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Discarding personal possessions increases psychophysiological activation in patients with hoarding disorder

Hannah C. Levy[a,*], Alyssa Nett[a,b], David F. Tolin[a,c]

[a] Anxiety Disorders Center, Institute of Living, Hartford, CT, USA
[b] University of Hartford, Hartford, CT, USA
[c] Yale University School of Medicine, New Haven, CT, USA

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ABSTRACT

Difficulty discarding is the core behavioral symptom of hoarding disorder (HD). Patients with HD report greater subjective distress when discarding their own possessions as compared to others' possessions. To date, no prior studies have examined psychophysiological activation, an objective measure of anxious arousal, during discarding among individuals with HD. The current study assessed psychophysiological responses during a baseline resting period and two discarding tasks, one involving personal possessions and the other involving matched control ("experimenter-owned") items in 52 patients with a primary diagnosis of HD. Results showed that, compared to discarding control items, discarding personal possessions increased skin conductance and heart rate and decreased end tidal carbon dioxide. There were no differences in heart rate variability, respiratory sinus arrhythmia, and respiration rate between the two discarding tasks. Despite the fact that discarding increased psychophysiological arousal, self-reported HD symptoms (including difficulty discarding) failed to predict psychophysiological responses during the discarding tasks. The findings suggest that there may be discordance between objective and subjective measures of hoarding-related distress, and are discussed in terms of incorporating psychophysiological measures into the assessment and treatment of HD.

1. Introduction

Hoarding disorder (HD) is characterized by difficulty discarding personal possessions, regardless of their value, which results in excessive clutter in the home (American Psychiatric Association, 2013). Most individuals with HD also engage in excessive acquiring (Frost et al., 2009), although this symptom is not required for the HD diagnosis. HD is a severe and debilitating problem. Individuals with HD report greater psychiatric work impairment than do those with major depression, anxiety disorders, and substance use disorders, and comparable work impairment to patients with severe mental illnesses (e.g., bipolar disorder; Tolin et al., 2008). Current cognitive-behavioral treatments are only modestly effective for HD, and most patients continue to have significant hoarding symptoms after treatment (Tolin et al., 2015). Further research into the mechanisms of HD is needed in order to inform the development of more effective treatments.

Difficulty discarding is the core behavioral symptom of HD. When discarding personal possessions, HD patients take longer to make discarding decisions, report greater distress when discarding, and show greater activation of brain regions implicated in decision-making than when discarding others' possessions (Tolin et al., 2009, 2012). Not surprisingly, patients with HD save more items when sorting and discarding than do healthy control participants without psychiatric disorders and patients with obsessive-compulsive disorder (Tolin et al., 2012). Recent research has implicated deficits in emotion regulation (ER) as a potential mechanism of difficulty discarding in hoarding. Broadly speaking, ER refers to the ability to manage emotional experiences effectively. In the case of HD, deficient ER skills may involve engaging in unhelpful or maladaptive behaviors, such as excessive acquiring and saving, in order to regulate negative emotional states. Prior studies have found lower self-reported ER skills in patients with HD compared to healthy controls (Fernandez de la Cruz et al. 2013; Tolin et al., 2018), even when controlling for depression and anxiety symptoms (Tolin et al., 2018). Individuals with hoarding symptoms self-report heightened emotional reactivity both generally and in response to imagined discarding (Shaw et al., 2015), so they may be vulnerable to intense emotional experiences at baseline that may overwhelm their coping resources during stressful situations like discarding.

It is unclear how emotional distress and associated physiological activation may be contributing to or even causing difficulty discarding

* Corresponding author at: Anxiety Disorders Center, Institute of Living, 200 Retreat Avenue, Stearns Building, Hartford, CT 06106, United States.
E-mail address: hannah.levy@hhchealth.org (H.C. Levy).

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among patients with HD. Based on the extant literature, patients with HD may be particularly vulnerable to intense negative emotions that may make it challenging to engage in effective decision-making when discarding. Further, the existing literature supports a strong link between psychophysiological responses and ER skills. In nonclinical samples, it has been shown that lower heart rate variability (which indicates poorer cardiac health) is associated with greater self-reported ER difficulties in undergraduate students (Williams et al., 2015). Among clinical samples, prior research suggests that patients with borderline personality disorder exhibit lower respiratory sinus arrhythmia (which also indicates poorer cardiac health) and higher heart rate than healthy control participants, particularly when watching emotional film clips (Austin et al., 2007). Patients with generalized anxiety disorder (Thayer et al., 1996) and major depressive disorder (Udupa et al., 2007), who tend to engage in unhelpful ER strategies such as worry and rumination, also show reduced heart rate variability compared to nonanxious controls. Given that anxiety and depression are commonly comorbid with HD (Frost et al., 2011), there is good reason to suspect that patients with HD may show abnormal psychophysiological responses, as has been shown in other disorders that are characterized by ER difficulties. In the only psychophysiological investigation of HD to date, Zakrzewski et al. (2018) found that patients with HD showed lower skin conductance responses during error commission on a standard (emotionally neutral) error task than healthy control participants. These results provide preliminary support for psychophysiological activation abnormalities in HD patients, although the degree to which these abnormalities are present during emotional tasks like discarding remains unknown.

To our knowledge, no prior studies have examined psychophysiological responses in patients with HD during discarding. By determining the physiological correlates of excessive saving behavior, we may better understand the decision-making process and be better able to address these difficulties in treatment. Psychophysiological measures have the added advantage of assessing objective emotional arousal, which may overcome some of the inherent limitations of self-report questionnaires.

The present study examined psychophysiological responses in a sample of 52 patients with a primary diagnosis of HD. Psychophysiological measures were recorded throughout four study phases, which included a baseline resting period, a discarding task with personal possessions, a second discarding task with matched control ("experimenter-owned") items, and a final recovery period. We predicted that psychophysiological activation would be greater in the discarding tasks as compared to the resting periods. We further predicted that the personal possessions task would result in greater psychophysiological activation than the control task. We also predicted that self-reported HD severity would predict changes in psychophysiological activation over the course of the study.

2. Method

2.1. Participants

Fifty-three adult patients with a primary diagnosis of HD were recruited from a research registry of patients who had previously consented to being contacted about research opportunities, and through the regular patient flow of a large outpatient clinic. Participants were also recruited from an ongoing waitlist-controlled trial of group cognitive-behavioral therapy (CBT) for HD, which examined the neural mechanisms of CBT response in HD. Because this trial used functional magnetic resonance imaging, participants had to be free of non-removable metal in the body and have no history of claustrophobia or substance use disorders; be off psychiatric medications or remain stable on current medications for at least eight weeks prior to participating in the trial; and have no history of neurological disorder or anoxic or traumatic brain injury with loss of consciousness for more than five minutes.

To be eligible for the current study, patients had to have a primary diagnosis of HD of at least moderate severity (determined by the *Clinical Global Impression* scale, see below). If patients had previously received CBT through the clinical trial or the outpatient clinic, they had to have at least moderate HD severity after treatment to be eligible for the study. Exclusion criteria were past or present bipolar or psychotic disorder and evidence of mental retardation, dementia, brain damage or other cognitive dysfunction that would interfere with the capacity to provide informed consent. One participant who completed the study was excluded from the analyses due to noncompliance with the discarding tasks.

Participants were not asked to refrain from medications (benzodiazepines, stimulants, and beta blockers) or substances (caffeine and nicotine) known to affect psychophysiological arousal. However, they were asked to indicate whether they used any of these medications or substances on the day of the study. Five patients endorsed stimulant use, six patients endorsed beta blocker use, and seven patients reported benzodiazepine use. Twenty-nine patients reported caffeine use, and only one patient endorsed nicotine use.

2.2. Measures

2.2.1. Diagnostic assessment

HD and comorbid disorders were assessed using the *Diagnostic Interview for Anxiety, Mood, and Obsessive-Compulsive Neuropsychiatric Disorders* (DIAMOND; Tolin et al., 2018), a structured diagnostic interview based on the DSM-5 that has demonstrated good reliability and validity estimates for anxiety, obsessive-compulsive, and depressive disorders (Tolin et al., 2018). For patients recruited from the research registry and the outpatient clinic, the *Clinical Global Impression* (CGI) scale (Guy, 1976) was used to determine overall symptom severity. For participants recruited from the clinical trial, a modified version of the CGI (the CGI-HD; Tolin et al., 2018) was used to determine overall HD symptom severity on six dimensions, including clutter, difficulty discarding, acquiring, health or safety hazard, functional impairment, and distress. Whichever dimensions yields the highest severity rating becomes the CGI-HD score (e.g., if clutter receives a rating of "severe" and all remaining domains receive lower severity ratings, the CGI-HD score will be "severe"). Interviewers were doctoral students or postdoctoral fellows that were supervised by licensed psychologists or licensed psychologists. All interviewers received extensive training in administration of the DIAMOND according to a standardized training protocol, which involved watching training videos, observing live interviews, and being observed while administering interviews. Interviewers were also trained in the CGI and CGI-HD. We did not explicitly assess interrater reliability for the current study, although the DIAMOND (Tolin et al., 2018) and CGI-HD (Tolin et al., 2018) have demonstrated adequate reliability in prior validation studies.

2.2.2. Self-report measures

Self-reported HD symptoms were assessed using the *Saving Inventory-Revised* (SI-R; Frost et al., 2004), a 23-item measure that assesses the core symptoms of HD (acquiring, difficulty discarding, and clutter). The SI-R contains three subscales for the three core symptoms, which are then summed to compute a total score. Items are rated on a 5-point Likert scale (0 = *none* and 4 = *almost all/complete*) with higher scores indicating greater hoarding severity. The SI-R has demonstrated adequate reliability as well as strong convergent and discriminant validity (Frost et al., 2004), and it showed adequate to excellent internal consistency in the current sample (SI-R total score, $\alpha = 0.95$; acquiring subscale, $\alpha = 0.84$; difficulty discarding subscale, $\alpha = 0.88$; clutter subscale, $\alpha = 0.95$). Participants were asked to verbally rate their subjective distress using the *Subjective Units of Distress Scale* (SUDS), which was worded as follows: "On a scale from 0 to 100 if 0 is neutral and 100 is the worst distress you can imagine, how anxious do you feel right now?" Participants verbally rated their sadness using a similar scale, which was worded as follows: "On a scale from 0 to 100 if 0 is neutral and 100 is the worst sadness you can imagine, how sad do you feel right now?" Participants provided these ratings before and after the resting periods and discarding tasks.

2.2.3. Psychophysiological measures

All measures were collected using the BIOPAC MP150 system (BIOPAC Systems, Inc., Goleta, CA), a widely used and well validated tool in psychophysiological research. The system includes AcqKnowledge software version 5 (BIOPAC Systems, Inc., Goleta, CA), which was used for transforming, filtering, and analyzing data.

2.2.3.1. Cardiac variables. Heart rate variability (HRV) reflects variation in the time interval between heartbeats, and is measured by the variation in the beat-to-beat interval. Lower HRV indicates poorer cardiac flexibility and overall cardiac health. We collected HRV data via electrocardiogram (ECG) leads attached to the center of the wrists and left ankle. We used the Root Mean Square of the Successive Differences (RMSSD) as the measure of HRV, which reflects the successive differences of time intervals between heart beats. We also collected heart rate (HR) data using the same ECG leads. Higher HR indicates greater psychophysiological arousal. Respiratory sinus arrhythmia (RSA) refers to the rhythmic variations in HR that occur during breathing, characterized by increased HR during inhalation and decreased HR during exhalation. Like HRV, lower RSA indicates poorer cardiac health. We also collected respiration rate (RR) data; higher RR is suggestive of greater arousal. Both the RSA and RR data were obtained via the same ECG leads attached to the wrists and ankle.

2.2.3.2. Skin conductance variables. Electrodermal activity (EDA) refers to perspiration-related variation in the electrical characteristics of the skin. We recorded skin conductance level (SCL) with a constant voltage of 0.5 V across two electrodes placed on the first and second fingers of the right hand. We also recorded the number of skin conductance responses (SCRs) per minute, which reflect the number of peaks in the SCL signal. Higher SCL and number of SCRs indicate greater psychophysiological arousal.

2.2.3.3. End tidal CO_2 ($ETCO_2$). $ETCO_2$ reflects the concentration of carbon dioxide at the end of an exhaled breath. If $ETCO_2$ levels are low, this indicates potential hyperventilation because the body's store of carbon dioxide becomes depleted when hyperventilating. $ETCO_2$ was collected via nasal cannula. We used a statistical transformation to compute mmHg from the breath-by-breath measurements of percent $ETCO_2$.

2.2.3.4. Quality control. Participants were required to rinse their hands prior to attaching the EDA sensors. No additional cleaning or abrasion was needed using these sensors. In line with best-practice guidelines for EDA measurement (Fowles et al., 1981), we attached the EDA sensors a minimum of five minutes in advance of the baseline resting period to ensure accurate readings. After attaching the sensors, we asked participants to hold their breath for a few seconds and visually inspected the EDA signal to verify that the signal responded to the breath-holding (EDA waveforms typically increase during breath-holding). The ECG sensors did not require any additional cleaning or abrasion. These sensors are single-use and come pre-gelled with a liquid electrolyte gel. Prior to beginning the study protocol, we visually inspected the ECG signal for QRS peaks to verify that the sensors were recording properly.

Participants were instructed to remain still throughout the study protocol. They were instructed to keep their feet flat on the floor, with their knees at a 90-degree angle. They were asked to keep their arms and hands still, resting on the arms of the chair in the testing room. Participants were closely observed by a research assistant throughout the study. Any movements were recorded on a testing form, along with the timing in which they occurred. If there were spontaneous movements recorded on the testing form that then produced artifacts in the ECG signal, the phase in which the movement occurred was excluded from the analyses (e.g., if the movement occurred 10s into the start of the baseline resting period and lasted for 1 s, that 1–5s of the ECG signal containing the artifact was excluded from the analyses). As an added precaution against movement-related artifacts, the ECG leads on the wrists and ankle were taped down to prevent shifting. To further prevent movement, participants were shown their mail items during the discarding tasks (see below), rather than requiring that they handle the mail items themselves and risk moving the wires. Any missed heart beats in the ECG signal were excluded from the analyses. We recorded the timing of any missed heart beats or other signal artifacts and excluded those timings from the analyses.

We used recommended filtering procedures for the ECG and EDA signals, in consultation with the BIOPAC team. For HRV, we applied a band pass filter (low frequency cutoff = 1 Hz; high frequency cutoff = 35 Hz; QRS peak threshold = 0.5 mV, which was adjusted as needed upon visual inspection of each individual ECG waveform). For RSA, we applied a band pass filter (low frequency cutoff = 0.05 Hz; high frequency cutoff = 1 Hz; respiration peak threshold = 0.00 V). For EDA, we first applied a 0.05 Hz high pass filter and used 0.02 microseimens as the SCR threshold level.

2.3. Discarding task

We used a similar discarding task as in our prior research (Tolin et al., 2009). Participants were asked to bring a large amount of unopened junk mail items (envelopes, magazines, catalogs, etc.) to their study appointment. The experimenter provided similar mail items that were used as control items. The mail items were placed in two separate clear bins labeled "[Participant's name] Mail" and "Experimenter's Mail". Directly next to each bin were two other clear bins that were labeled "[Participant's name] Keep" and "Experimenter's Keep". Prior to the discarding tasks, participants were informed that they were not required to discard any mail, but the purpose of the tasks was to discard as much mail as possible. During the personal mail discarding task, participants were presented with each of their personal mail items and given 8 seconds to make a verbal decision about the item (either "keep" or "discard"). If the decision was "discard", the item was shredded using a paper shredder positioned directly in front of the participants. If the decision was "keep", the item was placed in the "[Participant's name] Keep" bin. After a brief resting period (to minimize carryover effects), participants then completed the control mail discarding task using the same protocol. Both tasks lasted 7 minutes. The order of tasks was counterbalanced, such that an equal number of participants began with the personal mail task as the control mail task.

2.4. Procedure

The study was approved by the local institutional review board. On the day of the study appointment, participants read through and signed the informed consent form. They were seated comfortably in the testing room and fitted to the BIOPAC system. Three ECG leads were placed on the wrists and left ankle. A nasal cannula was placed under the nostrils. EDA fingertip sensors, with gel (BIOPAC GEL101, an isotonic, 0.05 molar NaCl electrode paste), were placed on the first and second fingers of the right hand. Once fitted to the system, participants were given a few minutes to habituate to the laboratory environment and then began the baseline resting period, which lasted 3 minutes. Participants provided distress and sadness ratings before and after the baseline period. They then completed the two discarding tasks and provided distress ratings before and after each task. The final study phase was the recovery resting period, which also lasted 3 minutes. Participants provided distress ratings before and after the recovery period. Following the recovery period, participants were debriefed and compensated $25 for their participation.

2.5. Data analytic plan

Data were first checked for extreme scores (± 3 standard deviations above or below the mean); any extreme scores were changed to the next highest or lowest value that did not exceed ± 3 *SD*. After these corrections, skewness and kurtosis values were in the acceptable range, indicating normal distributions.

First, we tested whether previous treatment and comorbid depression impacted psychophysiological responses using independent samples *t* tests. We also conducted preliminary analyses to determine whether the use of medications or substances impacted psychophysiological responses during the baseline resting period. For these analyses, we used independent samples *t* tests to compare patients who had and had not used these substances on the day of the study. These analyses revealed some group differences, so we controlled for substance use on certain hypothesis tests (see below). We also conducted analyses to examine whether the order of discarding tasks impacted psychophysiological responses; for these analyses, we used 2 (order: control vs. personal mail task first) x 4 (time) mixed analyses of variance (ANOVAs). Second, we used repeated measures ANOVAs or analyses of covariance (ANCOVAs, if controlling for substance use was needed) and partial eta squared effect sizes to examine differences in psychophysiological responses across the four study phases. Third, we conducted pairwise comparisons of specific study phases using paired samples *t* tests or repeated measures ANCOVAs (if controlling for substance use was indicated). Finally, we used Hierarchical Linear and NonLinear Modeling (HLM) to test whether self-reported HD severity predicted slopes of change in psychophysiological responses across time (baseline resting period through final resting recovery period). For these analyses, we conducted a series of two-level regression models, with the psychophysiological responses as the dependent variables. At level 1, we included the change slope, which was centered at time 0 (i.e., the baseline resting period). At level 2, we entered SI-R total or subscale scores (separately). We repeated these analyses with just the two discarding task time points at level 1 which were centered at time 0 (i.e., the control mail task).

3. Results

3.1. Sample characteristics

The sample was 79% female and ranged in age from 34 to 79 ($M = 61.10$, $SD = 9.84$) years old. The majority of the sample had a comorbid depressive disorder. Scores on the SI-R ranged from 25–86 ($M = 55.12$, $SD = 15.75$) indicating moderately severe hoarding symptoms on average. See Table 1 for demographic characteristics of the sample.

3.2. Preliminary analyses

Independent samples *t* tests revealed that psychophysiological responses across study time points did not differ between those who had previously received CBT ($n = 29$) and those who had not ($n = 23$; all $ts < 1.00$, all $ps > 0.05$). Similarly, psychophysiological responses did not differ between patients with (60%) and without (40%) a comorbid depressive disorder (all $ts < 1.88$, all $ps > 0.05$), with the exception of skin conductance during the personal mail discarding task. Mean SCL ($t = 2.24$, $p = .030$) and number of SCRs ($t = 2.07$, $p = .044$) were higher during personal mail vs. control mail discarding among patients *without* co-occurring depression. Taken together, these results suggest that psychophysiological responses during the study were generally not attributable to previous treatment or comorbid depression.

The mixed ANOVAs revealed no significant order x time interactions (all $ps > 0.05$), with the exception of number of SCRs [$F(3, 126) = 5.51$, $p = .001$, $\eta^2 p = 0.12$]. Those who started with the personal mail task had higher SCRs across study time points.

Table 1
Characteristics of the sample.

Variable		
Age, *M* (*SD*)	61.10	9.84
Female sex, *n* (%)	41	78.8
Race, *n* (%)		
White	49	94.2
Black	2	3.8
Other	1	1.9
Hispanic/Latino ethnicity, *n* (%)	1	1.9
Comorbid anxiety disorder, *n* (%)	13	25.0
Comorbid OCD, *n* (%)	3	5.8
Comorbid depressive disorder, *n* (%)	31	59.6
Previous CBT, *n* (%)	29	55.8
SI-R Total, *M* (*SD*)	55.12	15.75
SI-R Clutter, *M* (*SD*)	23.63	7.63
SI-R Saving, *M* (*SD*)	17.92	4.85
SI-R Acquiring, *M* (*SD*)	13.71	5.64

Note. OCD = obsessive-compulsive disorder. CBT = cognitive-behavioral therapy. SI-R = saving inventory-revised.

Due to small sample sizes for all substances except caffeine, we collapsed patients who had used stimulants, beta blockers, or benzodiazepines on the day of the study into one group ($n = 17$). Only one patient reported nicotine use, so we did not conduct any comparisons based on nicotine status. Those who had used these substances only differed on baseline respiration rate, $t(47) = 2.04$, $p = .047$, so we controlled for medication use in the respiration analyses (see below). Patients who had used caffeine on the day of the study had significantly greater SCL ($M = 3.90$, $SD = 2.90$) than those who had not [$M = 2.61$, $SD = 1.43$; $t(44) = 2.43$, $p = .019$]. Caffeine users also had greater SCRs ($M = 3.27$, $SD = 3.58$) than non-users [$M = 1.20$, $SD = 1.82$; $t(38.87) = 2.55$, $p = .015$]. We controlled for caffeine use in the SCL and SCR analyses (see below).

3.3. Behavioral data

There was a main effect of time for Pre and Post distress ratings, indicating differences across time points in subjective anxiety. Pairwise comparisons revealed that discarding personal mail was associated with higher anxiety than discarding control mail items and the resting periods (see Table 2). There was also an effect of time for Post sadness ratings but not for Pre sadness, indicating differences across time in post-discarding but not pre-discarding sadness. Pairwise comparisons indicated that this effect was driven by higher sadness when discarding personal mail than when completing the baseline resting period (see Table 2). Paired samples *t* tests showed that patients saved a greater proportion of mail in the personal mail phase than the control mail phase (see Table 2).

3.4. Psychophysiological responses

3.4.1. $ETCO_2$

There was a main effect of time for $ETCO_2$, indicating that $ETCO_2$ changed over the course of the study (see Fig. 1 for a graphical depiction of change in $ETCO_2$). Pairwise comparisons showed that discarding personal mail was associated with the lowest $ETCO_2$ values (see Table 3). When defined as < 35 mmHg (Oakes 1996; Meuret et al., 2008), the majority of patients were hypocapnic during the baseline (56%), control mail (63.5%), personal mail (73%), and recovery (56%) periods.

3.4.2. EDA

Controlling for caffeine use, there were main effects of time for SCL and SCR. Follow-up comparisons showed the highest SCL and SCRs in the personal mail discarding task (see Table 3 and Fig. 2).

Table 2
Behavioral data.

Variable	Main effect *F*, *p*, η^2p	Baseline *M* (*SD*)	Control mail *M* (*SD*)	Personal mail *M* (*SD*)	Mail comparison *Cohen's d*	Recovery *M* (*SD*)
Pre SUDS	4.43, .005, 0.08	15.06 (20.76)$_{a}$	18.50 (23.21)$_{a, b, c}$	19.94 (21.42)$_{b, c}$	−0.11	22.81 (24.09)$_{c}$
Post SUDS	19.37, <.001, 0.28	10.19 (17.28)$_{a}$	21.73 (24.93)$_{b}$	28.02 (26.17)$_{c}$	−0.38	15.77 (21.23)$_{d}$
Pre sadness	0.71, .546, 0.01	11.46 (19.65)$_{a}$	12.96 (22.22)$_{a}$	11.19 (20.61)$_{a}$	0.12	13.38 (22.42)$_{a}$
Post sadness	4.26, .006, 0.08	9.48 (17.73)$_{a}$	13.10 (22.06)$_{a, b, c}$	14.85 (22.51)$_{b, c}$	−0.21	12.23 (21.06)$_{a, c}$
% saved		–	25.0%$_{a}$	42.0%$_{b}$	−0.59	–

Note. SUDS = Subjective Units of Distress Scale. Percent saved refers to mail items saved/total mail items in that condition. Means that do not share subscripts are significantly different from each other, $p < .05$. Mail Comparison *Cohen's d* is the effect size for the comparison between personal vs. control mail discarding.

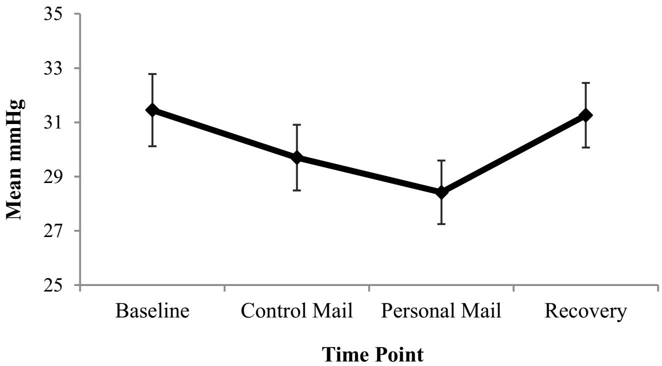

Fig. 1. Mean end tidal CO_2 values across study phases. Order of control and personal mail tasks is counterbalanced. Error bars represent standard errors.

3.4.3. HRV and HR

There was no main effect of time for HRV, indicating that HRV did not change over the four time periods. However, there was a main effect of time for HR. Follow-up comparisons showed significantly higher HR during the personal mail discarding task as compared to all other study phases (see Table 3 and Fig. 3).

3.4.4. RSA and RR

Controlling for medication use, RSA did not change over the course of the study. However, when controlling for medications, there was a main effect of time for RR; the two discarding tasks were significantly higher than the resting periods, but were not significantly different from each other (see Table 3 and Fig. 3).

3.5. Predicting change in psychophysiological responses

Given that there was no change in HRV and RSA over the course of the study (see above), we did not include these variables in the HLM analyses. The first set of HLM models that included all four study time points revealed that the SI-R total and subscale scores failed to predict change in psychophysiological responses over the course of the study. Similarly, the second set of HLM models containing only the two discarding tasks showed that the SI-R total and subscales did not predict change in psychophysiological activation during the discarding tasks.

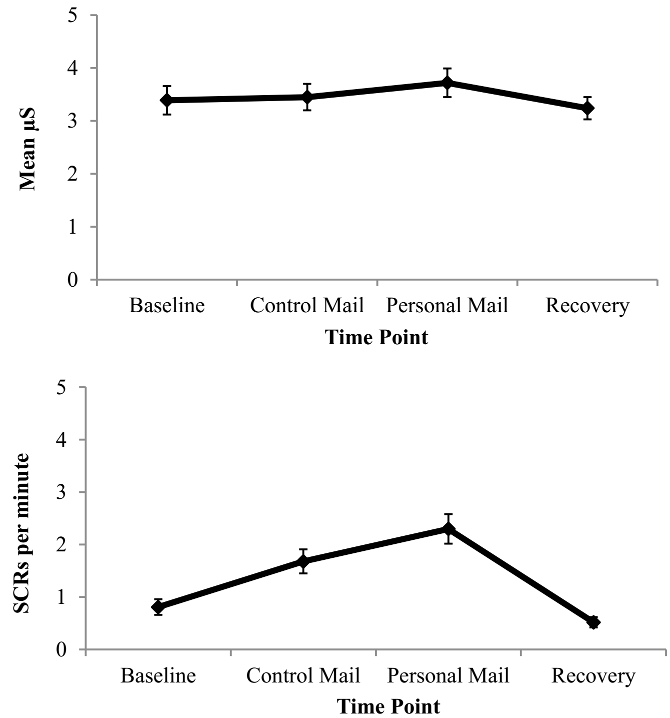

Fig. 2. Mean skin conductance level (top) and number of skin conductance responses (SCRs) per minute (bottom) across study phases, controlling for caffeine use. Order of control and personal mail tasks is counterbalanced. Error bars represent standard errors.

4. Discussion

To our knowledge, the present study is the first to examine psychophysiological responses during discarding among patients with HD. Consistent with our hypotheses, discarding personal possessions resulted in greater psychophysiological activation than discarding control possessions. $ETCO_2$ was lower during the personal mail discarding task, while SCL, SCR, and HR were higher during this task. Contrary to these results, there were no differences between the personal and control mail

Table 3
Psychophysiological responses.

Variable	Main effect *F*, *p*, η^2p	Baseline *M* (*SD*)	Control mail *M* (*SD*)	Personal mail *M* (*SD*)	Mail comparison *Cohen's d*	Recovery *M* (*SD*)
$ETCO_2$	10.52, <.001, 0.18	31.45 (9.42)$_{a}$	29.70 (8.63)$_{b}$	28.42 (8.29)$_{c}$	0.75	31.26 (8.38)$_{a, d}$
SCL+	5.88, .001, 0.12	3.39 (1.86)$_{a}$	3.45 (1.71)$_{a, c, d}$	3.72 (1.77)$_{b}$	−0.43	3.24 (1.42)$_{a, c, d}$
SCR+	17.17, <.001, 0.29	0.81 (1.04)$_{a}$	1.68 (1.56)$_{b}$	2.30 (2.01)$_{c}$	−0.36	0.52 (0.67)$_{a, d}$
HRV	0.50, .683, 0.01	17.19 (10.48)$_{a}$	18.19 (9.98)$_{a}$	18.78 (12.35)$_{a}$	−0.10	18.08 (13.25)$_{a}$
HR	6.41, <.001, 0.12	73.88 (10.81)$_{a}$	74.68 (10.84)$_{b}$	75.25 (11.19)$_{c}$	−0.33	73.38 (11.18)$_{a, d}$
RSA~	1.02, .384, 0.02	4.64 (1.82)$_{a}$	4.99 (1.77)$_{a}$	4.98 (1.57)$_{a}$	0.00	4.73 (1.57)$_{a}$
RR~	23.99, <.001, 0.35	13.89 (4.33)$_{a}$	17.46 (4.33)$_{b}$	17.80 (4.46)$_{b}$	−0.10	13.77 (4.16)$_{a, d}$

Note. + = Controls for caffeine use. ~ = Controls for medication use. Means that do not share subscripts are significantly different from each other, $p < .05$. Mail Comparison *Cohen's d* is the effect size for the comparison of control vs. personal mail discarding tasks.

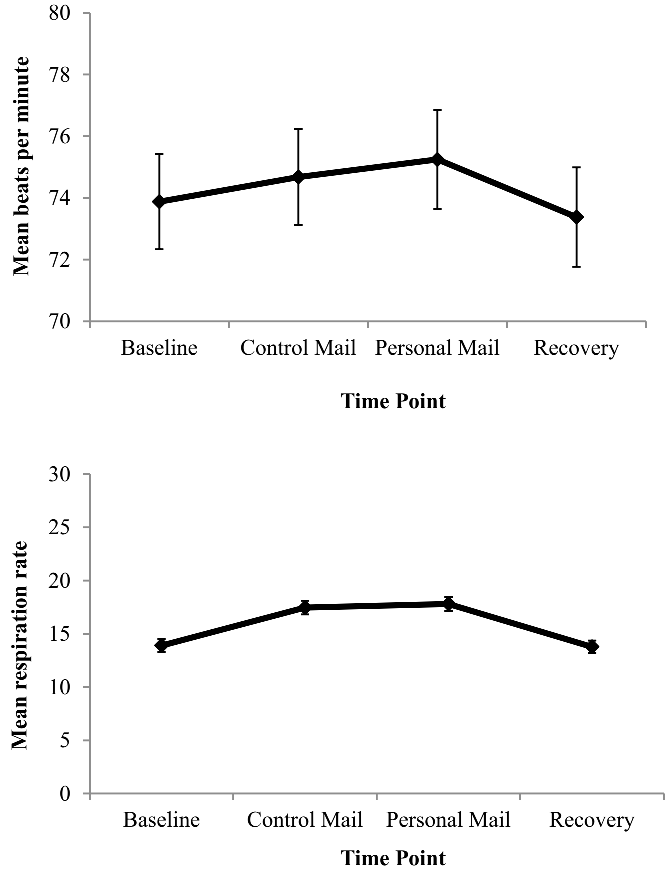

Fig. 3. Mean heart rate (top) and respiration rate (bottom) across study phases. Respiration rate values control for medication use. Order of control and personal mail tasks is counterbalanced. Error bars represent standard errors.

discarding tasks in terms of HRV, RSA, and RR. These findings are generally consistent with prior research that has found greater subjective distress and neural activation when HD patients sort and discard their own vs. others' possessions (Tolin et al., 2009, 2012). It could be that HRV and RSA, which are closely related and reflect vagal control of cardiac functioning, may be more stable and trait-like measures that are less responsive to phasic changes in psychophysiological activation during discarding. HRV is primarily influenced by the parasympathetic nervous system (Thayer et al., 2012), not the sympathetic system, which is responsible for acute changes in psychophysiological activation during stress (such as being faced with discarding personal possessions for patients with HD). Other studies in anxiety disorder patients have also failed to find differences in HRV during stressor tasks as compared to baseline despite increases in HR during the stressor tasks (e.g., Pittig et al., 2013). It will be interesting to further assess HRV and RSA and determine whether these more trait-like stable variables may relate to long-term outcomes in HD, such as clutter severity and/or treatment outcome.

We have previously proposed a biphasic neurobiological model of HD (Tolin et al., 2012), in which HD patients exhibit hypoactivity in frontal brain regions (e.g., anterior cingulate cortex) when making decisions about others' possessions, and hyperactivity in these regions when making personally-relevant decisions about their own possessions. Similarly, Zakrzewski et al. (2018) recently found lower SCR in HD patients compared to nonclinical control participants during a neutral error task, indicating hypoactive responses during emotionally neutral decision-making. Coupled with the current study's results, it appears that HD patients may have a biphasic psychophysiological response as well, characterized by hypoactivation during neutral tasks and excessive activation during emotional discarding-related tasks. These promising results warrant further investigation of the biphasic neurobiological model of HD in future studies, and our work on this is underway.

Contrary to our hypotheses, self-reported hoarding severity failed to predict changes in psychophysiological responses during the study. These findings suggest that self-reported HD severity (including difficulty discarding) is not associated with psychophysiological activation during discarding. These results indicate that there may be discrepancies between subjective and objective measures of hoarding-related distress. We conducted follow-up Pearson correlations between the SUDS ratings and psychophysiological measures and found no significant correlations across study time points, further supporting the notion that self-report and psychophysiological measures may be tapping unique facets of discarding-related distress. Other studies have also found discordance between psychophysiological and self-report measures of anxious arousal (for a review, see Lang et al., 2016), thus supporting the notion that these measures capture distinct domains of anxiety symptomatology. Along these same lines, the Research Domain Criteria (RDoC) Project put forth by the National Institute of Mental Health emphasizes the importance of assessing mental health disorders across *multiple levels of analysis* (e.g., psychophysiological, behavioral, etc.) in an effort to improve the diagnosis and classification of mental disorders (Cuthbert, 2014; Cuthbert and Insel, 2013; Insel et al., 2010). Taken together, these findings suggest that incorporating objective measures into HD assessment may be helpful in order to obtain a more comprehensive picture of current symptoms and impairment.

The results of the current study may have several clinical implications. First, it appears that psychophysiological measures may provide unique insight into hoarding symptoms that may not be captured by traditional self-report questionnaires. The results of the current study suggest that assessing both subjective and objective distress in the clinic may be useful and informative. Second, it may be helpful to incorporate biologically-based interventions into HD treatment (e.g., relaxation training, biofeedback). These interventions have shown promise as adjunctive or alternative treatments to traditional CBT for anxiety and related disorders (Chambless and Ollendick, 2001; Schoenberg and David, 2014). Based on the results of the current study, it may be useful to apply these interventions just prior to or during sorting and discarding practice in order to decrease baseline arousal and promote engagement in and willingness to do the practices. Given that current treatments for HD are only modestly effective (Tolin et al., 2015), efforts to improve current treatment options are critically needed. Patients with HD often have low motivation for treatment and may even resist therapeutic interventions (Christensen and Greist, 2001; Steketee et al., 2001), so it is possible that decreasing baseline arousal prior to discarding may increase motivation for behavioral change. The findings of the current study could also be incorporated into psychoeducation during CBT. Patients may benefit from knowing in advance that they are likely to experience (subjective and psychophysiological) distress when practicing sorting and discarding during CBT, and not to take this as a sign that they cannot cope with discarding-related distress and/or that treatment will not help them. Rather, they can be informed at the start of treatment that distress is to be expected during discarding, and will likely decrease with continued discarding practice. Previous research indicates that discarding-related distress decreases within a relatively short period of time ($<$15 min) in patients with HD (Frost et al., 2016), which may also be helpful information to share during psychoeducation.

The current study had several limitations. First, the absence of a healthy nonclinical control group precludes our ability to determine whether participating in a discarding task increases psychophysiological arousal specifically for patients with HD. Given this limitation, the results of the present study should be interpreted with caution and replicated using a nonclinical comparison group. Second, we had low samples sizes for most medications that we assessed, so we were unable to examine the effect of these medications individually and instead grouped them together for the analyses. Of course, each of these medications may have unique effects on psychophysiological responses, but we felt that examining them as a group was better than not taking them into account at all. It will be important to examine these medications individually in future studies and/or recommend that participants refrain from using them during study participation whenever possible. Our sample was limited in terms of racial and ethnic diversity, and we recruited some participants from a clinical trial that had somewhat stringent inclusion criteria (e.g., no history of substance use disorders). As such, our results may not generalize to all HD patients, particularly those from minority groups. Third, it should be noted that some psychophysiological measures are affected by speaking (e.g., $ETCO_2$), which only occurred during the discarding tasks and not the resting periods, so comparisons between discarding and the resting periods for these measures should be interpreted with caution. Fourth, as is the case for all laboratory-based experimental research, it is unclear whether discarding that occurs in the laboratory necessarily represents actual discarding behavior in the home environment. However, given that the discarding tasks significantly increased psychophysiological activation, we feel confident that our laboratory protocol was ecologically valid in assessing hoarding-related distress. Fifth, we did not assess weight, body mass index, or medical conditions that may affect cardiac and respiratory functioning (e.g., chronic obstructive pulmonary disease). It is possible that these conditions may have affected our ability to detect differences in HRV and RSA across the study phases. Given the high rates of obesity and chronic medical conditions among HD patients (Tolin et al., 2008), it will be important to assess the impact of weight and physical health problems in future psychophysiological investigations. Sixth, although we used a counterbalanced design and a resting period in between the two discarding tasks, a more formal ABAB design may have increased the methodological rigor of the study and provided additional control over order effects. Although we verified that task order did not impact psychophysiological responses (other than SCRs) during the study, future replications of this research should consider employing ABAB designs to further clarify differences between discarding personal vs. control items that are independent of order effects. Finally, more than half of our sample received treatment prior to participating in the current study. We verified that previous treatment did not impact psychophysiological responses during the study. Nevertheless, in future studies, it will important to replicate these findings and determine whether participating in cognitive-behavioral treatment decreases psychophysiological arousal during exposure-based procedures like sorting and discarding. This may have implications for the treatment of HD, such as the development of novel pharmacological agents that may improve the efficacy of exposure therapy (Garakani et al., 2006; Hofmann, 2007; Graham and Milad, 2011). Should we find that CBT decreases psychophysiological arousal across discarding practices, suggesting a habituation process akin to that described for fear (Foa and Kozak, 1986), we may consider testing the effects of pharmacological interventions that may improve extinction learning (e.g., N-methyl-D-aspartate agonists) during discarding.

To conclude, the results of the current study suggest that discarding personal possessions increases psychophysiological activation in patients with HD. We hope that this research will inspire future research in this area, particularly the development of novel treatments that target potential abnormalities in psychophysiological responses. It is possible that reductions in psychophysiological arousal may decrease subjective distress and increase motivation for discarding.

Declarations of interest

None.

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