

SENSORY PROCESSING IN BODY-FOCUSED REPETITIVE BEHAVIORS

A Dissertation

by

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ABSTRACT

Body-focused repetitive behaviors (BFRBs) such as hair pulling and skin picking are common practices that are part of ordinary grooming, but can proliferate excessively into maladaptive habits. Despite their negative consequences, affected individuals often experience great difficulty in stopping pulling/picking and report strong urges and hedonic reward associated with symptoms. Unfortunately, the psychobiological mechanisms underlying sensory features of BFRBs have been insufficiently studied. The current study aimed to explore potential sensory processing abnormalities in adults with Trichotillomania and Excoriation Disorder using several self-reported instruments and a vibrotactile behavioral battery. A total of 46 adults with either Trichotillomania or Excoriation Disorder were recruited, along with an age-matched sample of 46 healthy control participants. Participants completed clinician-rated interviews regarding their symptom severity and self-report instruments regarding interoceptive awareness and sensory gating. The vibrotactile battery consisted of several tests that assessed reaction time, sensorimotor integration, detection threshold, feed-forward inhibition, lateral inhibition, temporal processing, and duration discrimination.

Persons with BFRBs reported increased interoceptive awareness, a greater propensity to worry about their body states, and less trust in their own body. In addition, the BFRB group reported greater perceptual inundation, sensory distractability, over-inclusion, and a propensity to experience sensory abnormalities while fatigued or distressed. Persons with BFRBs did not display behavioral deficits in sensorimotor

integration, quickly adapting lateral inhibition, temporal processing, or duration discrimination. However, the BFRB group had lower tactile thresholds and deficient feed-forward inhibition. Deficient feed-forward inhibition was correlated with skin picking severity. These findings indicate that increased sensitivity to sensory stimuli and an inability to filter out excess sensory input is associated with a propensity to engage in BFRBs, perhaps as a method of distracting oneself from an aversive perceptual state.

DEDICATION

For my wife, Amanda, for her unwavering support and encouragement. Also, for Dr. Carol Yoder and Dr. Carolyn Becker, who believed in me when no one else did.

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TABLE OF CONTENTS

ABSTRACT.....	ii
DEDICATION.....	iv
ACKNOWLEDGEMENTS.....	v
CONTRIBUTORS AND FUNDING SOURCES.....	vi
LIST OF FIGURES.....	ix
LIST OF TABLES.....	x
CHAPTER I INTRODUCTION AND LITERATURE REVIEW.....	1
1.1 Problem Statement.....	1
1.2 Habits: Friend and Foe.....	2
1.3 How Habits Develop.....	10
1.4 Neurobiology of Pathological Habit Disorders.....	14
1.5 Evidence for Increased Habit Formation in BFRBs.....	16
1.6 Methods of Treating BFRBs.....	20
1.7 Sensory Features of BFRBs.....	28
1.7.1 Sensory Antecedents.....	28
1.7.2 Sensory Consequences.....	29
1.8 Sensory Processing Deficits in OC-Spectrum Disorders.....	30
1.9 Possible Mechanisms of Sensory Phenomena in BFRBs.....	34
1.10 Cortical Sensory Processing.....	35
1.11 Altered Sensory Processing in OC-Spectrum Disorders.....	39
1.12 Current Hypotheses.....	42
CHAPTER II METHOD.....	45
2.1 Participants.....	45
2.2 Measures.....	52
2.3 Procedure.....	56
2.4 Analyses.....	60
CHAPTER III RESULTS.....	62
3.1 Tests of Potential Covariates.....	62
3.2 Behavioral Data.....	62
3.3 Reaction Time and Basic Sensorimotor Function.....	64
3.4 Detection Threshold.....	65
3.5 Amplitude Discrimination.....	67
3.6 Frequency Discrimination.....	68
3.7 Duration Discrimination.....	70
3.8 Association Between Performance and Self-Report.....	71

CHAPTER IV DISCUSSION	74
4.1 Review of Findings	74
4.2 The Potential Role of Sensation in BFRB Psychopathology	79
4.3 Limitations and Future Directions	88
4.3.1 Etiology	88
4.3.2 Treatment	91
4.4 Conclusions	93
REFERENCES	94
APPENDIX A	126
APPENDIX B	127
APPENDIX C	128
APPENDIX D	129
APPENDIX E	135
APPENDIX F	137
APPENDIX G	139
APPENDIX H	141
APPENDIX I	142
APPENDIX J	146

LIST OF FIGURES

Figure 1. Performance on Reaction Time Tasks between groups	65
Figure 2. Performance on Detection Threshold Tasks between groups	67
Figure 3. Performance on Amplitude Discrimination Tasks between groups	68
Figure 4. Performance on Frequency Discrimination Tasks between groups	69
Figure 5. Performance on Duration Discrimination Tasks between groups	71

LIST OF TABLES

Table 1. Demographic Information and Psychiatric Comorbidity by Group	49
Table 2. Group Differences on Behavioral Data	63
Table 3. Regression Analyses Predicting Behavioral Data from Vibrotactile Performance.....	73

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

1.1 Problem Statement

Body-focused repetitive behaviors (BFRBs) are aberrant grooming routines such as hair pulling and skin picking. Occasional engagement in BFRBs is common and often benign, but when BFRBs are performed at extreme levels, they cause significant physical and psychosocial impairment (Tucker et al., 2011; Woods et al., 2006). Pathological hair pulling is diagnosable as a psychiatric condition known as Trichotillomania (TTM), and pathological skin picking is diagnostically referred to as Excoriation Disorder (ExD) (American Psychiatric Association, 2013).

Research suggests that BFRBs can be conceptualized as pathological habits that are maintained by cognitive, affective, and sensory antecedents and consequences (Mansueto et al., 1997). Most research on TTM and ExD has investigated cognitive and affective factors, but comparatively little research has investigated sensory factors. This research is important for several reasons. First, behavioral and self-report research indicate that symptoms of TTM are accompanied by sensory phenomena, but there is a paucity of research on experiential aspects of sensory phenomena in BFRBs or their underlying causes. This makes it difficult to understand the experience of persons affected by BFRBs and determine the involvement of sensory phenomena in BFRB etiology. Second, despite our limited understanding of sensory phenomena in BFRBs, existing behavioral treatments attempt to address them by teaching patients to resist engaging in symptoms when sensory phenomena occur, which is thought to facilitate

habituation to urges and a symptom extinction process. However, the notion that urge habituation occurs during treatment is speculative, and there is currently no understanding of how sensory phenomena are affected by treatment. In fact, recent data cast doubt on the notion that habituation of symptom-instigating affective and sensory variables (e.g., fear, urges) consistently occurs or is related to treatment outcome in related conditions such as anxiety and tic disorders (Craske, Treanor, Conway, Zbozinek, & Vervliet, 2014; Houghton et al., 2017). Perhaps a better understanding of the mechanisms supporting sensory phenomena would enable the development of measurement technologies and subsequent investigation of how they are affected by BFRB treatment. Third, research has demonstrated that sensory phenomena occur in similar obsessive-compulsive related disorders, meaning that sensory phenomena could be an underlying endophenotype that support obsessive-compulsive psychopathology across diagnostic boundaries.

In the following sections, I describe evidence-based models of BFRBs and propose how an improved understanding of sensory phenomena will lead to improved conceptualization and treatment of BFRBs. It is then proposed that an investigation of sensory phenomena in BFRBs can begin by examining the cortical mechanisms involved in sensory processing through behavioral psychophysics.

1.2 Habits: Friend and Foe

Habits are a common human behavior. Individuals prefer to engage in activities that are familiar and that have been previously reinforced (Thorndike, 1913), meaning that behavior tends to become shaped into routines. Reinforcement contingent upon a behavior makes that behavior more likely to occur in future similar contexts, and thus

continued reinforcement can create stable behavior patterns. For example, many individuals prefer to drive the same route to work every single day, eat meals at the same time, wear their favorite clothes repeatedly, and engage in ritualistic morning and bedtime routines. A habit can be defined as a behavior that is learned, occurs repeatedly, is performed automatically, and follows a structured action sequence (Graybiel, 2008).

The idiom, “we are creatures of habit” speaks to the tendency for human behavior to follow predictable patterns and resist deviation from established routines. Indeed, the habitual nature of behavior is so ubiquitous that the subject has spurred debate amongst researchers about the existence of free will (Baumeister, 2008; Skinner, 1971). From an evolutionary perspective, habits are adaptive, as they are often associated with positive outcomes and facilitate behaviors that are safe and effective (e.g., looking both ways before crossing the street, brushing one’s teeth every night before bed). Habits are also cognitive and behavioral shortcuts, in that they help individuals make fewer decisions about their actions and repeat behavioral patterns that consistently lead to rewarding outcomes.

However, inasmuch as habit formation promotes adaptive behavior, habits can also be maladaptive. The operant contingencies that control behavior need to be linked closely in time, ideally just a few seconds. Longer-term consequences (i.e., those that come hours or days later) have a reduced degree of influence on behavior. Thus, operant conditioning is short-sighted, leaving an opportunity for maladaptive behaviors to emerge. Numerous behaviors can be initially pleasurable but ultimately socially unacceptable, risky, and/or unhealthy (e.g., promiscuous sexual activity, tobacco

smoking), and behaviors that are initially adaptive can become maladaptive when performed excessively (e.g., binge eating, exercise addiction).

Thus, if pathological habits can be thought of as behaviors that are immediately reinforced but proliferate excessively, one way to conceptualize BFRBs is that they originate as part of normal grooming routines. This notion is supported by research on the prevalence and function of grooming behaviors in humans and animals. Non-human animals such as birds, mice, and apes engage in grooming habits such as licking and combing the fur, feather picking, barbering (hair plucking), and parasite removal (Feusner, Hembacher, & Phillips, 2009). Humans also engage extensively in grooming behaviors such as bathing, skin exfoliation, teeth cleaning, and nail clipping. Grooming habits serve hygienic purposes, but they also have important psychological and social functions. For instance, grooming in animals helps form social bonds (Pellis & Pellis, 2010), aids in communication (Ferkin & Leonard, 2010), and helps establish social hierarchies (Pellis & Pellis, 2010). Evidence suggests that grooming is an important part of many animals' daily routines, as mammals commonly spend between 20% and 40% of the day grooming (Spruijt, Vanhoff, & Gispen, 1992). Human grooming serves an important role in social status, attractiveness, and cultural rituals related to adorning the body (e.g., hair styles, makeup, artificial hair and nails) (Wax, 1957). Indeed, non-pathological BFRBs are commonly performed for such purposes. Eyebrow plucking is practiced by many individuals (Blume-Peytavi, 2011), and people commonly pluck grey hairs or pick at split ends (Dawber, 2003). Non-pathological skin picking occurs commonly when individuals pick at rough scabs, pimples, or other skin imperfections

(e.g., ingrown hairs, dry or cracked skin) (Wilhelm et al., 1999). These behaviors could sometimes be considered adaptive, as modern beauty norms emphasize cosmetic features achieved through extensive grooming such as shapely eyebrows, smooth skin, and manicured nails (Benbow-Buitenhuis, 2014; Lennon & Rudd, 2000; Patton, 2006). As such, grooming behaviors are most likely encouraged by general social reinforcement (e.g., positive interactions with others), specific social reinforcement (e.g., being asked on a date), and internal reward (e.g., self-confidence).

Although a moderate frequency of grooming behavior that occurs as part of an individual's normal routine might be adaptive, excessive grooming has significant negative consequences. When captive mice and chimpanzees engage in excessive barbering/hair plucking, the result is irregular patches of hair loss that can increase risk for hypothermia (Findley, Marchant, & Brand, 2015; Garner, Weisker, Dufour, & Mench, 2004). A similar behavior occurs in dogs, whereby normal licking of the fur becomes excessive in a condition known as acral lick dermatitis, which causes fur loss, lesions, and infections (Patel, 2010). In addition, about 10% of avian populations engage in feather picking (Levine, 1984), which serves no known functional benefit and can result in flight impairment, infection, hypothermia, and even fatal hemorrhages when "blood feathers" are picked (Grindlinger, 1991). Excessive hair pulling and skin picking in humans results in abnormal hair loss and skin lesions, respectively (Mostaghimi, 2012). Hair pulling can occur on any site of the body where hair grows, but the most frequent topographical targets are the scalp, eyebrows, and eyelashes (Woods et al., 2006). Most hairs are pulled from the root. Individuals with pathological hair pulling

also frequently pick at the skin near pulling sites, which can cause inflammation, erythema, and scarring alopecia (Mostaghimi, 2012). When individuals pull in diffuse patterns, thinning of the hair in the targeted area can occur, but when pulling is directed at a specific location, there are often clearly definable bald spots (Haaga et al., 2016; Houghton et al., 2016). The most common sites for skin picking includes the face, neck, back, chest, arms, hands, and legs (Arnold et al., 1998; Wilhelm et al., 1999). Healthy skin is often a target of picking, but skin imperfections such as pimples, scabs, insect bites, or existing lesions are also frequently picked. The physical consequences of excessive skin picking can range from minor sores to severe tissue damage, with some individuals creating deep craters, bleeding frequently, incurring infections, and causing up to over 100 lesions (Wilhelm et al., 1999).

In addition to physical costs of BFRBs, affected individuals suffer considerable psychological consequences. Studies on the immediate consequences of symptoms have shown that individuals experience increased anger, guilt, and sadness after pulling/picking (Diefenbach, Mouton-Odum, & Stanley, 2002; Snorrason, Smari, & Olafsson, 2010). Persons with TTM and ExD also report that they use alcohol or substances to cope with pulling/picking and believe that symptoms create other emotional problems such as anxiety, depression, life impairment, and stress (Calikusu, Yucel, Polat, & Baykal, 2003; Flessner & Woods, 2006; Hayes, Storch, & Berlanga, 2009; Lewin et al., 2009; Tucker et al., 2011; Woods et al., 2006). Additionally, research suggests that an overwhelming majority of people with TTM and ExD experience feelings of physical unattractiveness, shame, poor body image, and worthlessness (Casati

et al., 2000; Soriano et al., 1996; Stemberger, Thomas, Mansueto, & Carter, 2000; Weingarden & Renshaw, 2015). The psychosocial distress associated with BFRBs is sometimes so extreme that it increases suicidal ideation (Arnold et al., 1998).

As a result of the taboo nature of hair pulling, skin picking, and their physical sequelae, persons with BFRBs suffer in social domains. Indeed, hair pulling is viewed negatively by peers (Marcks, Woods, & Ridosko, 2005; Woods, Fuqua, & Outman, 1999). Studies have found that persons who pull their hair are rated as less socially acceptable and less likely to be hired for a job than persons who do not pull (Boudjouk et al., 2008; Long et al., 1999), that greater hair loss and more intense pulling is associated with more negative social perceptions by others (Ricketts, Brandt, & Woods, 2012; Woods, Fuqua, & Outman, 1998), and that people rate severe hair loss from TTM as indicative of medical and psychological problems (Ricketts et al., 2012). Persons with TTM have reported that their social lives and ability to maintain social relationships with others have been damaged by pulling (Woods et al., 2006), and a majority of persons with ExD report sometimes refraining from engaging in an intimate relationship because of skin picking (Flessner & Woods, 2006). Indeed, a recent study found that there is a negative association between hair pulling severity and relationship satisfaction, perceived social support, and intimacy, and a positive association with social anxiety and perceived criticism (Falkenstein & Haaga, 2016).

Efforts to hide BFRBs and their consequences are quite significant, with over 25% of adults spending at least 15 minutes per day applying makeup, styling their hair, or affixing wigs to conceal hair loss (Woods et al., 2006). A substantial number of adults

with TTM also admit to avoiding vacations, restricting daily activities, social events, and group activities as a result of their pulling (Mansueto et al., 1997; Wetterneck, Woods, Norberg, & Begotka, 2006; Woods et al., 2006). In ExD, several studies have found that affected individuals feel socially embarrassed and avoid social situations because of their picking (Arnold et al., 1998; Bohne et al., 2002; Keuthen et al., 2000; Wilhelm et al., 1999). More specifically, Flessner and Woods (2006) found that many individuals with ExD avoid group activities, formal events, entertainment activities, restaurants, and vacations because of skin picking. The use of cosmetics, bandages, and clothing to conceal skin picking is also reported in persons with ExD (Flessner & Woods, 2006; Keuthen et al., 2000; Wilhelm et al., 1999). Moreover, one study showed that one-quarter of persons with TTM had not told their closest friend about their disorder, and one-fifth had not told their romantic partner (Falkenstein & Haaga, 2016).

The pernicious effects of hair pulling and skin picking also appear to permeate the school and workplace environments, as impact in areas of academic and occupational functioning are common (Flessner & Woods, 2006; Wetterneck et al., 2006). Persons with TTM and ExD have reported quitting their jobs because of pulling/picking, increased absenteeism, failing to pursue job advancements or interviews, and being negatively impacted in their ability to work productively (Flessner & Woods, 2006; Tucker et al., 2011; Woods et al., 2006). Persons who are in school report missing schooldays, difficulties in performing school-related activities, and difficulty studying (Flessner & Woods, 2006; Tucker et al., 2011; Woods et al., 2006).

More globally, most studies indicate the quality of life is abnormally low in BFRBs. Although one study found no differences in quality of life between persons with TTM and healthy controls (Keuthen, Dougherty, Franklin, & Bohne, 2004), two other studies found that persons with TTM had poorer quality of life (Diefenbach, Tolin, Hannan, Crocetto, & Worhunsky, 2005; Odlaug, Kim, & Grant, 2010). Comorbid mood problems might greatly affect the negative impact of TTM on quality life, as evidenced by correlational evidence showing that depression is associated with negative quality of life in TTM samples (Odlaug et al., 2010), even after controlling for TTM severity (Diefenbach et al., 2005; Houghton et al., 2016; Keuthen et al., 2004; Tung et al., 2014). In ExD, quality of life is lower than healthy controls, may be poorer than in TTM, and is negatively correlated with skin picking severity (Nejatisafa, Mohammadi, Balighi, Farnia, & Arbabi, 2008; Odlaug, Kim, & Grant, 2010).

Given the highly negative consequences associated with BFRBs, it is unclear why individuals would continually engage in the behavior. Research has shown that the frequency of behavior is proportionate to the amounts of reinforcement and punishment available for that behavior (Herrnstein, Laibson, & Rachlin, 2000). If more reinforcement than punishment is available for a behavior, frequency of the behavior increases, and vice versa. This means that the rate of BFRB symptoms should correspond to the ratio between amounts of reinforcement and punishment received for symptoms. However, research on habit formation shows that goal-directed behavior can become automated into habitual behavior through neuroplastic processes in cortico-striatal circuitry (Burguiere, Monteiro, Feng, & Graybiel, 2013; Burguiere, Monteiro,

Mallet, Feng, & Graybiel, 2015; Graybiel, 2008; Smith & Graybiel, 2013). Habitual behavior thus becomes more resistant to self-control and extinction, meaning that once BFRBs become habitual, affected individuals may become insensitive to devaluation of rewards associated with BFRB performance, and punishing consequences may have little influence on BFRBs. This would mean that BFRB performance becomes so automatic that it does not matter whether pulling/picking continues to serve a cosmetic purpose or whether it leads to negative consequences. In exploring this hypothesis, the following section will describe the habit formation processes, evidence for pathological habit formation in BFRBs, and how treatments aim to disrupt BFRB habits.

1.3 How Habits Develop

Habits are important to the science of repetitive behavior because they involve a dichotomy between higher-order, goal-directed behavioral control and lower-order, stimulus-response behavior patterns (Graybiel, 2008). On one end of the behavioral control spectrum, humans are able to bypass their ‘basic instincts’ in order to facilitate behavior in accordance with complex, abstract goals. Indeed, the brainpower associated with higher-order cognition allows humans to maintain control over our behavior, solve complex problems, avoid anti-social behaviors, and create abstract mental representations. At the neural level, goal-directed behavior is enabled primarily through a highly evolved cerebral cortex, specifically the prefrontal cortex (Fuster, 1988), which is significantly larger in humans than in other animal species and primates (Roth & Dicke, 2005). In contrast, the opposite end of the behavioral control spectrum is characterized by lower-order behavioral control, such as reflexes, motor regulation, stimulus-response behavior, and basic instincts. Lower-order behavior is facilitated

mostly by subcortical brain structures including the basal ganglia and mesencephalon. These regions guide our behavior absent of deliberate control.

There appears to be a differentiation between behavior that is guided by conscious thought/long-term goals and behavior that follows habitual patterns. Indeed, research has shown that goal-directed behavior and habitual behavior are mediated through different neural circuits. When the brain structures involved in declarative learning (i.e., hippocampus, medial temporal lobe) are damaged, subjects have difficulty learning facts and solving problems involving contextual cues but show no deficits in procedural learning (Bayley et al., 2005; Packard & McGaugh, 1996; Salat et al., 2006). In contrast, damage to the brain structures involved in procedural learning (i.e., basal ganglia) impairs performance on tasks involving stimulus-response and probabilistic associations but does not affect declarative memory (Knowlton, Mangels, & Squire, 1996; Poldrack et al., 2001). This double-dissociation illustrates the unique contributions of different brain structures to different types of learning (Packard, 2009). Evidence shows that both areas are active during various learning scenarios, but one area is more highly active when tasks demands favor the type of learning facilitated by that structure. Striatal activity is relatively stronger than medial temporal activity during tasks that favor implicit learning, whereas the opposite is true with tasks that favor explicit learning (Foerde et al., 2006; Poldrack et al., 2001; Willingham et al., 2002). Moreover, evidence suggests that habit formation systems coordinate activity with explicit learning systems during extensive training, such that when conditional procedures are extensively learned, connections between the striatum and hippocampus become highly coordinated

(DeCoteau et al., 2007). This means that learned behaviors are often both somewhat goal-directed and habitual, and that both types of behavioral decision-making should be employed flexibly. However, in some cases, habitual behavior might override goal-directed behavior, and a shift of behavioral control occurs.

A series of studies conducted on reward-based learning in rodents demonstrated how behavior can shift from being primarily goal-oriented to habitual (Adams & Dickinson, 1981; Balleine & Dickinson, 1998; Colwill & Rescorla, 1985). During the initial stages of learning, all behaviors are primarily goal directed. For example, the typical goal of maze paradigms is that an animal is working to obtain food. Goal-oriented, action-outcome (AO) behaviors such as food searching only occur when the value of the reinforcer is sufficient to motivate effort. For instance, if a rat is satiated with food, it is unlikely to enter the maze to find food. However, upon extended training, rats will often begin performing trained behaviors repeatedly when cued, even when the reward is devalued (i.e., when the rat is satiated or when food is paired with noxious stimuli). This habitual pattern of responding can be termed stimulus-response (SR) behavior. As such, AO behaviors are performed for current or future goals, while SR behaviors are performed through associations between antecedent stimuli and previous goals. Studies utilizing lesion and optogenetic methodologies have demonstrated that shifts from AO to SR behavior occur through transitions in neural circuits mediating the behaviors. Lesioning either the sensorimotor striatum or infralimbic prefrontal cortex causes rats to exhibit sensitivity to reward value, such that they will reduce responding when rewards are devalued and fail to show SR behavior (Killcross & Coutureau, 2003;

Yin & Knowlton, 2004). In contrast, lesions to either the caudomedial striatum or prelimbic prefrontal cortex reduce sensitivity to reward devaluation and cause rats to shift quickly to SR behavior (Killcross & Coutureau, 2003; Yin, Knowlton, & Balleine, 2005). In one study, researchers overtrained rats in a T-maze task to induce habitual behavior and recorded spike activity in cortical and striatal sites during training (Smith & Graybiel, 2013). Results showed that shifts from purposeful to habitual behavior were accompanied by changes in neural spiking and timing in the infralimbic neocortex and sensorimotor striatum. Shifts in neural activity were required in both areas in order for habits to crystallize, but optogenetic stimulation of infralimbic activity prevented habit formation, suggesting that increased activity in pre-frontal cortical regions can reduce vulnerability to pathological habits. Further, another study found that habits could be reversed by stimulating cortical-striatal circuits with optogenetics (Burguiere, Monteiro, Feng, & Graybiel, 2013). Mutant mice with deficient behavioral response inhibition showed defective down-regulation of striatal projections from cortical neurons and developed habitual responses to maze tasks after overtraining. When focused optogenetic stimulation was applied to the lateral orbitofrontal cortex and its terminals in the striatum, behavioral response inhibition was restored and habitual responding decreased. Thus, habit formation can be caused by deficient top-down regulation of cortical neuronal activity onto the striatum, and can be both induced and reversed via neuroplastic processes within cortico-striatal circuits.

Based on these findings and converging evidence from computational neuroscience, researchers have proposed a model of dual behavioral controllers (e.g.,

Daw et al., 2005; Smith & Graybiel, 2013). This first behavioral controller is model-based, and uses a step-by-step reinforcement system that explores potential actions and their outcome values, makes outcome predictions, and updates subsequent behavioral models based on these outcomes. Thus, the model-based controller facilitates goal-directed behavior. Habitual behavior is facilitated through a model-free controller in the striatum that determines a fixed value for behaviors that is stored but not updated, meaning that it is inflexible and supports SR behavior.

1.4 Neurobiology of Pathological Habit Disorders

According to the dual behavioral controller model of habit formation, BFRBs might begin as goal-directed behaviors and become habitual, thus developing excessive frequency and resistance to change. However, not all persons who pull their hair or pick their skin develop pathological BFRBs, meaning that some etiological risk factor must facilitate a shift from voluntary to compulsive BFRB performance. Indeed, research suggests that deficits in goal-directed control might predispose individuals to develop rigid habits (Everitt & Robbins, 2005; Graybiel & Rauch, 2000).

A series of studies by Gillan and colleagues demonstrated that over-reliance on model-free versus model-based reinforcement learning is associated with obsessive-compulsive disorder and similar conditions characterized by habitual behavior (e.g., addiction). Using a well-validated reinforcement learning task designed to measure the degree to which persons rely on model-free and model-based learning styles (de Wit, Niry, Wariyar, Aitken, & Dickenson, 2007), OCD patients showed deficits in goal-directed action and a bias toward habitual behavioral responding (Gillan et al., 2011). Indeed, biases toward habitual behavioral responding on this task are also evident in

persons with binge eating disorder and methamphetamine addiction, and this habit formation bias has been associated with reduced gray matter in the caudate and medial orbitofrontal cortex (Voon et al., 2015). Another study examined the ability of individuals with OCD to use counterfactual decision making, which involves making economic choices among various prospective action-outcome scenarios (Gillan et al., 2014a). OCD patients showed increased reliance on the pre-determined value of economic choices (i.e., habits), demonstrating impaired ability to use counterfactual comparisons to guide decision making (i.e., goal-directed behavior). This tendency to rely on habitual decision making in OCD appears to cut across approach and avoidant behavioral paradigms, as individuals with OCD show increased avoidance habits as compared to healthy controls (Gillan et al., 2014b). Participants were trained to avoid electric shocks to the hands by pressing foot levers rapidly after stimulus presentation. Stimulus devaluation was performed by visibly disconnecting the wire providing electric shocks to one hand and testing whether participants still responded by foot pressing when stimuli were presented to the previously signaled impending shock on the disconnected hand. After overtraining, persons with OCD continued to respond by foot pressing when presented with a devalued stimulus more so than healthy controls, thus showing evidence of increased avoidance habits and deficits in goal-directed control. A follow-up study found that avoidance task-related performance in OCD patients was correlated with increased activation in the caudate and medial orbitofrontal cortex (Gillan et al., 2015a). Furthermore, results showed that activation in the caudate was positively correlated with obsession severity, and activation in the medial orbitofrontal

cortex occurred during the acquisition of habits. There is also evidence that intact model-based learning protects against habit learning, as persons with increased model-based learning are sensitive to reward devaluation and do not develop habit-based responding (Gillan et al., 2015b). Broadly, deficits in goal-directed control appear to specifically increase risk for compulsive psychopathology, as such deficits in a community sample have shown to be correlated with symptoms of compulsive behavior and intrusive thought and not non-compulsive aspects of psychopathology (Gillan et al., 2016).

1.5 Evidence for Increased Habit Formation in BFRBs

Behavioral research on BFRBs supports the notion that symptoms develop into rigid and stereotypic habits, but evidence from cognitive neuroscience is mixed. Support for the habit hypothesis of BFRB symptoms comes primarily from brain imaging studies showing abnormalities in cortico-striatal circuits, which are involved in cognitive control over behavior, motivation, and reward dependent learning (Bornstein & Daw, 2011). However, evidence for neurocognitive deficits in motor control and executive functions (i.e., impulsivity, planning, and organization) is more mixed. These areas of research are discussed below.

Considerable evidence from neuroimaging and electrophysiology suggest that BFRBs are associated with reduced top-down control over behavior. One study that compared cortical thickness between persons with ExD, TTM, and healthy controls (Roos, Grant, Fouche, Stein, & Lochner, 2015) found that persons with ExD had greater volumes in the ventral striatum bilaterally and reduced cortical thickness in right frontal areas than persons with TTM and the healthy controls, whereas persons with TTM had greater thickness in the right parahippocampal gyrus compared to ExD and healthy

participants. Because the parahippocampal gyrus may play a role in dissociative symptomatology, this may explain the presence of ritualized, automatic hair pulling episodes seen in persons with TTM (Flessner et al., 2007). Studies finding support for impaired top-down control and reward insensitivity in TTM found increased gray matter densities in the left striatum and the bilateral cingulate, supplementary motor area, and frontal regions (Chamberlain et al., 2008), as well as increased cortical thickness in right/inferior frontal gyri (Odlaug et al., 2014). Two studies with nearly identical findings found that persons with ExD and TTM showed disorganization in white matter tracts in the right frontal gyrus, anterior cingulate cortex, and presupplementary motor area, which are involved in motor generation and suppression (Chamberlain et al., 2010; Grant, Odlaug, Hampshire, Schreiber, & Chamberlain, 2013). Furthermore, one study showed reduced resting state functional connectivity between the anterior cingulate cortex and nucleus accumbens in TTM (White et al., 2013), which could also signal reduced top-down cognitive control. Evidence from psychophysiology has found decreased response monitoring in TTM, as measured by smaller error-related negativity signals from the anterior cingulate region (Roberts, Stanley, Franklin, & Simons, 2014). This could signal impaired action monitoring, which is consistent with reduced goal-directed control. Finally, one study examined organization of white matter tracts in frontal-striatal-thalamic pathways and found that greater disorganization in these tracts was associated with longer TTM duration and increased TTM severity (Roos, Grant, Fouche, Stein, & Lochner, 2014).

Despite evidence supporting altered cognitive control over behavior in BFRBs, there is little evidence of abnormalities in neural structures supporting habitual behavior in the basal ganglia. Roos et al. (2015) did show increased volumes in the ventral striatum bilaterally in persons with ExD, which could signal alterations in reward sensitivity. However, Rauch et al. (2007) found no alterations in performance on an implicit learning task in persons with TTM, nor was there greater activation in the striatum, hippocampus, or any other brain regions during the task. Two studies have found no differences in caudate volumes between persons with Trichotillomania and healthy controls (Odlaug et al., 2014; Stein, Coetzer, Lee, Davids, & Bouwer, 1997). However, O'Sullivan et al. (1997) found reduced putamen volumes, which might reflect alterations in movement control, particularly during instrumental and implicit learning.

The data on top-down cognitive control over BFRBs symptoms using neuropsychological tasks are more mixed. One study found that when individuals with ExD engaged in an executive planning task (the tower test), patients showed reduced activation in a neural circuit involving the bilateral dorsal striatum, anterior cingulate, and right medial frontal regions (Odlaug, Hampshire, Chamberlain, & Grant, 2015). Indeed, a more recent study found similar deficits in spatial planning and organization in children with TTM (Flessner, Brennan, Murphy, & Francazio, 2016). These results suggest a general deficit in planning and action monitoring in BFRBs. In contrast, there are considerable mixed findings regarding whether persons with TTM and ExD have deficits in response inhibition using the stop signal and Go/No-go tasks (Bohne, Savage, Deckersbach, Keuthen, & Wilhelm, 2008; Brennan, Francazio, Gunstad, & Flessner,

2015; Chamberlain, Fineberg, Blackwell, Robbins, & Sahakian, 2006; Martin et al., 1993; Grant, Odlaug, & Chamberlain, 2011; Odlaug, Chamberlain, Derbyshire, Leppink, & Grant, 2014; Odlaug, Chamberlain, & Grant, 2010; Snorrason et al., 2011). However, strong evidence for deficits in response inhibition came from Chamberlain et al. (2014), who found that performance on response inhibition tasks was associated with genetic association to TTM, in that unaffected first-degree relatives of persons with TTM had better response inhibition than persons with TTM but poorer response inhibition than unrelated, healthy controls. In addition, studies on cognitive flexibility – the ability to shift attentional focus - in BFRBs have been mixed. There is evidence for intact cognitive flexibility in TTM (Chamberlain, Fineberg, Blackwell, Robbins, & Sahakian, 2006; Chamberlain et al., 2007; Flessner, Brennan, Murphy, & Francazio, 2016), and mixed evidence regarding cognitive flexibility in ExD (Grant et al., 2011; Odlaug et al., 2010).

In summary, converging evidence primarily points to impaired goal-directed control in BFRBs. This neurobiological research has supplemented the findings from behavioral researchers, who long suspected that BFRBs could be habitually controlled (e.g., Azrin, Nunn, & Frantz, 1972). Such behavioral accounts argued that hair pulling and skin picking function to reduce tension and/or provide tactile stimulation (Miltenberger, Long, Rapp, Lumley, & Elliot, 1998; Rapp, Miltenberger, Galensky, Ellingson, & Long, 1999; Woods, & Miltenberger, 1995). Like any problematic behavior, researchers suggested that BFRBs could be managed through techniques

derived from applied behavior analysis. These approaches are described in the following section.

1.6 Methods of Treating BFRBs

Because symptoms of BFRBs are thought to be habitually controlled, it follows that they are highly resistant to self-control, which is supported by research showing that BFRBs tend to be chronic conditions (Bohne, Keuthen, & Wilhelm, 2005). In addition, phenomenological research has shown that BFRB symptoms are frequently performed automatically, requiring little conscious awareness (Flessner et al., 2007; Walther et al., 2009). Thus, in order to facilitate fewer instances of symptom performance, behavioral treatments have been employed to block symptom performance and initiate extinction of the BFRB habit. It is believed that upon continued abstinence from the BFRB symptoms, reinforcement is no longer delivered, and the behavior should become less frequent over time.

Basic behavioral treatments based on contingency management have been successfully applied to BFRBs, particularly in children. Studies have shown that reinforcement of alternative behaviors (e.g., verbally praising appropriate behavior and ignoring hair pulling), aversive taste treatment (e.g., applying a bad tasting substance to the skin), and response prevention (e.g., having the child wear gloves or orthodontic splints) are effective means of stopping hair pulling, skin picking, cheek biting, nail biting, and thumb sucking in children (Woods & Houghton, 2015). However, such interventions are not always practical or well-tolerated. Moreover, they do not address the fact that habitual behaviors are often insensitive to reward devaluation and can spontaneously re-emerge.

As such, a more contemporary form of behavior therapy known as Habit Reversal Training (HRT; Azrin & Nunn, 1972) has been implemented. HRT consists of 3 components: Awareness Training, Competing Response Training, and Social Support. In the first stage, awareness training, the client and therapist engage in exercises aimed at increasing awareness of BFRB symptoms and the urges that provoke symptoms. Competing response training then prescribes a competing behavior that is incompatible with hair pulling behavior, such that the individual can perform the competing response instead of symptoms. Finally, social support includes verbal reinforcement provided for therapeutic effort, and in some cases a tangible reward system, which can be particularly useful in children. Behavioral treatment packages for TTM and ExD also typically incorporate functional analysis/intervention and stimulus control. Functional analyses are performed in order to elucidate contextual variables that exacerbate hair pulling or skin picking behavior, such as certain settings (e.g., bathroom mirrors, riding in the car) or activities (e.g., watching television, reading before bed). In turn, functional interventions are aimed at avoiding or mitigating problematic environmental influences on symptoms (e.g., limiting time in front of the mirror, placing a plush toy in the hands while watching television). Stimulus control procedures are derived from traditional behavioral approaches, whereby one physically removes variables that tend to elicit symptoms. For instance, it might be recommended that clients throw away tweezers, use moisturizer to combat dry skin, strictly limit time in front of bathroom mirrors, or trim their fingernails.

There is significant evidence supporting HRT for hair pulling and skin picking, as clinical trials have shown that HRT outperforms placebo and wait-list control treatments. A randomized controlled trial of HRT versus massed negative practice (a placebo treatment) found that HRT was nearly twice as effective (Azrin, Nunn, & Frantz, 1980). However, although the authors reported that many participants were pulling at near-zero rates, their outcome measure (self-monitoring) was not psychometrically validated. Moreover, most participants experienced some degree of relapse at follow-up. A similar trial compared HRT to wait-list control for ExD and found that HRT produced greater changes at post-treatment and follow-up (Teng, Woods, & Twohig, 2006). There was no evidence of significant relapse, but the mean number of picking episodes per day remained at 6.2 for the HRT group, indicating that picking was still frequently occurring in treatment responders. HRT has also been tested in an internet-based delivery system for ExD and appears to be effective, showing a 50% response rate as compared to 33% who received an unverified de-coupling treatment (Moritz, Fricke, Treszl, & Wittekind, 2012). Most recently, a stepped-care clinical trial for TTM provided HRT to those who didn't respond to internet-based care (Rogers et al., 2014), and found that 36% showed clinically significant improvement, which was statistically significant when compared to a wait-list control group. However, there was some relapse at 3-month follow-up. Collectively, studies on HRT for TTM and ExD show that it is superior to no treatment or placebo, but may not be very strong and durable.

The fact that BFRBs are somewhat resistant to change via HRT could be due to the intractable nature of pathological habits. HRT is designed to prevent engagement of hair pulling and skin picking by giving patients a competing response that helps resist engaging in symptom performance in the presence of urges and other symptom-provoking stimuli. As such, HRT is an enhanced self-control strategy. Functional analysis/intervention and stimulus control components also help patients avoid contextual variables that exacerbate symptoms, thus providing additional self-control methods. The combination of HRT and a high degree of motivation might indeed help individuals refrain from pulling/picking for prolonged periods, such as during acute treatment. As a result of prolonged abstinence from pulling/picking in the presence of antecedents that normally trigger pulling (i.e., cognitions about hair, familiar pulling settings, anxiety), the association between those antecedents, pulling/picking, and reinforcing consequences of pulling/picking is thought to be weakened. Accordingly, pulling and picking should happen less frequently in the presence of antecedents that formerly triggered pulling and picking, resulting in disorder remission.

However, research on pathological habits (e.g., drug addiction) suggests that as neural activity shifts from goal-directed to habit-driven behavior, plasticity occurs in multiple brain regions that alters the predominant activity in a given learning context over time. For instance, as addictions are formed, pleasurable sensations provided by drug administration activate the ventral tegmental area, ventral pallidum, and shell of the nucleus accumbens (Smith, Mahler, Pecina, & Berridge, 2010), but the neural activity of drug administration after established addiction is associated with the core of the nucleus

accumbens and neocortical regions (Sellings & Clarke, 2003). Once addictions are formed, cues associated with the addictive behavior create increased dopaminergic activity in the striatum, neocortex, and amygdala (Phillips et al., 2003). These neuroplastic changes could explain why persons with addiction experience cue-reactive cravings long after maintaining abstinence (Hunt, Barnett, & Branch, 1971; Herd, Borland, & Hyland, 2009; Ludwig & Wikler, 1974; Wilson et al., 2005). Indeed, research has found that individuals with TTM show increased attentional disengagement from hair-related stimuli, which may represent attempts to down-regulate negative emotions that are associated with hair pulling-related cues (Lee, Franklin, Turkel, Goetz, & Woods, 2012). This suggests that once BFRBs are established pathologically, cues may continue to elicit cravings to pull or pick for long after treatment ends.

Another explanation for why HRT has a less than desirable effect size and durability is because it may not address all of the contingencies that support hair pulling and skin picking. Mansueto et al. (1997) proposed a comprehensive behavioral model of TTM in which symptoms are maintained through various cognitive, affective, sensory, motoric, and environmental contingencies. For instance, just as BFRB symptom can be classically conditioned to occur in specific environments (e.g., when in front of the bathroom mirror), symptoms could also become associated with certain internal experiences (e.g., boredom, anxiety, stress). Moreover, evidence has suggested that hair pulling and skin picking modulate uncomfortable internal experiences (described below). HRT treatment packages that include functional analysis/intervention and stimulus control primarily address motoric and environmental cues for pulling and

picking. For instance, when an individual finds themselves resting their head on their hand, this could be seen as a ‘high risk’ zone for pulling to occur, in which a competing response should be performed. Stimulus control procedures, such as wearing gloves, could also be seen as combating the motoric automaticity in which symptoms are typically initiated. Finally, sensory cues for pulling/picking are only addressed by HRT insofar as noting that hair pulling and skin picking are often triggered by aversive physiological sensations, or urges. Clients are encouraged to identify these feelings and perform competing responses in their presence. However, cognitive and affective contingencies for pulling and picking are neglected in HRT, and, as the next section will discuss, are an important part of BFRB psychopathology.

Just as compulsions modulate obsessions (Gillan & Sahakian, 2015), symptoms of BFRBs have soothing effects on several cognitive and affective experiences. Hair pulling and skin picking are often performed in response to obsession-like cognitions such as over-focusing on skin imperfections (Arnold et al., 2001), thoughts that the hairline is asymmetrical (Woods et al., 2006), or that one has too many grey hairs (O’Sullivan, Mansueto, Lerner, & Miguel, 2000). Several studies have shown that affected individuals report that hair pulling and skin picking are preceded by negative affect (e.g., anxiety, tension, and boredom) and that the behaviors facilitate reductions in negative affect (Diefenbach, Mouton-Odum, & Stanley, 2002; Meunier, Tolin, & Franklin, 2009; Snorrason, Smari, & Olafsson, 2011; Roberts, O’Connor, Aardema, & Belanger, 2015). Furthermore, research has found that BFRBs are associated with maladaptive emotion regulation (Begotka, Woods, & Wetterneck, 2004; Calikusu,

Yucel, Polat, & Baykal, 2002; Houghton et al., 2014; Norberg et al., 2007; Roberts, O'Connor, & Belanger, 2013; Wetterneck et al., 2016), meaning that affected individuals tend to cope with unpleasant emotions via avoidance and other maladaptive behaviors.

Based on these findings, researchers have tested HRT-based behavioral treatment packages that include techniques derived from cognitive therapies to address cognitive and affective facets of symptoms (Lerner, Franklin, Meadows, Hembree, & Foa, 1999; Rangaswami, 1997). Two randomized controlled trials examined the efficacy of cognitive-behavioral therapy (CBT) for adults with TTM and found that CBT was superior to selective serotonin reuptake inhibitors and placebo/wait-list (Ninan, Rothbaum, Marsteller, Knight, & Eccard, 2000; van Minnen, Hoogduin, Keijsers, Hellenbrand, & Hendricks, 2003). Furthermore, one open-label trial found that CBT for children with TTM resulted in significant change in symptoms (Tolin et al., 2007), and a randomized controlled trial of CBT for children with TTM showed that CBT was superior to psychotherapy placebo (Franklin et al., 2011). For ExD, one randomized controlled trial found that CBT was superior to wait-list (Schuck, Keijsers, & Rink, 2011). Similar treatments incorporating elements of acceptance and commitment therapy and dialectical behavior therapy have shown evidence of effectiveness in TTM and ExD (Crosby, Dehlin, Mitchell, & Twohig, 2012; Keuthen et al., 2012; Twohig & Woods, 2004; Twohig, Hayes, & Masuda, 2006; Woods, Wetterneck, & Flessner, 2006). The addition of cognitive techniques to HRT appears to have been warranted, as evidence

suggests that they improve the efficacy of behavior therapy for TTM (McGuire et al., 2014), but no similar analyses has been done on behavioral treatments for ExD.

Still, despite the evidence supporting CBT and similar treatments for BFRBs, there is significant room for improvement. The effect sizes of behavior therapy for TTM and ExD are medium to large (pooled standardized mean difference for TTM = 1.41, for ExD = 0.69) (McGuire et al., 2014; Schumer, Barley, & Bloch, 2016), and response rates are generally satisfactory at between 38% to 85.7% (Franklin et al., 2011; Keuthen et al., 2012; Lerner et al., 1998; Schuck et al., 2011; Twohig & Woods, 2004; van Minnen et al., 2003; Woods, Twohig, & Masuda, 2006; Woods, Wetterneck, & Flessner, 2006). However, complete remission of symptoms is infrequent (Woods & Houghton, 2014), as persons who are classified as treatment responders often continue to endorse occasional symptoms (Houghton et al., 2015). This means that many individuals are not immune from continued problems associated with pulling or picking, and they may often be vulnerable to relapse. Indeed, evidence indicates that somewhere between 11-75% of participants in clinical trials who were acute responders show long-term remission, meaning the durability of CBT is highly variable (Falkenstein et al., 2015; Keuthen et al., 2012; Lerner et al., 1998; Twohig & Woods, 2004; Woods, Twohig, & Masuda, 2006).

As such, although it appears that CBT for BFRBs is an effective treatment, improving response rates and durability of gains might be achieved through continued research on the processes maintaining symptoms. As researchers discover more about compulsive symptomatology in BFRBs, we might better understand how to deliver CBT

and reinstate goal-directed control over symptoms. Moreover, burgeoning research on cognition and affect regulation in TTM and ExD might further enhance cognitive therapy approaches. However, one area of research on BFRBs that has been almost completely neglected involves sensory phenomena. The paucity of research in this area is particularly troublesome given that hair pulling and skin picking are self-defacing behaviors that have obvious impacts on the sensory and perceptual system. Yet, few studies have specifically examined sensory phenomena in BFRBs. In the next section, previous research on sensory aspects of BFRBs will be discussed along with a rationale for why additional research is vital for understanding the function of BFRBs and providing insights on treatment.

1.7 Sensory Features of BFRBs

1.7.1 Sensory Antecedents

Early behavioral research on BFRBs utilizing self-reports and behavioral analysis found that sensory cues were part of BFRB habit formation. Sensory cues for hair pulling and skin picking include visual and tactile sensations, such as undesired colors (e.g., gray hairs, blemishes) or other aesthetic qualities (e.g., visual skin imperfections or curly, split, out of place hairs) (Mansueto et al., 1997; Wilhelm & Margraf, 1993). Tactile cues for BFRBs include urges, itching (pruritus), tingling, pressure, burning sensations, and other cutaneous stimuli (e.g., rough scabs, coarse hair, pimples, brittle nails, dry and cracked skin) (Christenson & Mansueto, 1999; Tucker et al., 2011; Wilhelm & Margraf, 1993; Woods et al., 2006). A recent study investigated the phenomenology of urges in TTM by comparing urges to pull hair with urges to eat unhealthy food, and found that urges to pull hair were rated as more intense and less

controllable than unhealthy food urges (Madjar & Sripada, 2016). In addition, rituals involving tactile stimulation are often performed prior to pulling and picking, whereby individuals comb through the hair and over the skin, tug at individual hairs, and stroke parts of the skin (Woods & Houghton, 2014).

1.7.2 Sensory Consequences

There are a variety of sensory consequences that reinforce pulling and picking. Most individuals with BFRBs report that they experience a sense of pleasure, gratification, or relief after symptom performance (Christenson, Mackenzie, & Mitchell, 1991; Bohne et al., 2002; Keuthen et al., 2000; Meunier et al., 2009; Tucker et al., 2011; Woods et al., 2006). Post-pulling and -picking rituals also have sensory-perceptual effects, such as rolling hair between the fingers and mouthing or consuming hair and skin (Woods & Houghton, 2014). Beyond self-report data, two behavior analytic studies support the notion that pulling is maintained by automatic sensory reinforcement. The first study recorded one adult and one child who pulled their hair in various settings and found that pulling most often occurred when participants were alone as compared to when anxious or upset (Miltenberger, Long, Rapp, Lumley, & Elliot, 1998), supporting the notion that hair pulling was performed to achieve a sensation. The second study replicated these findings in an adult with hair pulling and found that hair pulling reduced in frequency while the participant played with pulled hairs and while the participant wore a rubber glove (Rapp, Miltenberger, Galensky, Ellingson, & Long, 1999), further supporting the presence of automatic sensory reinforcement for hair pulling. Moreover, studies indicate that persons with ExD and TTM experience cravings for the feelings associated with pulling and picking, and that pulling and picking create feelings of

hedonic reward (Grant, Odlaug, & Potenza, 2007; Snorrason, Olafsson, Houghton, Woods, & Lee, 2015; Snorrason, Smari, & Olafsson, 2011). There is no known mechanism of hair pulling or skin picking that creates pleasurable sensations, suggesting that the topic of self-generated somatic reward in BFRBs deserves further empirical attention.

1.8 Sensory Processing Deficits in OC-Spectrum Disorders

Preliminary evidence suggests that altered sensory processing mechanisms could produce sensory phenomena in BFRBs. Several studies have shown that individuals with BFRBs report increased interoceptive awareness (Teng, Woods, Twohig, & Marcks, 2002; Woods, Miltenberger, & Flach, 1996), meaning that persons may experience heightened aversive sensations and cutaneous stimuli, leading to increased urges to pull/pick. Furthermore, preliminary data show that individuals with pathological BFRBs report abnormal sensory patterns in six modalities: auditory, visual, taste/smell, movement, body position, and touch (Houghton, Alexander, Bauer, & Woods, 2018). Using a well-validated self-report measure of sensory processing, the Adult/Adolescent Sensory Profile (AASP; Brown, Tollefson, Dunn, Cromwell, & Fillion, 2001), persons with pathological BFRBs reported increased sensitivity to sensation and a tendency to avoid sensory stimulation. These data suggest that BFRBs may be associated with pathological sensory hypersensitivity and intolerance.

Evidence for sensory abnormalities in BFRBs is bolstered by extensive evidence for altered sensory experiences in related disorders, such as Tourette Disorder (TD) (Houghton, Capriotti, Conelea, & Woods, 2014) and Obsessive-Compulsive Disorder (OCD) (Ferrao et al., 2012). This research has primarily involved affected individuals'

self-reported experiences with everyday stimuli, psychophysiological indications of sensory functions, and structural and functional neuroimaging research on neural structures/regions involved in sensory processing.

Persons with TD and OCD experience urge phenomena that instigate symptoms, and symptoms appear to result in short-term reductions in aversive urges (Capriotti, Brandt, Turkel, Lee, & Woods, 2014; Gillan & Sahakian, 2015). In TD, these urges generally take on specific somatic properties and are described as itches, tension, pressure, energy surges, or “not just right” feelings (Woods, Piacentini, Himle, & Chang, 2005). Compulsions in OCD are largely maintained by cognitive obsessions (i.e., fear of contamination), but research has found that individuals with OCD commonly report bodily and mental sensations such as physical urges, energy surges, and feelings of incompleteness that are sometimes perceived as more severe than obsessions (Ferraio et al., 2012; Miguel et al., 2000). Like in BFRBs, individuals with TD and OCD report abnormal interoceptive awareness and sensory intolerance, such that they are more sensitive to bodily sensations and tend to avoid sensory input (Belluscio, Jin, Watters, Lee, & Hallett, 2011; Ben-Sasson & Podoly, 2017; Dar, Kahn, & Carmeli, 2012; Eddy & Cavanna, 2013; Ganos et al., 2015; Lewin, Wu, Murphy, & Storch, 2014; Woods, Miltenberger, & Flach, 1996). Moreover, recent research has shown that individuals who report sensory intolerance are more likely to have a lifetime history or current diagnosis of TD and/or OCD (Taylor, Conelea, McKay, Crowe, & Abramowitz, 2014; Wu, Lewin, Murphy, & Storch, 2014). Psychophysiological research has echoed these findings and shown that TD and OCD are associated with abnormal sensory gating (Ahmari,

Risbrough, Geyer, & Simpson, 2012; Castellanos et al., 1996; Orth & Munchau, 2013; Rossi et al., 2005; Savage et al., 1994; Smith & Lees, 1989; Swerdlow et al., 1993, 2001; Zerbardast et al., 2013) and that individuals with OCD have amplified neural activity in response to somatic stimulation (Shagass, Romer, Straumanis, & Josiassen, 1984).

Neuroimaging research has shown that individuals with TD have stronger activation in the somatosensory cortex just prior to symptom onset, and a positive association has been discovered between regional volumes in that area and the strength of tic-related urges (Draganski et al., 2010; Wang et al., 2011). Potentially shedding light on the physiology underlying urges to tic, one study found evidence of increased resting state connectivity between the insula (which is believed to facilitate premonitory urges [Jackson et al., 2011]) and the sensorimotor cortex in TD (Tinaz et al., 2014).

Concerning urge phenomena in OCD, grey matter volume increases in the left and bilateral sensorimotor cortices are associated with premonitory urges (Subira et al., 2015), and research has provided evidence of functional and structural abnormalities in regions controlling sensory-related cues for action such as the anterior cingulate, the insulo-opercular region, and the temporal cortex (Brennan et al., 2015; Choi et al., 2006; Pujol et al., 2004).

Collectively, evidence suggests that obsessive-compulsive spectrum conditions are associated with sensory phenomena. Research showing problematic sensory gating and excess sensory neural activity implicates dysfunctional inhibitory processes, which may represent the cortical substrates of sensory phenomena that maintain symptoms. For instance, excess sensory information could lead to persistent feelings of discomfort and

unrest, urges to relieve distress through symptom performance, and abnormal experiences of relief or pleasure after symptom performance. Indeed, researchers have suggested that deficient sensory inhibition mechanisms could be important parts of the psychopathology of obsessive-compulsive related disorders (Abruzzese & Berardelli, 2003; Russo et al., 2014). According to this notion, the motoric symptoms of BFRBs and other compulsive disorders do not occur spontaneously; symptoms are preceded by instigating stimuli.

Several reviews have argued that the pathophysiology of TD and OCD involves not only dysfunctional top-down control in pre-frontal areas and motor generation systems in the basal ganglia, but that abnormal sensory inhibition and integration processes may be responsible for the intrusive, irresistible urges to engage in symptoms (Abruzzese & Berardelli, 2003; Rajagopal, Seri, & Cavanna, 2013). They argued that tics are primarily a subcortical condition characterized by excessive motoric activity in the basal ganglia, but that disinhibited afferent sensory inputs may continuously innervate striatal areas, the pre- and supplementary motor areas, and the motor cortex, creating intrusive urges to move and activating tic-generation pathways. This hypothesis converges with a cognitive-psychophysiological model of TD (O'Connor, 2002), which argues that heightened physiological awareness creates a tendency to continuously enact action patterns to facilitate relief and induce relaxation. Similar speculations on OCD suggest that altered sensory-motor integration could underlie symptoms. Russo and colleagues argued that impaired inhibition of sensory afferents could lead to intrusive urges to enact compulsions (Russo et al., 2014). Using paired-pulse transcranial

magnetic stimulation (TMS), they demonstrated that impaired gating of afferent stimuli resulted in increased neural motor output, shedding light on how sensory information might cause increased urges to perform repetitive actions in OCD. Unfortunately, no studies have investigated sensorimotor integration in BFRBs, but the fact that BFRBs show similar sensory phenomenology to TD and OCD suggest that similar psychophysiological mechanisms may be in place.

1.9 Possible Mechanisms of Sensory Phenomena in BFRBs

An operant conditioning model applied to compulsive behaviors would suggest that aversive sensations are attenuated by symptom performance, resulting in a negative reinforcement process that incentivizes symptom performance when future aversive sensations arise. Likewise, the pleasurable sensations that result from symptoms might activate a positive reinforcement process that increases the hedonic reward of pulling/picking. The incentive salience and hedonic reward associated with addictive and compulsive behaviors involve dopaminergic neural circuits in the basal ganglia that subserve reward and reward-related cues (Berridge, 2007; Berridge, Robinson, & Aldridge, 2009; Robinson & Berridge, 1993). Studies have shown that persons with ExD and TTM have abnormalities in the striatum (Chamberlain et al., 2010; Roos et al., 2015). Yet, whereas some addictive behaviors and substances are known to activate dopaminergic reward centers (e.g., gambling, eating, cocaine) (Berridge, Ho, Richard, & DiFeliceantonio, 2010; Linnet, 2014; Robinson & Berridge, 1993), there is no known effect of hair pulling or skin picking that produces such reward.

However, a growing body of literature suggests that grooming-related behaviors have stress and anxiety-reducing properties. In non-human animals, ethological research

has documented a range of non-functional stereotypic behaviors that occur during stressful contexts, such as feather fanning, hair grooming, skin scratching, and behavioral stereotypies (Troisi, 2002). Humans also show similar patterns of stress-induced behaviors, such as self-contact actions (e.g., stroking the skin), that are perceived as signs of anxiety (Ekman & Friesen, 1972; Troisi, Spatella, & Pasini, 1998; Waxer, 1977), disapproval (Rosenfeld, 1966), and emotional conflict (Shreve et al., 1988). These actions are known as “displacement behaviors” due to their purported ability to temporarily attenuate or distract oneself from the subjective state of unwanted arousal (Troisi et al., 1998). Indeed, evidence suggests that the activation of neural structures mediating anxiety-related behaviors and administration of anxiogenic compounds elicits scratching in monkeys (Ninan et al., 1982; Redmond & Huang, 1979), whereas anxiolytic drug administration attenuates scratching behavior (Maestriperi et al., 1992; Schino et al., 1991). Non-pathological tactile processes (e.g., petting, stroking, contact) can also have calming, stress-reducing, and prosocial effects in both non-human animals and people (Field, 2001; McGlone et al., 2007; Panksepp, 1998; Pellis & Pellis, 2010; Schino et al., 1988). Perhaps body-focused actions have soothing perceptual properties, and abnormalities in the sensory nervous system could increase the incentive salience or hedonic reward associated with these behaviors. This possibility is explored below.

1.10 Cortical Sensory Processing

The central nervous system is responsible for processing sensory input, which is important for cognition and behavior (Fruhstorfer et al., 1970; Grissom & Bhatnagar, 2009). The human body has an immense sum of sensory receptors, including

chemoreceptors, photoreceptors, mechanoreceptors, thermoreceptors, and nociceptors. Sensory receptors are rarely, if ever at complete rest, meaning they are constantly conveying afferent sensory messages to the brain. In fact, most sensory neurons fire steady streams of low-rate action potentials even in the absence of stimuli (Hendry & Hsiao, 2013). The brain has to decipher important information from streams of afferent sensory inputs that occur in complex temporal patterns (Arabzadeh, Petersen, & Diamond, 2003), which is accomplished via an intricate sensory processing network involving both subcortical and cortical structures (Hendry & Hsiao, 2013). Sensory processing is instrumental for enabling accurate cognitive representations of the physical world and the body. If this complex procedure of sensory processing did not occur, one would be overwhelmed with cascades of mostly irrelevant sensory information, which would impede perception, attention, cognitive operations, and adaptive behavior.

One of the most important neural mechanisms involved in sensory processing is integration, which occurs through a balance of excitatory and inhibitory neural activity (Isaacson & Scanziani, 2011). Sensory integration confers numerous benefits, such as sharpened spatial and temporal resolution as well as increased processing speed (Gabernet, Jadhav, Feldman, Carandini, & Scanziani, 2005; Isaacson & Scanziani, 2011; Piouille & Scanziani, 2001; Swadlow, 2002). Disruption of sensory processing can occur through alterations in cortical white matter structure (Kercher et al., 2012; Tamnes, Fjell, Westlye, Ostby, & Walhovd, 2012) and gamma-aminobutyric acid (GABA) concentration (Stagg et al., 2011; Tavassoli, Auyeung, & Murphy, 2012). Importantly, GABAergic neurons propagate inhibitory post-synaptic potentials, and GABAergic

interneurons in somatosensory cortical white matter tracts facilitate sensory integration processes.

Dysfunctional sensory processing has measurable behavioral correlates on psychophysical tasks (Puts et al., 2013). Reaction time and detection threshold are well-researched sensory functions, and performance on these tasks is sensitive to cortical white matter structure (Kercher et al., 2012; Tamnes et al., 2012). Other sensory discrimination tasks such as feed-forward inhibition, lateral inhibition, temporal processing, and event timing involve more complex sensory integration processes. Feed-forward inhibition is a regulatory process that influences the timing and population coding of afferent sensory signals. When sensory neurons in subcortical regions propagate afferent signals, they innervate cortical sensory neurons and GABAergic interneurons, the latter of which produce inhibitory signals and regulate signal transmission (Isaacson & Scanziani, 2011). Similarly, lateral inhibition works through GABAergic interneurons that span laterally across nearby somatotopic sensory tracts and regulate simultaneous signal transmission in order to sharpen sensory input. When sensory receptors are located nearby somatotopically, such as digits 1 and 2 on the same hand, they are often activated simultaneously. In order to determine specific properties of sensory stimuli (e.g., timing, frequency, and amplitude) that activate both digits, inhibitory interneurons regulate excitatory afferents between the parallel digit sensory streams to the cortex. Temporal processing works by determining the timing properties of stimuli applied quickly and repeatedly (e.g., tapping quickly on the skin). Timing stimuli are encoded via periodic firing of neuronal groups in the somatosensory cortex

that are regulated by GABA. Increased GABA concentration in the somatosensory cortex improves frequency discrimination (Puts et al., 2011), whereas GABA antagonists impair periodic firing and disrupt frequency discrimination (McLaughlin & Juliano, 2005). Finally, event timing, or the ability to determine how long a stimulus occurs, is controlled by a series of neural networks including a fronto-parietal stream and a fronto-cortico-cerebellar stream (Belin et al., 2002), and evidence points to the particular importance of the cerebellum (Keele & Ivory, 1990; Miall & Reckess, 2002). The ability to accurately determine the duration of stimuli is important for a number of tasks, particularly motor coordination and predictive timing (i.e., perception of physical reality) (Keele & Ivory, 1990).

Disrupted sensory processing and poor sensory filtering is believed to cause individuals to experience abnormal response to sensory information, such as hyper/hypo-sensitivity and an inability to habituate to sensory experiences. For instance, persons with autism spectrum disorder experience sensory difficulties such as increased sensory sensitivity and intolerance to certain stimuli (e.g., elastic sock bands, bright lights) (Rogers & Ozonoff, 2005), and recent work has attempted to characterize these sensory deficits via psychophysical paradigms. Several studies have found that child and adults found that adults with autism spectrum disorder showed reduced feed-forward inhibition as compared to healthy controls (Puts, Wodka, Tommerdahl, Mostofsky, & Edden, 2014; Tannan et al., 2008), and similar deficits in adaptive spatial discrimination and temporal judgment have also been found to be deficient in this population (Tommerdahl, Tannan, Cascio, Baranek, & Whitsel, 2007; Tommerdahl, Tannan, Holden, & Baranek,

2008). Because autism spectrum disorder has similar behavioral characteristics to obsessive-compulsive spectrum disorders (e.g., repetitive, stereotypical behaviors [American Psychiatric Association, 2013]), it has been suggested that the same sensory processing deficits are evident in obsessive-compulsive disorders (Güçlü et al., 2015; Puts et al., 2015).

1.11 Altered Sensory Processing in OC-Spectrum Disorders

Using a vibrotactile behavioral battery that is sensitive to somatosensory cortical dynamics (Puts, Edden, Wodka, Mostofsky, & Tommerdahl, 2013), one study investigated sensory processing in TD (Puts et al., 2015). In addition, GABA concentration in the sensory and motor cortices was measured using Magnetic Resonance Spectroscopy. A group of 23 children with TD were compared to 67 healthy children (HC) on behavioral tasks and imaging data. There were no differences in reaction time between groups, meaning that there were no deficits in gross sensorimotor control in TD. On a measure of detection threshold, however, the TD group showed higher detection thresholds than healthy controls, meaning that they had trouble detecting the presence of weak stimuli. A dynamic detection threshold task was used to activate feed-forward inhibition processes. In a dynamic detection threshold task, instead of providing a static stimulus at a certain amplitude and asking the subject to respond if they detect the stimulus, a sub-threshold stimulus is applied and steadily increased in amplitude until detected. This dynamic increased in stimulus intensity activates feed-forward inhibition, which should raise detection thresholds beyond those seen in static detection threshold tasks. The TD group showed no change in detection thresholds between dynamic and static detection threshold task conditions, whereas the HC group

showed increased detection thresholds between tasks, reflecting a lack of feed-forward inhibition in the TD group. Participants were also subjected to an amplitude discrimination task meant to activate lateral inhibition. During this task, participants were asked to determine which of two different stimuli applied to adjacent digits had greater amplitude. A deficit in the ability to make amplitude distinction reflects problematic lateral inhibition. The TD group and HC group showed no differences in amplitude discrimination. However, when an adapting stimulus was presented on one digit just prior to amplitude discrimination trials, the HC group's thresholds increased while the TD group's thresholds remained unchanged. The adapting stimulus generally reduces the perceived intensity of the subsequent test stimulus through GABAergic inhibition (Whitsel et al., 1989), meaning that amplitude discrimination should be impaired when the GABAergic system responds flexibly. In contrast, the TD group showed a lack of adaptive, ongoing, GABA-mediated lateral inhibition. Finally, participants completed a frequency discrimination task designed to measure GABAergic frequency encoding. Interestingly, results showed that the TD group outperformed the HC group on the frequency discrimination task wherein stimuli were presented simultaneously to adjacent digits, which is thought to disrupt GABAergic frequency encoding. When results on this task were compared to imaging data, it was discovered that GABA concentration was correlated with frequency discrimination performance in HC subjects and not TD subjects. The authors reasoned that children with TD may be less dependent on GABA-driven frequency encoding, and thus compensate by using

some other neural communication method in order to make fine judgments between simultaneous stimuli.

In a similar study, Güçlü et al. (2015) administered many of the same vibrotactile behavioral tasks to thirty-two children and adolescents with OCD and thirty-two age- and gender-matched healthy controls. The authors also conducted comparative analyses within OCD subgroups. These subgroups consisted of (a) younger versus older participants (younger = 7-12; older = 13-18), (b) different genders, (c) tic-related OCD (25%) versus non-tic-related OCD (75%), and (d) the presence of sensory phenomena (e.g., tactile obsessions/compulsions and “just right” perceptions) (59%) versus the lack of sensory phenomena (41%). Results replicated the findings in TD, showing that OCD subjects had increased detection thresholds compared to healthy controls. When a dynamic detection threshold procedure was implemented to activate feed-forward inhibition, there were no differences between all OCD subjects and healthy controls, suggesting no generalized deficits in feed-forward inhibition. However, when subgroup analyses were performed, certain persons with OCD appeared to have deficits in feed-forward inhibition. Those with OCD who experience sensory phenomena and those with tic-related OCD showed impaired dynamic detection thresholds. The OCD group also showed overall poorer amplitude discrimination, suggesting that OCD is associated with impaired lateral inhibition.

As such, existing evidence suggests there are abnormalities in the cortical dynamics underlying sensory inhibition in TD and OCD. Because BFRBs, TD, and OCD have similar sensory and perceptual abnormalities, there is a strong possibility that

sensory inhibition deficits are also present in BFRBs. There also remain several important questions to be answered by research on sensory processing in BFRBs. If the deficits in sensory inhibition found in TD and OCD are also present in BFRBs, these problems could be seen as representing endophenotypes of obsessive-compulsive spectrum psychopathology. Thus, by investigating sensory processing abnormalities in an additional group of related conditions, identification of a common etiological mechanism is made possible. In addition, researchers examining sensory processing in TD and OCD speculated that their results could be the neural signatures of the cortical mechanisms supporting urge phenomena and other sensory abnormalities in TD and OCD. However, only the study on OCD determined whether performance on sensory processing tasks were associated with the presence or absence of certain sensory phenomena (Güçlü et al., 2015). This question is important because individuals with obsessive-compulsive spectrum disorders report varying frequency and intensity of urges (Houghton et al., 2015; Miguel et al., 2000; Woods et al., 2005). If disturbances in sensory processing do lead to urge phenomena, then the magnitude of sensory processing dysfunction should positively correlate with behavioral reports of sensory phenomena. Moreover, neither study examined whether the proposed sensory processing deficits are associated with symptom severity, which makes it difficult to understand the causal role of these deficits on behavior.

1.12 Current Hypotheses

Based on these gaps in the literature, the current study will employ the same vibrotactile battery as Puts et al. (2014, 2015) and Güçlü et al. (2015) to measure sensory processing in BFRBs.

For the primary aim of this study, we will determine whether individuals with BFRBs demonstrate abnormal sensory processing as compared to healthy controls. It is hypothesized that individuals with BFRBs will show abnormal performance on vibrotactile tasks reflecting poor sensory inhibition, relative to healthy controls. Specifically, it is predicted that individuals with BFRBs will possess deficits in feed-forward inhibition. Several other potential sensory abnormalities were also tested, including lateral inhibition, temporal processing, and event timing. These hypotheses were tested using a cross-sectional, between-groups design.

The secondary aim of this study is to determine if the magnitude of sensory processing dysfunction in individuals with BFRBs predicts the self-reported severity of sensory phenomena and BFRB symptoms. If the purported deficits in cortical sensory processing do indeed underlie the sensory phenomena that maintain symptoms, then performance on the vibrotactile battery should correlate with self-reported measures of sensory phenomena and BFRB severity.

I also intend to conduct exploratory analyses to determine whether any phenomenological characteristics of BFRBs are associated with vibrotactile task performance. Should I find that individuals with BFRBs indeed show task performances indicative of abnormal cortical sensory processing, it is important to elucidate whether these neural mechanisms are associated with any specific behavioral phenotype. First, I will determine whether task performances are affected by BFRB severity, such that increased severity of the disorder should be associated with greater deficits in the purported etiological substrate. Second, I will determine if phenomenological variables

such as pulling style are associated with task performance. This is important because there could be subgroups of hair pullers and skin pickers whose symptoms have different functions. For instance, those who pull in a less automatic manner may have a stronger connection between their symptoms and sensory phenomena, whereas other groups may pull/pick for other functions (i.e., emotion regulation).

CHAPTER II

METHOD

2.1 Participants

From November 2016 until June 2017, participants were recruited through several methods. Participants with BFRBs were recruited from the Texas A&M University – College Station community and from a BFRB specialty clinic in Houston, Texas. At Texas A&M, email advertisements were distributed through the Campus General Interest listserv, which includes all faculty, staff, and students (except those who have opted out) (See Appendix A).

Upon responding to the recruitment email, participants were given more information about the study and asked to provide a brief description of their BFRB prior to scheduling a study appointment. Those eligible and interested were scheduled for an in-person study appointment, where they provided informed consent and completed the study. Participants were compensated with \$15.

At Psychology Houston, flyers describing the study were placed in the waiting room (See Appendix B), and staff psychologists provided eligible participants brief information about the study. Those interested in the study were referred to the study coordinator, whereupon a study appointment was scheduled. Informed Consent and participation took place in a room typically reserved for psychotherapy sessions at Psychology Houston.

Inclusion criteria for participants with BFRBs consisted of (1) age ≥ 18 and ≤ 65 and (2) participant met all DSM-5 criteria for Trichotillomania or Excoriation Disorder.

Exclusion criteria consisted of (1) diagnosis of Autism, a Psychotic disorder, or a neurological disorder and (2) participant was currently taking medications with GABAergic properties, such as anti-epileptics and benzodiazepines. Children and older participants were not included for several reasons. First, BFRBs tend to onset during early adolescence (Snorrason, Belleau, & Woods, 2012), and evidence suggests that the sensory states associated with BFRBs tend to evolve as symptoms become more established (Meunier et al., 2009). This finding suggests that neuroplastic processes in the sensory/perceptual qualities of hair pulling and/or skin picking may occur during the early stages of disorder onset. Thus, measurement of sensory phenomena, which are thought to maintain pathological symptoms, should be conducted only once symptoms have become stable and chronic. Moreover, the focus of the current study is to examine sensory and perceptual factors that purportedly maintain BFRBs, not initiate them. To reduce the amount of variance associated with disorder onset, only adults were recruited for the current study.

There is also significant evidence that age-related changes in the nervous system lead to diminished reaction time and tactile perceptual abilities in older adults (Zhang, Francisco, Holden, Dennis, & Tommerdahl, 2011), particularly after age 65 (Deshpande, Metter, Ling, Conwit, & Ferrucci, 2009; Gescheider, Bolanowski, Hall, Hoffman, & Verrillo, 1994; Stevens, 1991), making age a possible confound. Persons with the aforementioned diagnoses were excluded because sensory experiences would be expected to deviate from population norms in persons with autism spectrum disorders (Puts et al., 2014), substance use disorders (Thoma et al., 2011), psychosis (Siegel,

Waldo, Mizner, Adler, & Freedman, 1984), and many neurological disorders. Finally, persons on GABAergic, glutamatergic, or dopaminergic medications were excluded because these medications likely act on the dependent variables of the current study.

Healthy control subjects were recruited from email advertisements that were distributed through the Texas A&M University Campus General Interest listserv (See Appendix C). Interested respondents whose ages matched a participant in the BFRB group were invited to participate. All participants in the healthy control group provided informed consent prior to participation and were compensated with \$15. 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 psychological disorder as measured by the MINI International Neuropsychiatric Interview (described below).

A total of 46 participants with BFRBs were recruited and completed the study, as well as an age-matched sample of 46 healthy control subjects. Age-matching was performed in order to account for any possible age-related differences in sensorimotor abilities. A total of 8 participants provided informed consent but did not complete the study. There were 6 participants who presented and claimed to have a BFRB but did not meet full diagnostic criteria for either Trichotillomania or Excoriation Disorder. An additional participant who presented with a BFRB recalled halfway through the study that they were taking Topiramate, and the participant was asked to discontinue participation and their data were not included in analyses. Yet another participant, who

would have participated as a healthy control subject, withdrew their consent after having to suddenly leave the testing session for personal reasons.

The age range of participants was 18-47, and a full description of demographic information between groups can be found in Table 1. As can be seen, participants in the BFRB group presented with significant frequencies of comorbid psychopathology. Several participants in the healthy control group met DSM-4 criteria for substance (marijuana) or alcohol abuse, but had not consumed substances recently (i.e., in the 24 hours prior to participation) and did not appear to be intoxicated or suffering from withdrawal symptoms. In addition to the MINI diagnostic information, participants in the BFRB group reported significant frequencies of other psychiatric problems. For instance, 4 persons reported that they had been previously hospitalized for a psychiatric issue, 5 persons had a history of non-suicidal self-injury (none were currently self-harming), and 5 persons reported that they had been diagnosed with attention-deficit/hyperactivity disorder. A significant portion (12 persons, 26.1%) also reported some degree of suicidal ideation. By comparison, no individuals in the healthy control group reported psychiatric diagnoses, but 1 participant did report occasional, mild suicidal ideation (and did not meet criteria for major depression).

Table 1. *Demographic Information and Psychiatric Comorbidity by Group*

	Clinical	Healthy
	<u>BFRBs</u>	<u>Controls</u>
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: <i>M(SD)</i>	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

Table 1. *Continued*

	Clinical	Healthy
	<u>BFRBs</u>	<u>Controls</u>
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	0	0
Features		
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	12 (26.0%)	0
Diagnoses		

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

The presence of psychoactive medications was also more frequent in the BFRB group than in the healthy control group. In the BFRB group, 30.4% had taken selective serotonin reuptake inhibitors (SSRIs), 15.2% had taken other types of antidepressants (e.g., atypical antidepressants, selective norepinephrine reuptake inhibitors, tricyclics), 10.9% had taken mood stabilizers, 4.3% reported a past history of glutamate modulators (none were current), 15.2% reported a past history of psychostimulants, 17.4% reported a past history of anticonvulsants (none were current), and 8.7% reported a past history of benzodiazepines (none were current). No participants reported a history of neuroleptic medication. In the healthy control group, 2.2% reported a past history of SSRI medication, 2.2% reported a past history of benzodiazepines, and 2.2% reported past Botox injections in the face.

Participants self-reported any significant medical problems, and any problems that might affect the current study were queried by the experimenter to ensure they wouldn't affect the participant's ability to complete the study or confound their results. No participant was removed from the study for a medical issue. However, 5 participants in the BFRB group and 6 participants in the healthy control group reported at least 1 past concussion or traumatic brain injury, but none of these persons reported any lingering neurological symptoms resulting from their head injuries.

The BFRB group was primarily composed of persons with Excoriation Disorder, and a smaller number of participants were diagnosed with Trichotillomania or both conditions. There were 39 participants with a diagnosis of Excoriation disorder, and 3 of those persons also reported subclinical hair pulling. There were 10 participants

diagnosed with Trichotillomania, and 4 of those persons also reported subclinical skin picking. Only 3 participants met criteria for both Trichotillomania and Excoriation Disorder. Based on the HDI and participants' responses on self-report measures of BFRB severity (described below), the experimenter classified participants on their overall level of hair pulling or skin picking severity using the Clinical Global Impressions Scale (described below). Regarding hair pulling severity, 3 participants were rated as "borderline ill", 1 participant was rated as "mildly ill", 7 participants were rated as "moderately ill", 1 participant was rated as "markedly ill", and 1 person was rated as "severely ill". Regarding skin picking severity, 2 participants were rated as "borderline ill", 3 participants was rated as "mildly ill", 23 participants were rated as "moderately ill", 13 participants were rated as "markedly ill", and 1 participant was rated as "severely ill". The average score on the self-report measure of hair pulling severity (The Massachusetts General Hospital Hairpulling Scale, described below) was 15.31, and the average score on the self-report measure of skin picking severity (the Skin Picking Scale, described below) was 11.63. Collectively, these data indicate that the sample consisted primarily of participants with moderate hair pulling and/or skin picking severity.

2.2 Measures

As previously mentioned, several different assessments were used to make diagnoses and quantify BFRB severity. These measures are described below.

The MINI International Neuropsychiatric Interview (Sheehan et al., 1998) is a structured, clinician-rated diagnostic interview that assesses for common psychiatric conditions. The MINI was designed to establish both principal and co-occurring DSM-

IV diagnoses. 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 for the purpose of the current study (See Appendix D). The HDI is a structured, diagnostic assessment consisting of items derived from DSM-5 criteria for BFRBs. After a trained interviewer checked diagnostic criteria for each BFRB, he or she summarized these criteria endorsements into diagnostic decisions (i.e., Clinical BFRB, Subclinical BFRB, or No BFRB). No psychometric data are available on the HDI, but it was constructed based on the Trichotillomania Diagnostic Interview (Rothbaum & Ninan, 1994), which has been used extensively as a Trichotillomania diagnostic instrument. The HDI was designed to assess for diagnoses related to pathological hair pulling (Trichotillomania) and pathological skin picking (Excoriation Disorder).

The Massachusetts General Hospital Hairpulling Scale (MGH-HPS; Keuthen et al., 1995) is a 7-item self-report questionnaire that measures frequency, resistance, and control of hair-pulling urges and behaviors as well as distress associated with hair pulling (See Appendix E). Each item is rated on a 5-point rating scale ranging from 0 (lower severity) to 4 (higher severity). The total score is acquired by summing the responses for all 7 items. The MGH-HPS has consistently demonstrated strong internal consistency ($\alpha = 0.89$) and test-retest reliability ($r = 0.97$; Keuthen et al., 1995; O'Sullivan et al., 1995), as well as acceptable convergent and divergent validity (O'Sullivan et al., 1995).

The Skin Picking Scale (SPS; Keuthen et al., 2001) is a 6-item self-report questionnaire that measures skin picking frequency, urges to pick, time spent picking, interference and distress, and functional impairment (See Appendix F). Each item is rated on a 5-point rating scale ranging from 0 (lower severity) to 4 (higher severity). The total score is acquired by summing the responses for all 6 items. The SPS has demonstrated moderate internal consistency, good convergent and divergent validity, and good predictive validity (Keuthen et al., 2001).

Several additional self-report scales were used to measure the phenomenology of hair pulling. The Milwaukee Inventory of Subtypes of Trichotillomania – Adult Version (MIST-A; Flessner et al., 2008) is a 15-item self-report measure that assesses the degree to which individuals engage in “focused” and “automatic” pulling styles (See Appendix G). Each style of pulling is assessed using a unique subscale, and items are scored on a 10-point Likert scale ranging from 0 (“not true for any of my pulling”) to 9 (“true for all of my hair pulling”). The MIST-A has demonstrated acceptable reliability and validity (Flessner et al., 2008). The Milwaukee Inventory for the Dimensions of Adult Skin Picking (MIDAS; Walther et al., 2009) is a 21-item self-report measure that assesses the degree to which individuals engage in “focused” and “automatic” picking styles (See Appendix H). Each style of picking is assessed using a unique subscale, and items are scored on a 5-point Likert scale ranging from 1 (“not true for any of my picking”) to 5 (“true for all of my picking”). The MIDAS has adequate reliability and good validity (Walther et al., 2009).

Several self-report measures were used to measure abnormal sensory experiences (See Appendices I and J). The Sensory Gating Inventory (SGI; Hetrick et al., 2012) is a self-report measure of sensory gating. It has 36 items that are rated on a 6-point rating scale ranging from *Never True* to *Always True*. There are 4 subscales derived from factor analysis: Perceptual Modulation, Distractibility, Over-Inclusion, and Fatigue and Stress Vulnerability. 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), and has been used in research on TD (Sutherland Owens, Miguel, & Swerdlow, 2011). The Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling et al., 2012) is a 32-item self-report measure of interoceptive awareness and self-regulation of body states. It has 8 subscales: Noticing, Not-Distracting, Not-Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, Trusting. Each subscale score is calculated by summing the corresponding item scores, which are scored on a 5-point rating scale ranging from *1-Never* to *5-Always*. The measure possesses strong validity and internal consistency (Mehling et al., 2012).

Finally, the CM6 Vibrotactile Behavioral Battery (Puts et al., 2013), a psychophysical behavioral measure of sensory processing was used as the primary assessment of reaction time, sensorimotor integration, detection threshold, feed-forward inhibition, lateral inhibition, temporal processing, and event timing. 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 technique has been validated in children and adults (Puts et al., 2013), as well as used to measure

sensory phenomena in TD and OCD (Güçlü et al., 2015; Puts et al., 2015) and other clinical populations such as concussion (Tommerdahl et al., 2016), Parkinson's disease (Kursun, Tommerdahl, & Favorov, 2013), Autism (Khan et al., 2015; Puts, Wodka, Tommerdahl, Mostofsky, & Edden, 2014; Puts et al., 2016), Carpal Tunnel Syndrome (Maeda et al., 2014), and alcohol abuse (Nguyen et al., 2013).

2.3 Procedure

After consenting to participate in the study, potential participants were screened for inclusion/exclusion criteria using the MINI and HDI. If not screened out at that stage, participants completed several self-report measures of demographics, BFRB severity, sensory processing, and subtypes of BFRBs. Then, the vibrotactile behavioral battery was administered on the left hand. Several vibrotactile protocols were employed: reaction time, detection threshold, amplitude discrimination, frequency discrimination, and duration discrimination. These tasks are described below.

The reaction time task requires participants to press a computer mouse with their opposite hand as soon as they detect a vibration on their testing hand. Reaction time measures general sensorimotor integration and serves to establish a baseline level of sensory function. Two conditions are used within the reaction time task: 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 (of two possible choices). The sRT task reflects basic sensorimotor integration and reaction time abilities, whereas the cRT task reflects one's reaction time abilities with added attentional, cognitive, and sensorimotor coordination demands. For both the sRT and cRT tasks, there was 1 training trial and 10

test trials. Stimulus amplitude was set at 300 μ m, frequency at 25Hz, and duration at 400ms.

The detection threshold task involves two similar processes whereby 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 from supra-threshold levels to sub-threshold levels, and the level at which an individual can reliably detect the stimulus becomes that individual's detection threshold. In the sDT task, the initial stimulus is delivered at 25 μ m, 25Hz, and 40ms. A total of 3 training trials and 20 test trials were delivered (inter-trial-interval [ITI] = 5s), and depending on correct or incorrect responses the amplitude of the stimulus was either increased or decreased by 1 μ m. In the *Dynamic* Detection Threshold (dDT) task, each test stimulus is preceded by lower, sub-threshold stimulus, which steady increases in amplitude and activates FFI processes, thus raising detection thresholds. There were no practice trials, and after a variable delay of 0-2,500ms each 25Hz stimulus started at 0 μ m and was ramped up at a rate of 2 μ m/s. A total of 7 trials were conducted in 10-second intervals. If FFI processes are intact, one should observe an increase in *dynamic* detection threshold as compared to the *static* detection threshold (Puts et al., 2013).

The amplitude discrimination task involves two processes whereby individuals must determine which of two simultaneously presented vibratory stimuli was stronger. In the 'without adaptation' condition (Simultaneous Amplitude Discrimination [simAD]), the difference between stimulus amplitude decreases across trials until a

reliable threshold of discrimination is established. Both stimuli were 25Hz and 500ms. The standard stimulus amplitude was 200 μ m and the initial comparison stimulus amplitude was set to 400 μ m, and the comparison stimulus was adjusted by 20 μ m after each trial. There were 3 test trials and 20 test trials (ITI = 5s). The simAD task reflects individuals' ability to detect subtle differences in intensity between two simultaneously delivered stimuli, which involves attentional and perceptual factors. In the 'Single-Site Adaptation' (SSA) condition, one of the two stimuli is preceded by a stimulus (200 μ m, 25Hz, 500ms) that participants are told to ignore, which is thought to activate lateral inhibition and raise the amplitude discrimination threshold (Puts et al., 2013). A considerable body of evidence shows that sensory neurons respond adaptively to the recent sensory events (Kohn, 2007; Kohn & Whitsel, 2002). Indeed, the addition of this 'adapting' stimulus is believed to decrease neural firing in response to subsequent stimulus input, thereby reducing the perceived intensity of subsequent stimulation (Whitsel et al., 1989; Whitsel et al., 2003). Tannan et al. (2008) found that the addition of a single adapting stimulus to the simAD task disrupted performance in healthy adults by increasing their amplitude detection difference limen. However, studies have found that this effect is absent in children and adults with Autism Spectrum Disorder (ASD) (Puts, Wodka, Tommerdahl, Mostofsky, & Edden, 2014; Tommerdahl et al., 2008), suggesting that ASD is associated with reduced neural adaptation to repeated sensory stimuli and potential problems with sensory habituation. 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 μ m, 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, Simons, Dennis, & Tommerdahl, 2007) but not individuals with autism (Tommerdahl et al., 2007). Evidence has shown that dual adapting stimuli not only reduce the perceived intensity of subsequent stimuli, but they also enhance discrimination accuracy, perhaps because they reduce neural activity and sharpen sensory input (Goble & Hollins, 1993; Tannan et al., 2007). Again, the absence of this effect in ASD may reflect reduced neural adaptation and poor adaptive sensory discrimination abilities.

The frequency discrimination task measures temporal processing by applying sequential and simultaneously applied stimuli. The ability to discriminate between the frequencies of sequentially applied stimuli (seqFD) is determined by GABA concentration in the sensorimotor cortex, but simultaneously applied stimuli (simFD) disrupt temporal encoding and impair discrimination in persons with intact cortical synchrony and lateral inhibition (Puts et al., 2013). In the seqFD task, the lag between stimuli was 500ms. There were 3 training trials and 20 test trials. The standard stimulus was set to 300 μ m, 25Hz, and 500ms, while the initial comparison stimulus was set to identical amplitude and duration but 35Hz frequency. The frequency of the comparison stimulus was changed by 1Hz between trials, which were presented in 5s intervals. Parameters were identical in the simFD task except for the lack of a lag time between stimuli presentation.

The duration discrimination (DD) task measures event timing by applying sequentially applied stimuli of different durations. There were 3 training trials and 20

test trials and an initial lead lag time of 500ms. The standard stimulus was set at 300 μ m, 40Hz, and 500ms, while the initial comparison stimulus had identical amplitude and frequency but 750ms duration. The duration of the comparison stimulus was changed by 25ms depending on right or wrong answers, and the trials were presented in 5s intervals. The ability to discriminate between the durations of sequentially applied stimuli is subserved by fronto-cerebellar white matter tracts.

The simple reaction time task was administered again at the conclusion of the battery in order to measure the influence of fatigue or performance 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.

2.4 Analyses

Groups were tested for any differences in behavioral processes related to sensory processing dysfunction, including sensory gating and interoceptive awareness. These differences were tested via two-group independent-samples tests. It was then tested whether groups differed on basic sensorimotor processes, including reaction time and sensorimotor integration, as such differences would likely affect performance on subsequent tasks. A 2x2 (task x group) factorial ANOVA was performed comparing the groups' performance on the Simple Reaction Time and Choice Reaction Time tasks.

In order to test whether individuals with BFRBs possess faulty sensory processing mechanisms that cause poor sensory inhibition, several factorial ANOVAs were performed testing performance on vibrotactile tasks according to experimental group. Because the detection threshold task, amplitude discrimination task, and frequency discrimination task all involve two conditions (i.e., static vs. dynamic

detection threshold), a series of 2x2 (task condition x group) factorial ANOVAs were used to test main effects of task condition, experimental group, and interactions between task condition and group. Additionally, post-hoc tests were employed to examine significant interaction effects in more detail. Two-group, independent-samples tests were used to measure differences on the duration discrimination task. Furthermore, in order to test whether the level of sensory processing dysfunction is associated with behavioral symptoms related to sensory gating, interoceptive awareness, and symptom severity, those variables were regressed upon the differences between performances between task conditions.

Finally, prior to analyses, variables which could theoretically confound results (i.e., gender) were tested as potential covariates. Differences in performance on the Simple Reaction Time task were entered as covariates into all analyses except the first tests of Simple Reaction Time and Choice Reaction Time (where it would be unlikely for fatigue or performance effects to occur). In addition, because the cerebellum, as well as frontal areas, are often impacted by traumatic brain injuries and concussion (Jantzen, Anderson, Steinberg, & Kelso, 2004; MacDonald et al., 2013; Talavage et al., 2014), which are also known to lead to deficits in event and predictive timing (Ivry, Spencer, Zelaznik, & Diedrichsen, 2002; Maruta, Lee, Jacobs, & Ghajar, 2010), the presence of a self-reported concussion or traumatic brain injury was controlled for in analyses on the duration discrimination task. Data were examined both visually and statistically to ensure that all participants had produced adequate data and that the data met the assumptions required for parametric null hypothesis significance tests.

CHAPTER III

RESULTS

3.1 Tests of potential covariates

There were no differences between the BFRB group and healthy control group with regard to gender ($t(90) = 1.52, p = .13$) 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 (See Figure 1) ($t(45) = 5.92, p < .001$; $t(45) = 6.57, p < .001$).

3.2 Behavioral Data

All participants provided usable data on the SGI Perceptual Modulation Subscale and all subscales of the MAIA, but the other three SGI subscales had one missing data point each (2 from participants with BFRBs, 1 from a healthy control participant). Data did not meet the assumption of normal distribution, as evidenced by significant Shapiro-Wilks tests. As such, Mann-Whitney U tests were used for all comparative analyses on behavioral data. In addition, a bonferonni correction was applied to significance levels to combat Type I errors that could be caused by multiple comparisons ($\alpha = .005$).

Consistent with predictions, there were numerous differences on self-reported sensory gating and interoceptive awareness between groups (See Table 2). Participants with BFRBs reported greater problems associated with sensory gating on all subscales of the Sensory Gating Inventory. Furthermore, participants with BFRBs reported greater attention toward interoceptive sensations, a greater propensity to worry about their body

states, and less trust in their own body. There were no differences between groups on the Not Distracting subscale, the Attention Regulation subscale, the Emotional Awareness subscale, and the Self-Regulation subscale.

Table 2. *Group differences on behavioral data*

<u>Scale</u>	<u>BFRB Mean (SD)</u>	<u>Healthy Control Mean (SD)</u>	<u>U</u>	<u>p-value</u>
Sensory Gating Inventory				
Perceptual Modulation	35.57 (14.49)	22.61 (6.16)	467.50	< .001*
Distractibility	28.07 (9.58)	17.36 (7.31)	408.00	< .001*
Overinclusion	21.04 (7.74)	13.65 (5.39)	466.00	< .001*
Fatigue/Stress Vulnerability	16.76 (5.58)	10.39 (4.28)	395.00	< .001*
Multidimensional Assessment of Interoceptive Awareness				
Noticing	12.54 (3.73)	9.04 (4.57)	602.50	< .001*
Not Distracting	6.39 (2.53)	7.39 (3.11)	875.00	.15
Not Worrying	7.17 (3.63)	9.46 (2.73)	685.50	.003*
Attention Regulation	19.50 (6.65)	20.78 (7.13)	935.00	.34
Emotional Awareness	16.59 (4.07)	14.15 (5.82)	815.50	.06
Self-Regulation	9.28 (4.68)	11.67 (4.02)	730.50	.01
Body Listening	5.98 (3.70)	5.41 (3.74)	956.50	.43
Trusting	9.57 (3.40)	11.57 (2.82)	683.00	.003*

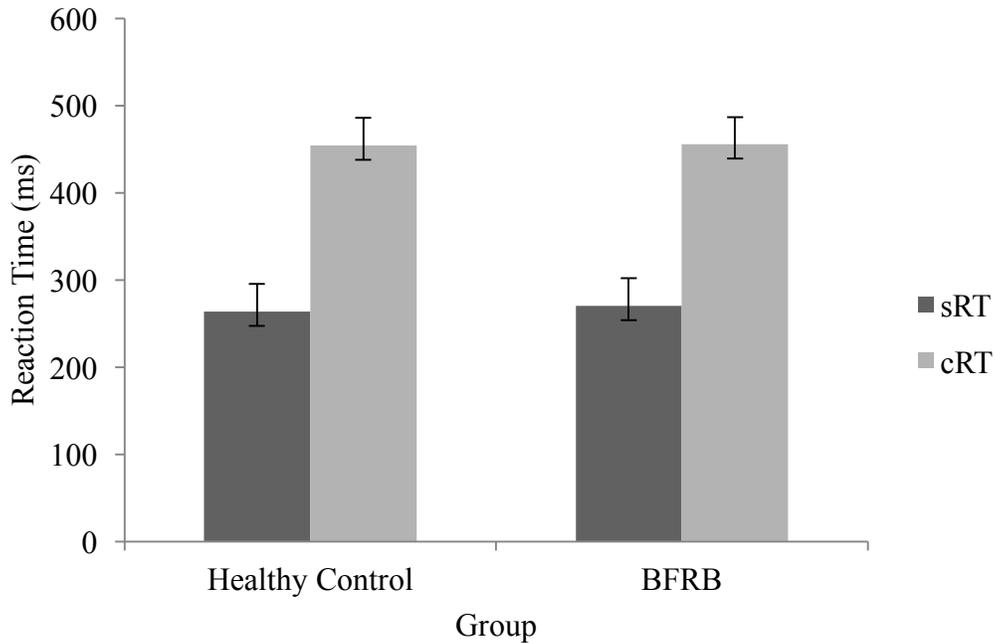
3.3 Reaction Time and Basic Sensorimotor Function

All 92 participants produced adequate data on sRT and cRT. Data were not normally distributed, as evidenced by significant Shapiro-Wilks' tests. This is unsurprising given that reaction time data are often skewed (Miller, 1998; Taylor, 1965). However, the data did meet the assumption of homogeneity of variance. Because the validity of *t*-tests are vulnerable to violations of normality (Erceg-Hurn & Mirosevich, 2007) while ANOVA is robust to this assumption violation (Schmidner, Ziegler, Danay, Beyer, & Bühner, 2010), Mann-Whitney U tests and Wilcoxon Signed Ranks tests were substituted for *t*-tests.

See Figure 1 for descriptive statistics regarding outcome variables. There were no baseline differences between groups on either the sRT ($Mdn_{BFRB} = 258.80$, $Mdn_{HC} = 250.70$; $U = 978.50$, $p = .55$) or the cRT ($Mdn_{BFRB} = 435.60$, $Mdn_{HC} = 437.70$; $U = 1008.00$, $p = .70$). There was 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 ($F[1, 90] = .07$, $p = .70$), and no task by group interaction ($F[1, 90] = .07$, $p = .79$). This suggests that the BFRB group did not show any greater change in reaction times between conditions. Results also indicated that there were no differences in consistency or accuracy between groups on SRT and CRT. There was no difference in the variability in reaction times on SRT between groups ($Mdn_{BFRB} = 23.00$, $Mdn_{HC} = 17.60$; $U = 996.50$, $p = .63$), and there was no difference in percent correct on CRT between groups ($Mdn_{BFRB} = 90.00$, $Mdn_{HC} = 100.00$; $U = 857.00$, $p = .08$). This

suggests that persons with BFRBs have normally developed sensorimotor integration on tasks requiring quick motor reactions.

Figure 1. *Performance on Reaction Time Tasks Between Groups.*



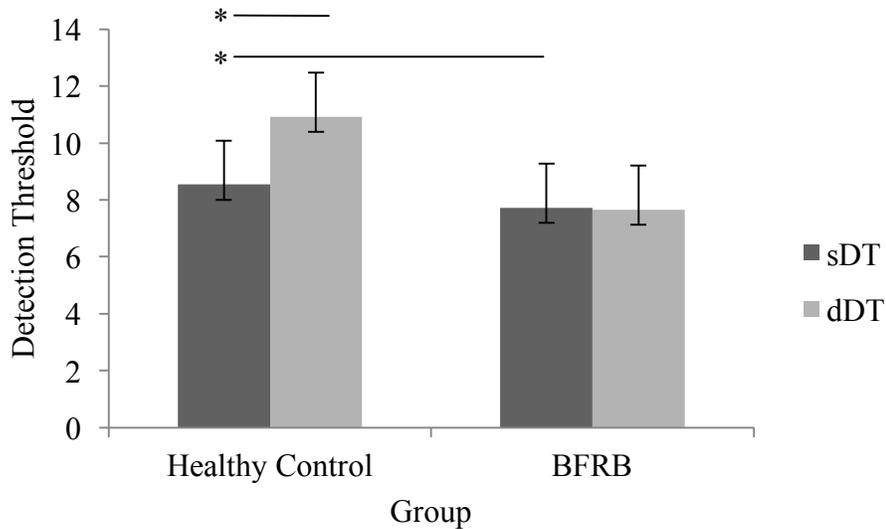
3.4 Detection Threshold

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. Significant Shapiro-Wilks' tests indicated that the data are not normally distributed, and Levene's test of equality of variances was significant for sDT ($F[1, 76] = 5.66, p = .02$). The violation of heteroscedasticity in the sDT condition was likely caused by a floor effect in the sDT data, whereby there was a strong positive skew and the modal result was the second lowest observed result

(6.20 μ m). As such, non-parametric tests were again substituted for *t*-tests, and results from the ANOVA should be interpreted with caution.

See Figure 2 for descriptive statistics for detection threshold performances between groups. Participants in the BFRB group had lower detection thresholds on both the sDT task ($Mdn_{\text{BFRB}} = 7.80$, $Mdn_{\text{HC}} = 8.40$; $U = 583.50$, $p = .036$) and the dDT task ($Mdn_{\text{BFRB}} = 8.10$, $Mdn_{\text{HC}} = 10.00$; $U = 457.00$, $p = .002$). 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 ($F[1, 76] = 5.18$, $p = .026$, $\eta_p^2 = .064$). Indeed, the detection thresholds of persons in the healthy control group increased between the sDT and dDT task ($Z = -2.55$, $p = .011$) while the detection thresholds of persons in the BFRB group showed no change between tasks ($Z = -.34$, $p = .73$). To ensure that pre-mature response tendencies (i.e., guessing) did not affect these results, the ANOVA was conducted once more with the percent correct on the dDT task entered as a covariate. When percent correct on dDT was entered as a covariate, effect sizes increased substantially, and there was still a significant main effect of condition ($F[1, 75] = 19.99$, $p < .001$, $\eta_p^2 = .21$), a significant main effect of group ($F[1, 75] = 13.94$, $p < .001$, $\eta_p^2 = .16$), and a significant interaction between condition and group ($F[1, 75] = 8.58$, $p = .004$, $\eta_p^2 = .103$). These results support the hypothesis of faulty feed-forward inhibition in BFRBs.

Figure 2. Performance on Detection Threshold Tasks Between Groups



3.5 Amplitude Discrimination

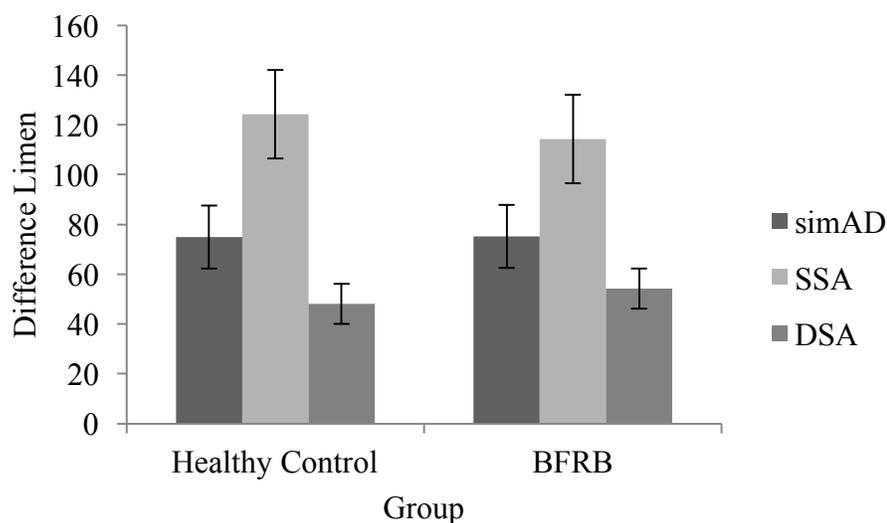
All 92 participants provided usable data on the amplitude discrimination tasks.

Significant Shapiro-Wilks' tests indicated that the data are not normally distributed, and Levene's test of equality of variances was significant for simAD ($F[1, 90] = 7.04, p = .009$), indicating a violation of heteroscedasticity. In addition, Mauchly's test of sphericity was significant ($X^2 = 16.49, p < .001$). As such, ANOVA was interpreted with caution through Greenhouse-Geisser corrections, and non-parametric tests were substituted for t -tests.

See Figure 3 for descriptive statistics regarding performances on amplitude discrimination tasks between groups. There were no differences between groups on the simAD task ($Mdn_{BFRB} = 68.00, Mdn_{HC} = 60.00; U = 930.50, p = .32$), SSA task ($Mdn_{BFRB} = 116.00, Mdn_{HC} = 124.00; U = 961.00, p = .45$), or DSA task ($Mdn_{BFRB} = 58.00, Mdn_{HC} = 46.00; U = 863.50, p = .13$). There was a main effect of condition ($F[2,$

180] = 56.01, $p < .001$, $\eta_p^2 = .38$), but no main effect of group ($F[1, 90] = .05$, $p = .83$) and no interaction between group and condition ($F[2, 180] = .77$, $p = .45$). There was no evidence of a different increase in scores between simAD and SSA between groups ($Mdn_{BFRB} = 41.50$, $Mdn_{HC} = 62.00$; $U = 952.50$, $p = .41$), and no evidence of a different decrease in scores between SSA and DSA ($Mdn_{BFRB} = 65.50$, $Mdn_{HC} = 83.00$; $U = 927.50$, $p = .31$). As such, these results do not suggest any abnormalities in lateral inhibition and/or dynamic sensory adaptation in BFRBs.

Figure 3. Performance on Amplitude Discrimination Tasks between groups



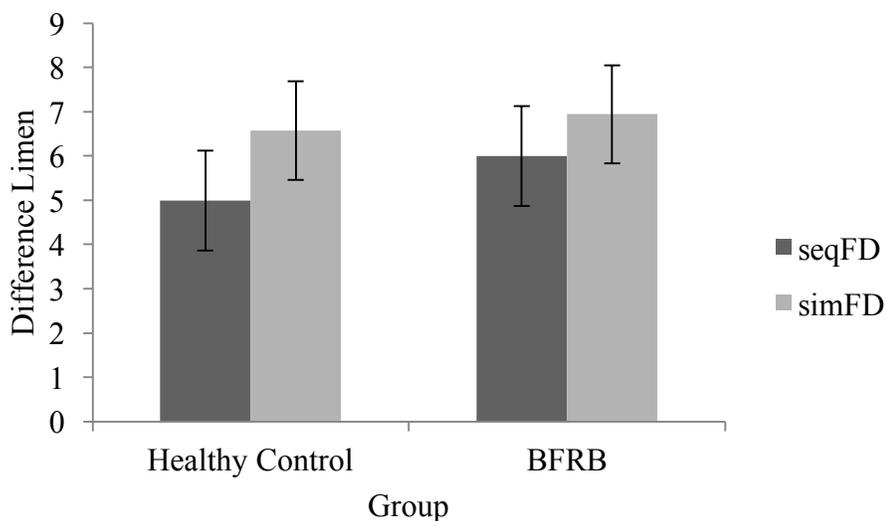
3.6 Frequency Discrimination

All 92 participants provided usable data on the frequency discrimination tasks.

Significant Shapiro-Wilks' tests indicated that the data are not normally distributed, and Levene's tests of equality of variances were non-significant. As such, non-parametric tests were substituted for t -tests but ANOVA can be interpreted with confidence.

See Figure 4 for descriptive statistics regarding performances on frequency discrimination tasks between groups. There was a main effect of condition ($F[1, 90] = 7.80, p = .006, \eta_p^2 = .08$), indicating that it was more difficult for participants to judge differences in frequency between vibrations applied simultaneously than vibrations applied sequentially. However, there was no main effect of group ($F[1, 90] = 1.13, p = .29$) and no interaction between group and condition ($F[1, 90] = .50, p = .48$), and there were no differences between groups on the seqFD task ($Mdn_{BFRB} = 4.60, Mdn_{HC} = 4.20; U = 975.00, p = .52$) or simFD task ($Mdn_{BFRB} = 6.30, Mdn_{HC} = 6.20; U = 1023.50, p = .79$). This indicates that the groups did not have different performance on each of the tasks, and there was no differential effect of the tasks on the group's performances. Overall, data indicate that BFRBs are not associated with any deficits in temporal processing.

Figure 4. Performance on Frequency Discrimination Tasks between groups.



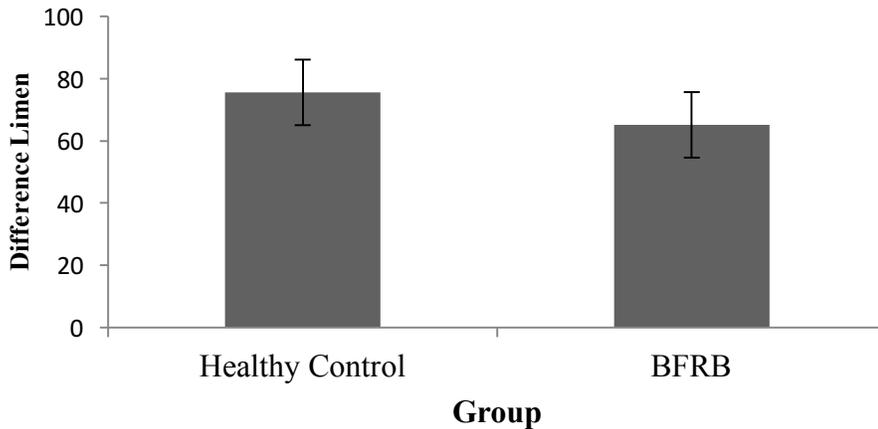
3.7 Duration Discrimination

All 92 participants provided valid data on the duration discrimination task.

Significant Shapiro-Wilks' tests indicated that the data are not normally distributed, so a Mann-Whitney U test was substituted for a t -test. Furthermore, as previously mentioned, 11 participants (5 with BFRBs, 6 healthy controls) reported a history of concussions or traumatic brain injuries. The presence of a concussion or traumatic brain injury was introduced into analyses as a covariate in a one-way ANCOVA. Levene's test was non-significant, meaning the ANOVA can be interpreted with confidence.

See Figure 5 for descriptive statistics regarding performances on the duration discrimination task between groups. Without controlling for head injuries, there was no difference in performance on the duration discrimination task between groups ($Mdn_{\text{BFRB}} = 57.5$, $Mdn_{\text{HC}} = 65.00$; $U = 876.00$, $p = .15$). Results of the one-way ANCOVA controlling for head injuries was similarly non-significant ($F[1, 89] = 1.84$, $p = .18$). As such, results do not support the presence any abnormalities in event timing in persons with BFRBs.

Figure 5. *Performance on Duration Discrimination Tasks between groups.*



3.8 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 reduced FFI as evidenced by an interaction between group and detection threshold tasks. As such, performance on the sDT task and the differences between sDT and dDT task were used as predictors in a series of regression analyses predicting behavioral data from vibrotactile data. All 80 participants with usable data on detection threshold tasks were included in analyses on the Sensory Gating Inventory and the Multidimensional Assessment of Interoceptive Awareness, but only participants with Trichotillomania and/or Excoriation Disorder were included in regressions predicting variables associated with BFRBs. Both predictor variables were not normally distributed, as was the MAIA Self-Regulation subscale. Accordingly, log transformations were performed on sDT data and the Self-Regulation subscale to meet the assumptions of linear regression. Because

some values of the difference between sDT and dDT were less than 0, log transformations could not be performed, and thus regression should be interpreted with some caution.

Significant relationships were observed when detection threshold predicted the Fatigue/Stress Vulnerability subscale of the Sensory Gating Inventory and when FFI predicted skin picking severity (See Table 3). These differences would not survive a bonferroni correction for multiple comparisons ($\alpha = .001$). As such, the hypotheses that performance on vibrotactile tasks would symptom severity and behavioral reports of sensory phenomena were only partially supported.

Table 3. *Regression analyses predicting behavioral data from vibrotactile performance.*

<u>Outcome</u>	<u>Predictor</u>			<u>FBI</u>		
	<u>Beta</u>	<u>t-value</u>	<u>p-value</u>	<u>Beta</u>	<u>t-value</u>	<u>p-value</u>
MGH-HPS	.10	.32	.76	-.51	-1.89	.088
SPS	.17	.97	.34	.40	2.48	.018*
MIST-A Focused	-.15	-.47	.65	-.42	-1.47	.17
MIST-A Automatic	-.13	-.41	.69	.50	1.83	.097
MIDAS Focused	.11	.64	.53	.19	1.08	.29
MIDAS Automatic	.05	.31	.76	.07	.37	.71
SIG – Perceptual Modulation	-.12	-1.08	.28	.07	.63	.53
SIG – Distractibility	-.14	-1.24	.22	.12	1.03	.31
SIG – Overinclusion	-.10	-.88	.39	.12	1.07	.29
SIG – Fatigue/Stress Vulnerability	-.31	-2.81	.006*	.06	.51	.61
MAIA – Noticing	.05	.46	.65	.02	.14	.89
MAIA – Not Distracting	-.01	-.09	.93	-.05	-.40	.69
MAIA – Not Worrying	.07	.62	.54	-.08	-.66	.51
MAIA – Attention Regulation	.12	1.02	.31	-.04	-.37	.71
MAIA – Emotional Awareness	.06	.57	.57	.04	.36	.72
MAIA – Self-Regulation	.14	1.22	.23	.01	.09	.93
MAIA – Body-Listening	.08	.73	.47	-.13	-1.12	.27
MAIA – Trusting	.16	1.44	.16	.004	.04	.97

* = significant difference

CHAPTER IV

DISCUSSION

4.1 Review of Findings

Results of the current study suggest that BFRBs are associated with several sensory and perceptual abnormalities. Persons with BFRBs reported increased interoceptive awareness, increased worry about body sensations, and less trust and/or feelings of security in their own bodies. In addition, persons with BFRBs reported more frequent and intense experiences associated with deficient sensory gating as compared to healthy adults. Results from the vibrotactile psychophysics battery showed that BFRBs were associated with decreased tactile detection thresholds and faulty FFI but no other sensory or motor abnormalities. In linking quantitative sensory abnormalities to phenomenology, it appears that increased sensitivity to tactile stimuli may be related to vulnerability to experiencing sensory phenomena while fatigued and/or distressed and that FFI may be related to BFRB severity.

The finding that individuals with BFRBs report increased interoceptive awareness is consistent with previous research. Two studies have found that individuals with BFRBs report increased perceived somatic activity. Teng et al. (2002) and Woods et al. (1996) found that persons with BFRBs reported increased frequencies of various somatic symptoms (e.g., eyes watering, itchy eyes or skin, ringing in ears) as compared to individuals with no BFRBs. However, prior to the current study, it was difficult to interpret the meaning of findings from those previous studies because several different factors can contribute to the perception of increased somatic experiences, such as

increased attention toward bodily processes as well as abnormally low detection thresholds. Our results indicate that persons with BFRBs report that they notice more bodily sensations, that they tend to worry more about their body sensations, and that they feel decreased trust in their own body sensations. Yet, there were no differences between the BFRB group and healthy control group on MAIA subscale scores related to propensity to distract oneself from bodily sensations, ability to direct attention toward body sensations, or the tendency to listen to one's own body. As such, it appears that persons with BFRBs have increased awareness of interoceptive experiences and that they tend to catastrophize about interoceptive and/or vestibular sensations and take a hypochondriac approach to their bodily processes. BFRBs do not appear to be associated with altered attention to bodily processes, and thus it would be incorrect to assume that persons with BFRBs report more bodily sensations due solely to increased attention toward their internal states. It is also important to note that the current results related to the MAIA Self-Regulation subscales were significant at the 95% confidence level, but this differences would not survive the bonferroni correction for multiple comparisons. This means that perhaps persons with BFRBs are also less able to adaptively self-regulate their internal states.

The notion that persons with BFRBs are more perceptive of their internal states, are less able to regulate their body states, and tend to assign negative valence toward bodily sensations is consistent with our findings regarding the SGI. Results showed that persons with BFRBs reported increased feelings of perceptual inundation, problems focusing on one stimuli to the exclusion of others, having lower sensory detection

thresholds, and being vulnerable to sensory phenomena when fatigued or distressed. As such, it is possible that BFRBs are not only associated with greater awareness of internal sensations, but that they feel overwhelmed with additional external stimuli in their environment, that they cannot shut out redundant sensory information, and that they are particularly vulnerable to perceptual anomalies when fatigued or distressed.

In addition to these self-reported abnormalities that speak to the abnormal sensory experiences felt by those with BFRBs, results from the vibrotactile behavioral battery provide insight into potentially underlying psychobiological endophenotypes. In addition, the fact that the current study yielded few but quite specific findings related to tactile abilities provides clear targets for future research.

Results revealed that individuals with BFRBs have lowered detection thresholds (increased sensitivity) and deficient feed-forward inhibition as compared to the healthy control group. Indeed, not only was there a main effect of group on the repeated measures test of performance on both the sDT and dDT tasks, but the BFRB group had lower detection thresholds on both tasks. These results clearly demonstrate an increased ability to detect low intensity tactile information in persons with BFRBs. In addition, results showed that the BFRB group's performance was unaffected by change in task, providing evidence of deficient FFI processes in BFRBs. FFI is facilitated by GABAergic inhibitory interneurons, and it is thought that FFI is a powerful and efficient method for suppressing neural activity in cases where sub-optimal, spurious, or redundant afferent information is perceived by the peripheral nervous system (Swadlow, 2002).

The other results point to intact neural inhibition in other sensory domains. There were no differences between the performances of persons with BFRBs and healthy controls on any of the amplitude discrimination tasks, which are believed to be sensitive to deficits in lateral inhibition and short-term sensory habituation. As such, while BFRBs may be associated with abnormal inhibitory interneuron activity that mediate the spiking of somatosensory neurons in response to ongoing stimuli, it does not appear that the receptive fields of sensory neurons – lateral inhibitory connections between closely connected somatotopic areas – or short-term sensory learning processes are affected in BFRBs. We should thus not expect individuals with BFRBs to exhibit poor spatial resolution with regard to somatosensory sensitivity, nor should we expect them to have difficulty habituating to stimuli presented intermittently. These results have several behavioral and phenomenological implications. First, it does not appear that individuals with BFRBs suffer from any impairments in their ability to accurately perceive their environments. Second, while individuals with Autism Spectrum Disorders (who perform abnormally on amplitude discrimination tasks) exhibit symptoms such as insistence on sameness, sensitivity to departures from routine, and trouble orienting to complex and rich sensory environments (Baranek, Little, Parham, Ausderau, & Sabatos-DeVito, 2014), there is no evidence that individuals with BFRBs report these symptoms nor show any neurophysiological abnormalities that might support such phenomena. Third, individuals with TD do show altered performance on the SSA task as compared to healthy controls (Puts et al., 2015), which may reflect altered sensory habituation processes in persons with tics. Furthermore, individuals with OCD have shown poor

simAD task performance as compared to healthy individuals (Güçlü et al., 2015), which may reflect poor lateral inhibition. When compared to results from the current study, this suggests that altered spatial resolution and short-term sensory habituation may not be features that span disorders across the Obsessive-Compulsive spectrum.

Results showing normal performance on the frequency discrimination tasks and duration discrimination task suggest that individuals with BFRBs have normal-functioning neuronal circuitry in somatosensory cortex and cortico-cerebellar tracts that are responsible for coding the temporal dynamics of stimuli. The ability to discriminate between periodic vibrations applied to the skin is accomplished through quickly adapting neurons in the somatosensory cortex, which represent the rate of stimulus frequency via spiking periodicity and rate (Hernandez, Zainos, & Romo, 2000). Event timing is subserved by coordinated neural populations located primarily in the cerebellum (Buhusi & Meck, 2005). The cerebellum is also involved in sensorimotor control and sensory anticipation (Teshe & Karhu, 2000), and research has found evidence of reduced cerebellar volumes in TTM (Keuthen et al., 2007). Moreover, researchers have speculated about the role of motor control and response inhibition in BFRBs (Bohne et al., 2008; Brennan, Francazio, Gunstad, & Flessner, 2015; Chamberlain et al., 2006; Grant, Odlaug, & Chamberlain, 2011; Leppink et al., 2016; Martin, 1993; Odlaug et al., 2014; Odlaug, Chamberlain, & Grant, 2010; Snorrason et al., 2011). However, the presence of abnormal cerebellar function in TTM or ExD does not appear to be reflected in the current study.

In summary, it appears that BFRBs are associated with abnormally high sensitivity to tactile and interoceptive sensations, feelings of worry and mistrust in their bodily sensations, perceptual anomalies, and dysfunctional sensory inhibition processes. Such dysfunctional inhibition may account for a modest proportion of symptom severity, and affected individuals may feel overly sensitive to stimuli while fatigued or stressed. Implications for the etiology of BFRBs are discussed below.

4.2 The Potential Role of Sensation in BFRB Psychopathology

BFRBs have been traditionally viewed as problems related to behavioral control. Indeed, research reviewed herein suggests that compulsive habits may be driven by excessive reliance on stimulus-response behavioral control systems. However, there is inconclusive research regarding the role of habit learning and impulse control in BFRBs, and the factors that instigate and maintain BFRBs are poorly understood. Although some research suggests that BFRBs can be part of a maladaptive emotion regulation strategy (Roberts et al., 2013), it may not be that BFRBs are initiated and performed solely to modulate cognitive/affective states. Rather, phenomenological research suggests that one important role of BFRBs involves the sensations preceding and/or accompanying symptoms (Mansueto et al., 1997), and the results of the current study suggest that BFRBs are associated with neurophysiological abnormalities in sensory thresholds and gating. Below, I present a preliminary framework of a model delineating the relationship between sensory abnormalities and BFRBs.

As previously mentioned, grooming behaviors are extremely common amongst animals and serve a variety of purposes, including hygiene, social bonding, and affect regulation. Grooming is also important in humans for a variety of purposes. In addition,

evidence indicates that self-manipulation of the body surface is a basic and fundamental motor pattern that emerges during infancy and follows a developmental trajectory. Humans exhibit BFRBs in utero (Murphy & Langley, 1963), and movement patterns involving self-manipulation such as face touching and thumb sucking tend to onset later during gestation along with other complex movement patterns, which may represent neurodevelopmental milestones (e.g., rehearsing the rooting reflex; Birnholz, Stephens, & Faria, 1978). Infants typically show various rhythmic body movements, including BFRBs, which are thought to help infants learn about the physical properties of their own bodies and develop sensorimotor skills (Kravitz & Boehm, 1971). Young children also often show behavioral stereotypies (e.g., finger wiggling, body rocking) and fixation on objects with certain sensory characteristics (e.g., cherished blankets, tight-fitting swaddles, stuffed animals), which may provide physical comforts related to the womb environment or be experienced as pleasing to the infant in a world that is filled with copious unpleasant stimuli. BFRBs most often occur during infancy and young childhood (Mehegran, 1970, Wright & Holmes, 2003) and wane in frequency as age increases (Evans et al., 1997; Foster, 1998). Research also suggests that early-onset BFRBs tend to spontaneously remit (Swedo, Leonard, Lenane, & Rettew, 1992) and thus have a more favorable course than later-onset BFRBs (Lewin et al., 2009; Santhanam, Fairley, & Rogers, 2008; Tay, Levy, & Metry, 2004). It may be that BFRBs can initiate as part of normal human sensorimotor development and function as comfort mechanisms in the complex and often aversive sensory environment that young children encounter, but as children develop and achieve a more balanced perceptual homeostasis (Murphy &

Hochberg, 1951) these behaviors are reinforced less and extinguish. By comparison, children with developmental disabilities, who often show sensory abnormalities (Green et al., 2013, 2015), tend to exhibit chronic patterns of ritualistic behavior, including BFRBs, possibly because these behaviors are continuously invoked by aversive sensory states. Persons at risk for BFRBs may also be abnormally sensitive to stimuli and less able to inhibit extraneous sensory information, meaning that BFRB symptoms are continuously reinforced and resistant to spontaneous extinguishing.

As for how BFRBs are automatically reinforced, it has been argued that BFRBs are particularly intriguing behaviors for children because body areas with hair, skin, and nails are densely populated with sensory receptors and easily stimulated (Penzel, 2003). As such, gently stroking or toying with one's body surface could often be experienced as pleasurable, particularly when bored or under-stimulated. Evidence indicates that more extreme self-cutaneous actions, such as scratching, may provide intense pleasure in certain contexts such as itching (Ayres, 1964). Self-contact actions may also be instigated under other circumstances, such as when an individual feels perceptually over-included. The fact that displacement behaviors are often seen under conditions of stress and tension is consistent with the notion that self-contact and cutaneous stimulation attenuates aversive over-stimulation. However, this view may seemingly stand in contrast to common sense, as it does not follow that someone who is over-stimulated would seek more stimulation, but rather more likely withdraw from stimulation. Yet researchers in occupational therapy have posited that when over-stimulated, persons tend to work to distract themselves from unpleasant stimuli by engaging in behaviors that result

in more pleasant stimulation, which compete for attention and distract one from the more aversive stimuli (Dunn, 2000).

Stimulus seeking is typically linked to impulsive, risky behaviors such as substance abuse and thrill-seeking (Whiteside & Lynam, 2003), which are then thought to stem from reward deficiency and under-stimulation (Blum et al., 2013). However, a link between over-stimulation and repetitive behavior can be established when one views organisms as acting in constant sensorimotor interaction with their environment. In this view, most behavior is performed automatically in stimulus-response (i.e., habitual) patterns. Humans possess highly advanced sensory processing and motor programming cortical regions, which afford an enormous range of complex behavioral possibilities that an individual must constantly select from when confronted by stimuli. This creates a “selection problem” by virtue of the range of possible behaviors that one could choose from in response to a given stimulus or context (Kozolil, Budding, & Chidekel, 2011, pp. 774). Action selection occurs in the basal ganglia through several parallel circuits, but they primarily follow direct and indirect pathways that facilitate desired behaviors and inhibit competing behaviors, respectively (Kaji, Urushihara, Murase, Shimazu, & Goto, 2005). Furthermore, action selection occurs in concert with perception, and these processes are inexorably linked (Dewey, 1896; Iverson, 2010; Nip, Green, & Marx, 2010; Raab, Johnson, & Heekeren, 2009). Researchers have suggested that there are four to five parallel cortico-striatal circuits that have significant overlap and receive projections from various cortical regions and the cerebellum, thereby allowing motor control to be influenced by cognitive, motivational, and sensory factors (Kozolil et al.,

2011). When disruptions in sensation and perception occur, including sensory excesses and gating failures, cortico-striatal motor selection circuitry are thus affected (Kaji, 2001; Kaji et al., 2005). Hence, action selection is disrupted, possibly due to deficient inhibition of the indirect motor pathway and reduced suppression of unwanted behaviors (Kozoi et al., 2011). Accordingly, in the case of OC-related disorders such as BFRBs, excessive sensory innervation of motor control areas may result in a lowered threshold of discriminant stimulus intensity for symptoms to be elicited.

The potential involvement of neurophysiological sensory abnormalities in movement disorders and compulsive behaviors has been hypothesized in several accounts. Indeed, disorders that are traditionally associated with impaired motor control and basal ganglia dysfunction, such as Parkinson's disease, Huntington's chorea, dystonia, Tourette's disorder, restless leg syndrome, and akathisia have been linked to alterations in sensory input that result in dysfunctional sensorimotor integration (Kaji et al., 2005; Patel, Jankovic, & Hallett, 2014). A recent study also found evidence for increased motor excitability and reduced short-term sensory inhibition in persons with OCD (Russo et al., 2014), suggesting that a combination of perceptual hypersensitivity and reduced motor control is associated with compulsive behavior. Further evidence indicates that a range of compulsive, ritualistic, and impulsive behaviors are associated with sensory processing impairment. Indeed, while sensory abnormalities have been well documented in Autism Spectrum Disorders (Green et al., 2013, 2015), evidence indicates that increases in perceptual sensitivity positively correlate with repetitive behavior severity in affected individuals (Baranek, Foster, & Berkson, 1996; Boyd et al.,

2010; Gabriels et al., 2008). Sensory processing abnormalities are also present in other disorders associated with repetitive and stimulus-seeking behavior, such as attention-deficit/hyperactivity disorder (Engel-Yeger & Ziv-On, 2011; Ghanizedah, 2011), bipolar disorder (Parker, Paterson, Romano, & Graham, 2017), and anxiety disorders (Burón, Bulbena, & Bulbena-Cabré, 2015; Clepce, Reich, Gossler, Kornhuber, & Thuerauf, 2012; Hofman & Bitran, 2007; Pause, Adolph, Prehn-Kristenson, & Ferstl, 2009; Segalàs et al., 2011).

As such, there is substantial empirical support for the notion that impairments in sensory inhibition and heightened perceptual awareness are associated with increased unwanted, compulsive behaviors. Yet, due to the complexity of sensory neurophysiology and the intricacies of sensorimotor integration, as well as the fact that sensory dysfunctions appear to cut across various forms of psychopathology, it is still somewhat unclear which specific neurophysiological and behavioral abnormalities cause these sensory phenomena. There are only a few studies on “sensory processing disorders” to provide insight into the etiology of sensory impairments in traditionally recognized psychopathology. These studies point to abnormal white matter microstructure in the posterior corpus callosum, posterior corona radiata, and posterior thalamic radiations (Owens et al., 2013), as well as developmental delays in sensory gating (Davies, Chang, & Gavin, 2009). As such, there is a clear need for more research on the etiology of sensory impairments associated with psychopathology and behavior problems.

At this time, the clearest evidence suggests that sensory excesses are associated with affective problems, which have been more traditionally linked to the

psychopathology of BFRBs. Indeed, BFRBs appear to wax and wane with concurrent fluctuations in stress and negative affect (Bohne et al., 2005). Other studies have found that children who report greater perceptual sensitivity have reduced parental bonding and poorer anxiety and depression (Liss, Timmel, Baxley, & Killingsworth, 2005), and perceptual sensitivity in adults is correlated with increased depression, anxiety, psychosocial distress, social introversion, interpersonal problems, perfectionism, anger, self-doubt, family and work problems, and substance abuse (Ben-Avi, Almagor, & Engel-Yeger, 2012). Because BFRBs appear to regulate both aversive emotions and sensations, it follows that affect and perception are intimately linked. Indeed, evidence indicates that aversive stimulation, including nociception as well as other somatic experiences are associated with stress, sadness, and fear, are processed in the amygdala through thalamic, insular, and other cerebral GABAergic projections (Avery et al., 2014; Jasmin, Rabkin, Granato, Boudah, & Ohara, 2003; Veintante, Yalcin, & Barrot, 2013). The amygdala integrates multiple nociceptive units of information, is influenced by higher-order brain centers involved in affect and cognition, and projects to pre-motor and cortical areas involved in behavioral and affective responses to nociception. As such, during periods of negative affect and cognition (e.g., stress), aversive stimuli may be more likely to result in maladaptive behavior.

There is also experimental evidence suggesting that negative affect can influence sensory thresholds. During periods of increased stress or fear, it may be beneficial for survival to heighten one's attention to certain sensory cues but decrease sensitivity to other sensory stimuli. For instance, when confronted with danger/fear/stress, improved

identification of threats is facilitated by increased visual acuity (Öhman, Flykt, & Esteves, 2001; Stolarova, Keil, & Moratti, 2006) and olfactory sensitivity (Ahs, Miller, Gordon, & Lundström, 2013; Hoenen, Wolf, & Pause, 2017; Jones, Choi, Davis, & Ressler, 2008; Kass et al., 2013; Krusemark & Li, 2012; La Buissonnière-Ariza, Lepore, Kojok, & Frasnelli, 2013; Lukowiak et al., 2008; Pacharra, Schäper, Kleinbeck, Blaszkewicz, & van Thriel, 2016; Sung et al., 2009). With regard to tactile sensitivity, it appears that detection thresholds are raised during acute fear (Kelley & Schmeichel, 2014), but stress and anxiety are consistently associated with decreased detection thresholds and increased interoceptive awareness (Chen, Lu, Yang, Ding, & Zuo, 2017; Clark, Yang, & Janal, 1986; Crettaz et al., 2013; Domschke, Stevens, Pfleiderer, & Gerlach, 2010; Kopp & Gruzelier, 1989; Lehofer, Liebmann, Moser, & Schaunstein, 1998; Marcinkiewicz et al., 2009). There is even evidence to suggest that prenatal stress is associated with increased infantile tactile sensitivity (Schneider et al., 2008), and it appears that early life stress can exert long-term changes in somatosensation, such as decreased sensory thresholds (Takatsura & Koibuchi, 2015) and disruption of glutamatergic synapses that balance sensory excitability/inhibition (Toya et al., 2014).

BFRBs may become paired with aversive perceptual experiences in persons whose grooming behavior becomes conditionally associated with affect and/or sensory regulation. For instance, evidence indicates that BFRBs are much more common in females than males (Snorrason, Belleau et al., 2011). Females tend to spend more time self-grooming than men, place more emphasis on cosmetics, and frequently report that their body hair is unwanted (Blume-Peytavi, 2011; Cash, 1988). Cosmetic use is

positively correlated with body image and positive affect in women (Cash & Cash, 1982; Cash, Dawson, Davis, Bowen, & Galumbeck, 1989), and women who are more self-conscious about their appearance tend to wear more makeup (Miller & Cox, 1982; Theberge & Kernaleguen, 1979). Further, evidence indicates that social grooming promotes tension reduction amongst male and female primates (Grandi & Ishida, 2015; Schino, Scucchi, Maestripieri, Turillazzi, 1988), facilitates trust and courtship in human romantic relationships (Nelson & Geher, 2007), and engages endogenous opioids in humans (Nummenmaa et al., 2016). Research has shown that stimulation of the hypothalamic region that is commonly activated during grooming promotes release of hypothalamic corticosterone and cerebrospinal substance P (Kruka et al., 1998; Morhenn, 2000), which can function to down-regulate aggressive behavior, negative affect, anxiety and stress. Grooming also provides pleasurable sensations through stimulation of unmyelinated mechanosensory nerves that are tuned to grooming-related behaviors (McGlone, Walker, & Ackerley, 2016). It thus stands to reason that grooming behavior may not only be experienced as pleasurable, but also be positively reinforced (i.e., improvements in self-image, pleasurable sensations) and negative reinforced (i.e., removal of unwanted bodily imperfections), particularly in females.

In summary, BFRBs may be part of normal human motor development and grooming routines. Persons with sensory dysregulation issues and who are more highly sensitive to environmental stimuli may experience reduced control over their behavior, thus leading to maladaptive behaviors such as BFRBs. Furthermore, negative affective

experiences may be associated with sensory/perceptual changes that further promote BFRB performance.

4.3 Limitations and Future Directions

4.3.1 Etiology

The current study tested sensory processing in BFRBs solely within the mechanoreceptive domain. While tactile sensations are likely relevant to BFRB phenomena, which typically involve cutaneous stimulation, there are other types of sensory experiences that may play an important role in hair pulling and skin picking. Hair follicles are primarily innervated by unmyelinated A fibers (Winkelmann, 1959). These fibers respond to touch stimulation, particularly when the hair is brushed or tugged at (Paus & Cotsarelis, 1999). However, various other types of sensory nerve responses and perceptual experiences associated with pulled hairs “popping” out of the skin are likely associated with hair pulling, and may be important. Furthermore, skin picking largely involves perturbing the outer layers of the dermas and exposing nerve endings, eliciting both primary and secondary pain. Thus, pain may play an important role in skin picking, and the current study did not investigate pain-related phenomena. The current study also did not investigate sensory processing in other domains, such as hearing and olfaction. If persons with BFRBs showed generalized sensory processing abnormalities across sensory modalities, this would indicate that the origin of such abnormalities occurs in central sensory processing neural areas. Future research should incorporate a wider range of sensory tasks in order to identify which specific deficits exist, which could lead to targeted neurophysiological investigations.

Regarding urges to pull or pick, results of the current study suggest that individuals with TTM and ExD experience tactile hypersensitivity, over-inclusion by sensory stimuli, and discomfort in their own bodies. However, while these results would seem to provide support for the notion that BFRB symptoms are driven largely by aversive sensory experiences, such as urges, evidence indicates many individuals with BFRBs do not report such experiences (Christenson & Mansueto, 1999; Conelea, Walther, & Flessner, 2012; du Toit, van Kradenburg, Niehaus, & Stein, 2001; Houghton et al., 2015; Lochner, Seedat, & Stein, 2010; Woods et al., 2006). It is possible that there is a subtype of persons with BFRBs who demonstrate altered sensory processing and pull/pick primarily to reduce somatosensory discomfort, whereas another group of persons with BFRBs possess normal perceptual abilities and perform symptoms for other reasons. Another possibility is that BFRBs are universally associated with abnormal sensory experiences, yet affected individuals become accustomed to sensory discomfort and fail to notice that specific sensory experiences elicit pulling/picking. Stated another way, perhaps affected individuals live in a state of perpetual sensory over-inclusion, and thus are less apt to notice when specific instances of sensory over-inclusion elicit symptoms. In order to investigate these possibilities, larger sample sizes need to be collected, and cluster analyses could be used to determine whether sensory processing dysfunction clusters with BFRB diagnosis or is only present in some persons with BFRBs.

Regarding the specificity of sensory processing dysfunction to BFRBs, it appears that deficits in sensory gating and low detection thresholds are present in several other

psychiatric and neurological conditions. Indeed, deficits in sensory gating have been documented in not only in Tourette's Disorder and OCD but also Schizophrenia, Huntington's disease, nocturnal enuresis, Autism Spectrum Disorder, 22q11 syndrome, Klinefelter syndrome, fragile-X syndrome, and blepharospasm (Swerdlow, Braff, & Geyer, 2016). As such, researchers have speculated that sensory gating is most broadly regulated by descending forebrain circuitry, disturbances of which are present in various psychiatric disorders (Swerdlow & Koob, 1987). This would mean that multiple psychopharmacological and neurophysiological abnormalities may create various neuronal "gating" deficits that result in a somewhat diverse spectrum of phenotypes (Swerdlow et al., 2016). Future research should seek to elucidate the risk factors that lead to deficits in sensory gating, the exact neurophysiological mechanisms related to how such deficits produce perceptual phenomena, and how these factors initiate and maintain specific symptoms or related types of symptoms, such as compulsive and repetitive behavior. Thus far these processes have only been theoretically linked, but a comprehensive account would provide insight into the causal mechanisms of repetitive behaviors and possibly lead to more effective interventions.

A potentially fruitful avenue of future research would be to longitudinally track sensory gating in developing children and investigate the association between delayed sensory gating and the development of psychopathology. The current study focused on adults with BFRBs in order to minimize the effects of developmental differences during childhood. A logical future direction would be to investigate whether children

with BFRBs demonstrate the same deficits. If so, research should focus on whether the onset of sensory processing abnormalities precedes the onset of symptoms.

4.3.2 Treatment

The results of the current study offer several implications for treatment, such that interventions may be enhanced by addressing sensory processing abnormalities. As previously mentioned, existing treatments that pay limited attention to sensory aspects of BFRBs possess evidentiary support but lack powerful effect sizes (Falkenstein et al., 2015; Keuthen et al., 2012; Woods, Wetterneck, & Flessner, 2006). There is a promising new behavioral treatment for BFRBs that targets heightened sensorimotor activation. Termed cognitive psychophysiological treatment (CPT; O'Connor, 2002). The premise of CPT is that individuals with BFRBs have an over-active and over-prepared style of planning and action, which leads to tension and a desire to relieve tension through sensorimotor means. Thus, CPT involves helping patients reduce elevated sensorimotor activation and frustration. A recent uncontrolled trial of CPT in adults showed a significant improvement in hair pulling symptoms, and 74% of patients showed clinically significant improvement (O'Connor, Lavoie, Desaulniers, & Audet, 2017). CPT appears to be a promising treatment for BFRBs, but future trials should test this treatment in children and in comparison to an active control condition.

In addition to CPT, perhaps interventions that have been used for sensory-related issues in other conditions could be applied to BFRBs. For instance, Autism Spectrum Disorder is associated with heightened perceptual sensitivity (Leekham, Nieto, Libby, Wing, & Gould, 2007), which has been addressed behaviorally with an occupational therapy treatment known as sensory integration therapy. However, a recent systematic

review found that most studies on sensory integration therapy produced null results, and many had serious methodological flaws (Lang et al., 2012). A different potential treatment avenue may be to apply behavioral treatments that have been successful for conditions associated with sensory intolerance, such as misophonia (or selective sound sensitivity syndrome). Several case series and an uncontrolled trial have found that a cognitive-behavioral intervention shows preliminary efficacy for treating misophonia (Bernstein, Angell, & Dehle, 2013; Dozier, 2015a, b; Johnson et al., 2013; McGuire, Wu, & Storch, 2015; Webber, Johnson, & Storch, 2014). The key component of CBT for misophonia appears to be counterconditioning, a procedure in which the aversive stimulus (i.e., high-pitched noises) is paired with a soothing stimulus (i.e., harp music) in order to decrease the aversive salience of the aversive stimulus. Perhaps such procedures could be applied to BFRBs by deliberately inducing aversive sensory states, such as is done with interoceptive exposure for panic (Lee et al., 2006) and exposure and response prevention in OCD (Foa, Yadin, & Lichner, 2012), and teaching patients how to self-soothe and use various coping mechanisms.

Other than behavioral treatments, perhaps pharmacological approaches could be used to address sensory abnormalities in BFRBs. However, the existing evidence for medications that address sensory hypersensitivities and sensory gating abnormalities points to options which have costs that may outweigh potential benefits. For instance, ketamine has been shown to alter central sensitization that occurs post-operatively (Stubhaug, Breivik, Eide, Kreunen, & Foss, 1997), but ketamine is an extremely powerful sedative with hallucinogenic properties. Sensory gating deficits in

schizophrenia have been shown to respond to nicotine administration (Adler et al., 1998; Adler, Hoffer, Griffith, Waldo, & Freedman, 1992; Adler, Hoffer, Wiser, & Freedman, 1993), and there is some evidence suggesting that second-generation anti-psychotics improve auditory sensory gating (Potter, Summerfeldt, Gold, & Buchanan, 2006). However, the negative health effects of nicotine and potential for adverse side-effects in anti-psychotics make these options unsuitable for BFRBs. More research is needed on addressing abnormal sensation and sensory gating in psychiatric disorders via pharmacotherapy, but experts suggest that future research investigate noradrenaline reuptake inhibitor drugs and methods of decreasing brain-derived neurotrophic factor (Nijs, Malfliet, Ickmans, Baert, & Meeus, 2014).

4.4 Conclusions

This is the first study, to my knowledge, that has found evidence of objective sensory abnormalities in BFRBs. Thus, the role of sensory features in BFRBs should no longer be ignored but rather integrated with parallel lines of research on affect regulation and cognitive factors. Furthermore, the next generation of treatments for BFRBs should include techniques that address heightened sensation and deficient sensory inhibition in BFRBs. It may be that, if effective, these techniques would not only lead to decreased symptoms but also increased quality of life and perceptual comfort.

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APPENDIX A

Research participants sought for study on body-focused habits and sensation.

The Department of Psychology at Texas A&M University is conducting a study that aims to better understand how people with body-focused habits perceive sensory information in the brain. Adults between the ages of 18-65 can participate in the current study. We are looking for the following types of individuals:

- (a) Those with body-focused repetitive behaviors (BFRBs) including hair pulling and skin picking.
- (b) The hair pulling or skin picking must be frequent enough to cause hair loss or skin lesions.

Participating in this study requires that you complete one visit to the psychology department on campus for about 45 minutes to 1 hour. During this visit, you will learn more about the study, fill out several questionnaires and complete interviews about common psychiatric concerns, and complete a vibrotactile behavioral battery. The vibrotactile behavioral battery tells us how your brain processes sensory information. It is painless and has games that involve a laptop computer. Once you have completed the study, you will be compensated \$15 for your time and effort.

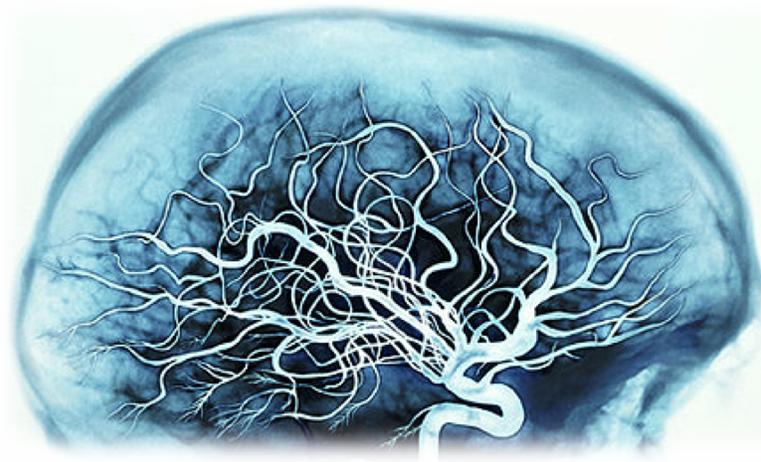
If you're interested in this study and think you might be eligible, contact David Houghton at 281-797-2130 or davidhoughton@tamu.edu.

Thank you,

David C. Houghton, M.S.
Psychology Department, Milner Hall, Room 002
davidhoughton@tamu.edu
(281)797-2130

APPENDIX B

Research Participants With Body-Focused Repetitive Behaviors Wanted



In collaboration with Texas A&M University, we are looking for 50 adults to participate in a research study on how body-focused habits might be related to sensory processing abnormalities.

Do you have Trichotillomania or Excoriation Disorder?

Are you between the ages of 18-69?

Interested in making \$15?

For more information, talk to your therapist or the front desk, or contact David Houghton at (281)797-2130 or davidhoughton@tamu.edu

APPENDIX C

Research participants sought for study on sensation and perception.

The Department of Psychology at Texas A&M University is conducting a study that aims to better understand how people with habits perceive sensory information in the brain. We are looking for generally healthy people who do not have any psychiatric conditions, particularly hair pulling and skin picking.

Participating in this study requires that you complete one visit to the psychology department on campus for about 45 minutes to 1 hour. During this visit, you will learn more about the study, fill out several questionnaires and complete interviews about common psychiatric concerns, and complete a vibrotactile behavioral battery. The vibrotactile behavioral battery tells us how your brain processes sensory information. It is painless and has games that involve a laptop computer. Once you have completed the study, you will be compensated \$15 for your time and effort.

If you're interested in this study and think you might be eligible, contact David Houghton at davidhoughton@tamu.edu.

Thank you,

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IRB Number: IRB2016-0607D; Approval Date: 10/11/2016;
Expiration Date: 10/01/2017

APPENDIX D

Habit Disorders Interview – Trichotillomania

0 = inadequate information 1 = absent 2 = subthreshold 3 = threshold/true

Questions

Criteria

Score

<p>1a. Do you currently pull out hair from anywhere on your body?</p>	<p align="center">Yes</p>	<p align="center">No</p>
<p>1b. Where do you pull hair from?</p>	<p align="center">Scalp Eyelashes Eyebrows Pubic hair Mustache Other</p>	<p align="center">Beard Trunk Armpits Arms Legs</p>
<p>1c. Do you have hair loss in the areas that you pull?</p>	<p>A. Recurrent pulling out of one's hair, resulting in hair loss.</p>	<p align="center">0 1 2 3</p>

2. Have you tried to stop pulling out your hair?	B. Repeated attempts to decrease or stop hair pulling.	0 1 2 3
3. Does the pulling bother you a lot? Does the pulling get in the way of your life?	C. The hair pulling causes clinically significant distress or impairment in social, occupational, or other important areas of functioning.	0 1 2 3
4. Do you have any skin rash, eczema, or other skin condition that may explain	D. The hair pulling or hair loss is not attributable to another medical condition	0 1 2 3

the hair loss?	(e.g., a dermatological condition).	
5. Why do you pull out your hair? Are you trying to “fix” your appearance?	E. The hair pulling is not better explained by the symptoms of another mental disorder (e.g., attempts to improve a perceived defect or flaw in appearance in body dysmorphic disorder).	0 1 2 3

DIAGNOSIS (Circle One)

No Trichotillomania

Subclinical Trichotillomania

Clinical Trichotillomania

Notes:

Habit Disorders Interview – Skin Picking

0 = inadequate information 1 = absent 2 = subthreshold 3 = threshold/true

Questions	Criteria	Score
1a. Do you currently pick or scratch at your skin?	Yes	No
1b. What areas of your body do you pick skin from?	Face Arms Shoulders Back Chest Other	Fingers Legs Toes Stomach
1c. Do you have damage to the skin in the areas you pick?	A. Recurrent skin picking resulting in skin lesions.	0 1 2 3

<p>2. Have you tried to stop picking your skin?</p>	<p>B. Repeated attempts to decrease or stop skin picking.</p>	<p>0 1 2 3</p>
<p>3. Does the picking bother you a lot? Does the picking get in the way of your life?</p>	<p>C. The skin picking causes clinically significant distress or impairment in social, occupational, or other important areas of functioning.</p>	<p>0 1 2 3</p>
<p>4. Do you have any, eczema, skin rash, or other skin condition that may explain picking?</p>	<p>D. The skin picking is not attributable to the physiological effects of a substance (e.g., cocaine) or another medical condition (e.g., scabies).</p>	<p>0 1 2 3</p>

<p>5. Why do you pick your skin? Are you trying to “fix” your appearance? Do you see things that aren’t there? Are you attempting to harm yourself?</p>	<p>E. The skin picking is not better explained by symptoms of another mental disorder (e.g., delusions or tactile hallucinations in a psychotic disorder, attempts to improve a perceived defect or flaw in appearance in body dysmorphic disorder, stereotypies in stereotypic movement disorder, or intention to harm oneself in nonsuicidal self-injury).</p>	<p>0 1 2 3</p>

DIAGNOSIS (Circle One)

No Skin Picking

Subclinical Skin Picking

Clinical Skin Picking

Notes:

APPENDIX E

MGH Hairpulling Scale

Instructions: For each question, pick the one statement in that group which best describes your behaviors and/or feelings over the past week. If you have been having ups and downs, try to estimate an average for the past week. Be sure to read all of the statements in each group before making your choice.

For the next three questions, rate only the urges to pull your hair.

1. Frequency of urges. On an average day, how often did you feel the urge to pull your hair?
 - 0 This week I felt no urges to pull my hair.
 - 1 This week I felt an occasional urge to pull my hair.
 - 2 This week I felt an urge to pull my hair often.
 - 3 This week I felt an urge to pull my hair very often.
 - 4 This week I felt near constant urges to pull my hair.
2. Intensity of urges. ON an average day, how intense or 'strong' were the urges to pull your hair?
 - 0 This week I did not feel any urges to pull my hair
 - 1 This week I felt mild urges to pull my hair
 - 2 This week I felt moderate urges to pull my hair
 - 3 This week I felt severe urges to pull my hair.
 - 4 This week I felt extreme urges to pull my hair.
3. Ability to control the urges. On an average day, how much control do you have over the urges to pull your hair?
 - 0 This week I could always control the urges, or I did not feel urges to pull my hair.
 - 1 This week I was able to distract myself from the urges to pull my hair most of the time.
 - 2 This week I was able to distract myself from the urges to pull my hair some of the time.
 - 3 This week I was able to distract myself from the urges to pull my hair rarely.
 - 4 This week I was never able to distract myself from the urges to pull my hair.

For the next three questions, rate only the actual hairpulling

4. Frequency of hairpulling. On an average day, how often did you actually pull your hair?

- 0 This week I did not pull my hair.
- 1 This week I pulled my hair occasionally.
- 2 This week I pulled my hair often.
- 3 This week I pulled my hair very often.
- 4 This week I pulled my hair so often it felt like I was always doing it.

5. Attempts to resist hairpulling. On an average day, how often did you make an attempt to stop yourself from actually pulling your hair?

- 0 This week I felt no urges to pull my hair.
- 1 This week I tried to resist the urge to pull my hair almost all of the time.
- 2 This week I tried to resist the urge to pull my hair some of the time.
- 3 This week I tried to resist the urge to pull my hair rarely.
- 4 This week I never tried to resist the urge to pull my hair.

6. Control over hairpulling. On an average day, how often were you successful at actually stopping yourself from pulling your hair?

- 0 This week I did not pull my hair.
- 1 This week I was able to resist pulling my hair almost all of the time
- 2 This week I was able to resist pulling my hair most of the time.
- 3 This week I was able to resist pulling my hair some of the time.
- 4 This week I was rarely able to resist pulling my hair.

For the last question, rate the consequences of your hairpulling.

7. Associated distress. Hairpulling can make some people feel moody, 'on edge', or sad. During the past week, how uncomfortable did your hairpulling make you feel?

- 0 This week I did not feel uncomfortable about my hairpulling.
- 1 This week I felt vaguely uncomfortable about my hairpulling.
- 2 This week I felt noticeably uncomfortable about my hairpulling.
- 3 This week I felt significantly uncomfortable about my hairpulling.
- 4 This week I felt intensely uncomfortable about my hairpulling.

APPENDIX F

SPSS

For each item, pick the one answer which best describes the past week. If you have been having ups and downs, try to estimate an average for the past week. Please be sure to read all answer choices in each group before making circling your answer.

1. How often do you feel the urge to pick your skin?

- 0 No urges
- 1 Mild, occasionally experience urges to skin pick, less than 1hr/day
- 2 Moderate, often experience urges to skin picking, 1-3 hrs/day
- 3 Severe, very often experience urges to skin pick, greater than 3 and up to 8 hrs/day
- 4 Extreme, constantly or almost always have an urge to skin pick

2. How intense or “strong” are the urges to pick your skin?

- 0 Minimal or none
- 1 Mild
- 2 Moderate
- 3 Severe
- 4 Extreme

3. How much time do you spend picking your skin? How frequently does it occur? How much longer than most people does it take you to complete routine activities because of your picking?

- 0 None
- 1 Mild, spend less than 1 hr/day picking my skin, or occasional skin picking
- 2 Moderate, spend 1-3 hrs/day picking my skin, or frequent skin picking
- 3 Severe, spend more than 3 and up to 8 hrs/day picking my skin, or very frequent skin picking
- 4 Extreme, spend more than 8 hrs/day picking my skin, or near constant skin picking

4. How much does your skin picking interfere with your social or work (or role) functioning? (If currently not working determine how much your performance would be affected if you were employed.)

- 0 None
- 1 Mild, slight interference with social or occupational
- 2 Moderate, definite interference with social or occupational performance, but still manageable
- 3 Severe, causes substantial impairment in social or occupational performance
- 4 Extreme, incapacitating

5. How much distress do you experience as a result of your skin picking? How would you feel if prevented from picking your skin? How anxious would you become?

- 0 None
- 1 Mild, only slightly anxious if skin picking prevented, or only slight anxiety during skin picking
- 2 Moderate, anxiety would mount but remain manageable if skin picking prevented, or anxiety increases to manageable levels during skin picking
- 3 Severe, prominent and very disturbing increase in anxiety if skin picking is interrupted, or prominent and very disturbing increase in anxiety during skin picking
- 4 Extreme, incapacitating anxiety from any intervention aimed at modifying activity, or incapacitating anxiety develops during skin picking

6. Have you been avoiding doing anything, going any place, or being with anyone because of your skin picking? If yes, then how much do you avoid?

- 0 None
- 1 Mild, occasional avoidance in social or work settings
- 2 Moderate, frequent avoidance in social or work settings
- 3 Severe, very frequent avoidance in social or work settings
- 4 Extreme, avoid all social and work settings as a result of the skin picking

14. I pull my hair to get rid of an unpleasant urge, feeling, or thought. _____

15. I pull my hair to control how I feel. _____

APPENDIX I

Sensory Gating Inventory

Below you will find a list of statements. Please indicate how true or untrue each statement is for you by selecting one answer on each line.

Circle one number on each line

	Never True	Mostly Not True	Somewhat Not True	Somewhat True	Mostly True	Always True
My hearing is so sensitive that ordinary sounds become uncomfortable.	1	2	3	4	5	6
There have been times when it seems that sights and sounds are coming in too fast.	1	2	3	4	5	6
For several days at a time I have such heightened awareness of sights and sounds that I cannot shut them out.	1	2	3	4	5	6
Every now and then colors seem more vivid to me than usual.	1	2	3	4	5	6
At times I have feelings of being flooded by sounds.	1	2	3	4	5	6
Sometimes it seems like someone has turned the volume up—things seem really loud.	1	2	3	4	5	6
I have feelings of being flooded by visual experiences, sights, or colors.	1	2	3	4	5	6
It seems like I take in too much.	1	2	3	4	5	6

Sometimes I find it difficult to focus on one visual site to the exclusion of others.	1	2	3	4	5	6
I hear sounds but I can't make sense of them all because it's like trying to do 2 or 3 things at once.	1	2	3	4	5	6
It's not bad when just one person is speaking but if others join in, then I can't pick it up at all. I just can't get in tune with that conversation.	1	2	3	4	5	6
Sometimes I notice background noises more than usual.	1	2	3	4	5	6
Background noises are just as loud or louder than the main noises.	1	2	3	4	5	6
I can't focus on one sound or voice to the exclusion of others.	1	2	3	4	5	6
It seems like I hear everything at once.	1	2	3	4	5	6
There are days when indoor lights seem so bright that they bother my eyes.	1	2	3	4	5	6
At times I have trouble focusing because I am easily distracted.	1	2	3	4	5	6
I am easily distracted.	1	2	3	4	5	6
I have more trouble concentrating than others seem to have.	1	2	3	4	5	6

I find it hard to concentrate on just one thing.	1	2	3	4	5	6
It is hard to keep my mind on one thing when there's so much else going on.	1	2	3	4	5	6
There are times when I can't concentrate with even the slightest sounds going on.	1	2	3	4	5	6
I find it difficult to shut out background noise and that makes it difficult for me to concentrate.	1	2	3	4	5	6
When I am in a group of people I have trouble listening to one person.	1	2	3	4	5	6
Not only the color of things fascinates me but all sorts of little things, like markings in the surface, attract my attention too.	1	2	3	4	5	6
I notice background noises more than other people.	1	2	3	4	5	6
Everything grips my attention even though I am not particularly interested in any of it.	1	2	3	4	5	6
The silliest little things that are going on interest me.	1	2	3	4	5	6
Maybe it's because I notice so much more about things that I find myself looking at them for a longer time.	1	2	3	4	5	6
I seem to hear the smallest details of sounds.	1	2	3	4	5	6

I seem to always notice when automatic appliances turn on and off (like the refrigerator or the heating and cooling system).	1	2	3	4	5	6
When I'm tired sounds seem amplified.	1	2	3	4	5	6
It seems that sounds are more intense when I'm stressed.	1	2	3	4	5	6
When I'm tired, the brightness of lights bothers me.	1	2	3	4	5	6
I cannot focus on visual images when I am tired or stressed.	1	2	3	4	5	6
When I am driving at night, I am bothered by the bright lights on oncoming traffic.	1	2	3	4	5	6

APPENDIX J

Multidimensional Assessment of Interoceptive Awareness

Below you will find a list of statements. Please indicate how often each statement applies to you generally in everyday life.

	Circle one number on each line					
	Never			Always		
When I am tense, I notice where the tension is located in my body	0	1	2	3	4	5
I notice when I am uncomfortable in my body	0	1	2	3	4	5
I notice where in my body I am comfortable	0	1	2	3	4	5
I notice changes in my breathing, such as whether it slows down or speeds up	0	1	2	3	4	5
I do not notice physical tension or discomfort until they become more severe	0	1	2	3	4	5
I distract myself from sensations of discomfort	0	1	2	3	4	5
When I feel pain or discomfort, I try to power through it	0	1	2	3	4	5
When I feel physical pain, I become upset	0	1	2	3	4	5
I start to worry that something is wrong if I feel any discomfort	0	1	2	3	4	5
I can notice an unpleasant body sensation without worrying about it	0	1	2	3	4	5
I can pay attention to my breath without being distracted by things happening around me	0	1	2	3	4	5
I can maintain awareness of my inner bodily sensations even when there is a lot going on around me	0	1	2	3	4	5
When I am in conversation with someone, I can pay attention to my posture	0	1	2	3	4	5
I can return awareness to my body if I am distracted	0	1	2	3	4	5
I can refocus my attention from thinking to sensing my body	0	1	2	3	4	5

I can maintain awareness of my whole body even when a part of me is in pain or discomfort	0	1	2	3	4	5
I am able to consciously focus on my body as a whole	0	1	2	3	4	5
I notice how my body changes when I am angry	0	1	2	3	4	5
When something is wrong in my life I can feel it in my body	0	1	2	3	4	5
I notice that my body feels different after a peaceful experience	0	1	2	3	4	5
I notice that my breathing becomes free and easy when I feel comfortable	0	1	2	3	4	5
I notice how my body changes when I feel happy/joyful	0	1	2	3	4	5
When I feel overwhelmed I can find a calm place inside	0	1	2	3	4	5
When I bring awareness to my body I feel a sense of calm	0	1	2	3	4	5
I can use my breath to reduce tension	0	1	2	3	4	5
When I am caught up in thoughts, I can calm my mind by focusing on my body/breathing	0	1	2	3	4	5
I listen for information from my body about my emotional state	0	1	2	3	4	5
When I am upset, I take time to explore how my body feels	0	1	2	3	4	5
I listen to my body to inform me about what to do	0	1	2	3	4	5
I am at home in my body	0	1	2	3	4	5
I feel my body is a safe place	0	1	2	3	4	5
I trust in my body sensations	0	1	2	3	4	5