods receives royalties from Oxford University Press and Springer Press. Dr. Tommerdahl is the co-founder of Cortical Metrics, a company licensed by the University of North Carolina to distribute devices that support the methods reported in this paper.

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