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RESEARCH ARTICLE

Associations Between Repetitive Negative Thinking and Habituation of Defensive Responding Within and Between Sessions

Carter J. Funkhouser[1] · Andrea C. Katz[2] · Emily E. E. Meissel[3] · Elizabeth S. Stevens[4] · Anna Weinberg[5] · Carver B. Nabb[6] · Stewart A. Shankman[6]

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Abstract

Repetitive negative thinking (RNT) is a transdiagnostic risk factor for internalizing psychopathology, and theoretical models suggest that RNT may maintain symptoms by interfering with psychophysiological habituation. The present study therefore examined associations between RNT and habituation within and between study sessions. Community members (*N*=86) completed a habituation task involving exposure to acoustic probes at up to five sessions spaced 7 days apart on average. Eyeblink startle response was measured using the electromyography startle magnitude. Self-reported anxiety was assessed before and after the habituation task at each session. Multilevel growth curve modeling indicated that RNT was associated with a higher "floor" (i.e., asymptote) of startle responding as evidenced by reduced within-session startle habituation at later sessions. Results suggest that RNT may disrupt startle habituation and are consistent with theoretical models proposing that RNT sustains physiological activation to support avoidance of negative emotional contrasts or perceived future threats.

Keywords Startle · Rumination · Worry · Stress · Avoidance

Internalizing disorders are prevalent and impairing (Kessler et al., 2009). Identifying risk factors for internalizing psychopathology is critical for improving understanding of etiology and the development of preventative interventions. In light of evidence that categorical DSM/ICD-defined diagnoses have suboptimal validity and psychopathology may be more accurately organized as a hierarchical model of dimensions (Kotov et al., 2017; Shankman et al., 2018), there is increasing interest in identifying risk factors that are transdiagnostic (rather than specific to a certain disorder) and understanding the mechanisms by which they lead to psychopathology (Mansell et al., 2008).

A large body of evidence highlights repetitive negative thinking (RNT, i.e., repetitive, uncontrollable thinking about negative topics; Ehring & Watkins, 2008) as a transdiagnostic risk factor for internalizing psychopathology. Although initial studies largely examined how separate forms of RNT (e.g., rumination vs. worry) related to separate disorders (e.g., depression, generalized anxiety disorder; Nolen-Hoeksema, 1991), more recent studies have shown that RNT may be unidimensional (Ehring et al., 2011; Segerstrom et al., 2000; Topper et al., 2014; Wahl et al., 2019) and is cross-sectionally and prospectively associated with a range of internalizing disorders (Aldao & Nolen-Hoeksema, 2010; Nolen-Hoeksema &

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✉ Carter J. Funkhouser
carterfunkhouser@gmail.com

[1] Department of Psychology, University of Illinois at Chicago, 1007 W. Harrison St, Chicago, IL 60607, USA

[2] VA Puget Sound Health Care System, Seattle Division, 1660 South Columbian Way, Seattle, WA 98108, USA

[3] Department of Psychology, San Diego State University/University of California San Diego, 6363 Alvarado Ct, San Diego, CA 92120, USA

[4] Jesse Brown VA Medical Center, 820 S. Damen Ave, Chicago, IL 60612, USA

[5] Department of Psychology, McGill University, 2001 McGill College Ave., Montreal, Quebec H3A 1G1, Canada

[6] Department of Psychiatry and Behavioral Sciences, Northwestern University, 680 N. Lake Shore Dr, Chicago, IL 60611, USA

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Morrow, 1991; Ruscio et al., 2011; Shaw et al., 2021; Spinhoven et al., 2018).

Individuals with internalizing psychopathology also consistently exhibit altered responding to negative or aversive information (Funkhouser et al., 2021; Michelini et al., 2021). Although most studies have focused on responses to a single aversive event or averaged responses across multiple aversive events, there is increasing interest in the time course of emotional processing (i.e., affective chronometry; Davidson, 1998). Emotional responding can be disaggregated into distinct temporal features that reflect different psychological processes and may play different roles in the development of psychopathology (Klumpp & Shankman, 2018). For example, initial reactivity (i.e., response to the first presentation of a stimulus) is thought to reflect initial stimulus processing and appraisal, and habituation (i.e., decreased reactivity following repeated exposure to a stimulus; Rankin et al., 2009) may reflect the ability to inhibit reactivity over time (Banks et al., 2007). Elevated initial psychophysiological reactivity and/or reduced within-session habituation to repeated aversiveness has been associated with a variety of internalizing disorders (Eckman & Shean, 1997; Funkhouser et al., 2019; Gorka et al., 2015; Jovanovic et al., 2009; Pole, 2007). These studies have often used measures such as skin conductance, heart rate, or the eyeblink startle response. The eyeblink startle response is a primitive, cross-species reflex (Koch & Schnitzler, 1997) that serves to protect the eyes from injury and is especially useful in this context as it reflects defensive or withdrawal motivation (Lang et al., 1997). Moreover, unlike skin conductance and heart rate, startle is sensitive to the valence of an individual's emotional state (Lang et al., 1990).

Although the specific mechanism(s) via which RNT leads to internalizing psychopathology are unclear, RNT may influence the magnitude and/or time course of responding to stress or aversiveness. The contrast avoidance model (Newman & Llera, 2011) proposes that RNT sustains negative affect and physiological activation to avoid a negative emotional contrast (i.e., a shift from a positive or euthymic state to a negative one). A second avoidance model, Borkovec et al.'s (2004) cognitive avoidance model, proposes that RNT may function as a form of cognitive avoidance of perceived future threats. This in turn may maintain negative affect, physiological activation, and internalizing symptoms by interfering with inhibitory learning (Craske et al., 2008) or emotional processing (Foa & Kozak, 1986). For example, RNT might interfere with corrective learning about the duration, frequency, dangerousness, and tolerance of aversive stimuli (Krypotos et al., 2015). The contrast avoidance model and cognitive avoidance model both predict that RNT is associated with reduced physiological habituation, although they propose somewhat different mechanisms underlying this association.

Few studies have examined whether RNT relates to habituation over the course of repeated exposure to stress or aversiveness. Two studies examining responses to psychosocial stress induction across two sessions found that RNT related to (a) reduced cardiovascular and cortisol between-session habituation, and (b) a smaller between-session change in within-session reactivity (Gianferante et al., 2014; Johnson et al., 2012). These studies provide preliminary evidence that RNT may be associated with reduced between-session physiological habituation, consistent with avoidance models of RNT. However, the inclusion of only two study sessions prevented testing of more nuanced (e.g., nonlinear) patterns of between-session habituation. Additionally, these studies did not examine RNT in relation to within-session habituation. Within- and between-session habituation are theorized to reflect distinct processes and are only weakly correlated (Baker et al., 2010; Craske et al., 2008). Within-session habituation putatively reflects short-term dissociation of a stimulus and fear response, whereas between-session habituation is thought to reflect longer-term corrective learning about stimulus characteristics (Foa & Kozak, 1986). Although empirical studies suggest that between-session habituation may be a stronger predictor of symptom reduction during exposure therapy (Baker et al., 2010; Cooper et al., 2017; Craske et al., 2008; Sripada & Rauch, 2015), both processes are proposed to contribute to internalizing symptom reduction (Foa & Kozak, 1986). In sum, examining both within- and between-session habituation may capture distinct habituation processes and translate to more nuanced insights into the association between habituation and RNT.

The present study therefore examined associations between RNT and within- and between-session habituation of defensive responding. Participants completed a task in which they were exposed to six acoustic probes at five separate study sessions. Defensive responding was measured using the electromyography (EMG) startle response to the probes, and self-reported anxiety was assessed before and during the task. Based on theoretical models suggesting RNT serves an avoidance function (Borkovec et al., 2004; Newman & Llera, 2011) and studies using other psychophysiological measures to examine between-session habituation (Gianferante et al., 2014; Johnson et al., 2012), it was hypothesized that RNT would be associated with less steep within- and between-session habituation of startle responding and self-reported anxiety.

Method

Participants

Eighty-six adults between the ages of 18 and 60 were recruited from the community in a large midwestern city in the USA as part of a larger study on the reliability of reward and threat sensitivity measures (Weinberg et al., 2021). Participants attended up to 5 study sessions (M = 4.07 sessions, SD =

1.34) spaced 7.02 days apart on average (SD = 5.09). The majority of the sample (n = 50 [58.1%]) completed all five study sessions. The remaining participants completed either four (n = 14 [16.3%]), three (n = 7 [8.1%]), two (n = 8 [9.3%]), or one (n = 7 [8.1%]) study session(s). Study sessions were required to be on nonconsecutive days. Exclusion criteria included a history of head trauma with loss of consciousness and left-handedness. Sample demographics are presented in Table 1. All participants provided informed consent.

Procedure

At each study session, participants completed two identical habituation blocks (Funkhouser et al., 2019). During each 2.5-min block, participants were told to relax and focus on a fixation cross presented on a monitor approximately one meter away. Six 40 ms, 103db bursts of white noise with near-instantaneous rise time were then presented binaurally through headphones. Inter-stimulus intervals between the probes ranged between 15 and 20 s (M = 17.6 s). In between the two habituation blocks, shock electrodes were attached to the participants' right wrist to create a more anxiogenic context. The effect of this anxiogenic context on startle responding was confounded with habituation because the anxiogenic context always occurred in the second habituation block, so the present study focuses on the first habituation block. The startle probes and visual stimuli were administered using PSYLAB (Contact Precision Instruments, London, UK), and psychophysiological data were acquired using Neuroscan 4.4 (Compumedics, Charlotte, NC).

Measures

Repetitive Negative Thinking

Repetitive negative thinking (RNT) was assessed prior to the habituation task at the first study session using the 22-item ruminative responses scale (RSS; Nolen-Hoeksema & Morrow, 1991; Treynor et al., 2003) and the 15-item perseverative thinking questionnaire (PTQ; Ehring et al., 2011). The RSS (α = 0.94) and PTQ (α = 0.96) had excellent internal consistency, and had mean scores of 45.6 (SD = 14.2) and 26.4 (SD = 14.3), respectively, which are comparable to means obtained from community and undergraduate samples (Nolen-Hoeksema et al., 1999; Raes, 2012). In light of the similarity in item content and strong correlation between the two measures, r = 0.72, p < 0.001, they were z-scored and averaged to form a composite measure of RNT, which was then z-scored.

Table 1 Demographic characteristics

Characteristic	No. (%)
Age (*M*, *SD*)	25.9 (10.1)
Sex (female)	39 (45.3%)
Ethnicity/race	
Caucasian	34 (39.5%)
Hispanic	9 (10.5%)
African American	15 (17.4%)
Asian	15 (17.4%)
Other	13 (15.1%)

Internalizing Symptoms

Although this was an unselected community sample, internalizing symptoms were assessed at the first study session using the Inventory of Depression and Anxiety Symptoms (IDAS-II; Watson et al., 2012) to characterize the sample. The IDAS-II contains 99 items that are rated on a scale from 1 (not at all) to 5 (extremely) and includes a 20-item general depression subscale and 18 factor-analytically derived, non-overlapping subscales representing distinct symptoms of internalizing psychopathology experienced over the past 2 weeks. These subscales demonstrated adequate internal consistency in the present study (mean α = 0.83, range = 0.65–0.91; see Table S1 in the supplementary materials). As expected, mean subscales scores were comparable to previous community and nationally normative samples (Funkhouser et al., 2020; Nelson et al., 2018; Watson et al., 2012).

Self-Reported Anxiety

At each session, self-reported anxiety was assessed immediately before the first habituation block by asking, "On a scale from 1 (not at all) to 7 (extremely), how nervous or anxious do you feel right now?" Immediately following the first habituation block, anxiety during the habituation block was assessed by asking, "On a scale from 1 (not at all) to 7 (extremely), how nervous or anxious did you feel while you were listening to the tones?"

Startle Responding

Startle responses were recorded from two 4-mm Ag/AgCl electrodes placed over the orbicularis oculi muscle below the right eye. One electrode was 1 cm below the pupil, and the other was 1 cm lateral of that electrode. The ground electrode was at the frontal pole (AFZ). Data were collected using a bandpass filter of DC-500 Hz at a sampling rate of 2000 Hz. Startle blinks were scored according to published guidelines (Blumenthal et al., 2005) using BrainVision Analyzer (Brain Products, Munich, Germany). Data processing included applying a 28-Hz high-pass filter, rectifying, and smoothing using a 50-Hz low-pass filter. After peaks were identified by software, blinks were visually inspected for acceptability.

Responses were accepted if they fell within the 20–150 ms period following the acoustic startle probe and were visually distinct from baseline activity. If no visually distinct blink was observed in the 20–150 ms time period, the blink was recorded as a non-response. Blinks were scored as missing if the baseline period included excess noise, muscular artifact, or a spontaneous blink occurring at the time of probe onset. On average, participants had 4.92 nonmissing blinks per session. The average number of blinks per session ranged across participants from 2.0 to 6.0. Approximately 7% of blinks (0.35 blinks per session on average) were non-responses.

Data Analysis

Startle Responding

Within- and between-session habituation of startle responding — and the moderating effects of RNT — were modeled using three-level (blinks within days within people) multilevel growth curve models. Growth curve models are also commonly estimated using a structural equation modeling framework (i.e., latent growth curve modeling). This study used a multilevel modeling framework because it more easily accommodates three-level data (McNeish & Matta, 2018), but the two frameworks are mathematically equivalent in many cases and have numerous similarities (e.g., Bauer, 2003). The primary difference is that random effects are specified as randomly varying regression coefficients in the multilevel modeling framework and as latent variables in the latent growth curve modeling framework.

The model included nested random intercepts at levels two (day) and three (participant) to allow means to vary across sessions and people. Within-session habituation was operationalized as the random slope of the number of elapsed seconds since the first startle probe ("within-session time"), and between-session habituation was operationalized as the fixed effect of the number of days elapsed since the first session ("Day").[1,2] These parameters evaluated whether startle responding decreased within or across sessions. A negative effect of within-session time would indicate a decline in startle responding over the course of the task (i.e., within-session habituation), and a negative effect of day would indicate a decline in startle responding across sessions (i.e., between-session habituation). The interaction between within-session time and day was also included to test whether within-session habituation slopes changed across sessions. In light of evidence that startle habituation data may be best fit by a quadratic curve (Lane et al., 2013), we also included the quadratic effect of within-session time and its interaction with day.[3] The association between RNT and estimated startle reactivity was represented by the main effect of RNT. Relationships between RNT and within-session habituation were represented by the 2-way interactions between RNT and the linear and quadratic effects of within-session time. RNT's association with between-session habituation was tested by the RNT by day interaction. Lastly, we tested the 3-way interactions between RNT, day, and the linear or quadratic effect of within-session time to determine whether individual differences in RNT related to between-session changes in within-session habituation.

In longitudinal growth models, the coding of the time variables impacts the meaning of the variances of the random intercepts, the intercept-slope covariance(s), and certain main effects and interactions (Biesanz et al., 2004; Kristjansson et al., 2007). For instance, if within-session time and day are both uncentered, the main effect of RNT represents the effect of RNT on initial startle reactivity to the first startle probe of the task (i.e., when within-session time = 0) at the first session (i.e., when day = 0). However, if within-session time and day are both mean-centered, the main effect of RNT represents the effect of RNT on startle reactivity at the mean value of within-session time (i.e., the midpoint of the task) and at the mean value of day (i.e., 13.8 days since session one). In the initial model, within-session time and day were mean-centered, making the intercept represent estimated startle magnitude at the midpoint of the task and mean value of day. The model was then rerun several times, each time changing the coding of within-session time and/or day as described above to manipulate the meaning of the main effect of RNT, the main effect of within-session time, and their interaction.

Interactions involving RNT were probed by testing simple effects or simple interactions at "low" (−1 SD) and "high" (+1 SD) levels of RNT. Rather than testing the effect of time at various values of day, between-session changes in within-session habituation slopes (i.e., within-session time by day interactions) were probed using the Johnson-Neyman technique (Johnson & Neyman, 1936) with a false discovery rate correction (Esarey & Sumner, 2018). The Johnson-Neyman technique calculates regions of significance and confidence bands delineating the exact values of a moderator (e.g., day) at which the effect of a predictor (e.g., within-session time, representing the within-session habituation slope) is and is not statistically significant, thus revealing exactly when within-session habituation slopes became statistically nonsignificant.

[1] These operationalizations of within- and between-session habituation are conceptually similar to (and highly correlated with) blink number and session number, respectively, but have the advantage of accounting for unequal amounts of time between startle probes and sessions.

[2] A random slope was initially included for day to represent individual differences in between-session habituation slopes, but was removed after preliminary models indicated that participant-level random intercepts and between-session slopes could not be differentiated.

[3] A quadratic effect of day was not included because preliminary models indicated it did not improve fit.

Self-Reported Anxiety

The time course of self-reported anxiety across sessions was similarly modeled using a three-level (anxiety ratings within days within people) multilevel growth curve model. These models primarily focused on between-session habituation because self-reported anxiety was only assessed twice per session. A random intercept and a random slope of day were included to allow mean levels and between-session habituation slopes to vary across participants. Rating time point (i.e., before versus during the habituation task), the linear and quadratic effects of day, and the two-way interactions between rating time point and the linear and quadratic effects of day, respectively, were specified as fixed effects. RNT's moderation of the time course of self-reported anxiety was tested using analogous parameters to the model predicting startle — i.e., the main effect of RNT and its interactions with rating time point and/or the linear or quadratic effects of day. Day was mean-centered in the initial model to make the intercept represent estimated self-reported anxiety at the mean value of day. The effect of RNT on anxiety at the first session was then examined by rerunning the model with day uncentered.

Although this study primarily focused on RNT, we also tested whether self-reported anxiety was associated with the intercept or habituation of startle responding within or between sessions. To this end, self-reported anxiety before the habituation task, self-reported anxiety during the habituation task, and their difference (anxiety during — anxiety before) were separately examined as level 2 fixed effect predictors of startle responding. Each model also tested whether self-reported anxiety moderated the slope of startle responding within and/or between sessions. As in the primary models, within-session time and day were mean-centered in the initial models and recoded in subsequent models to examine the effect of self-reported anxiety on startle reactivity to the first startle probe within each session (i.e., within-session time = 0) and/or at the first session (i.e., day = 0).

In light of evidence of sex and age differences in initial reactivity and habituation of startle responding (Blanch et al., 2018; Ellwanger et al., 2003; Lane et al., 2013), all models covaried for sex (simple coded; male=−0.5, female=0.5) and age (centered) as well as their interactions with linear within-session and/or between-session changes in startle or self-reported anxiety. Multilevel models handle individual differences in attrition by weighting parameter estimates such that participants with less missing data had stronger influences on parameter estimates (Snijders & Bosker, 2012), thereby allowing all available data to be included in the models. Models were estimated using maximum likelihood assuming missingness at random. The statistical significance of fixed effects was evaluated using t tests with degrees of freedom estimated using Satterthwaite's approximation, and the statistical significance of each random effect was evaluated using chi-square difference tests. Following recommendations (Wu et al., 2009), the global fit of each multilevel model was evaluated using conditional R^2, which reflects the proportion of variance explained by the fixed and random effects in the model (Nakagawa et al., 2017; Nakagawa & Schielzeth, 2013). Analyses were conducted in R using the lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), and interactions (Long, 2019) packages. Analyses were not formally preregistered and data are available upon request.

Results

Preliminary Analyses

RNT was significantly associated with 14 of the 18 IDAS-II subscales with moderate effect sizes (see Table S1 in the supplementary materials), supporting its status as a transdiagnostic risk factor for internalizing symptoms. RNT was not significantly related to the number of study sessions completed or the number of days between sessions ($|rs| < 0.19$, $ps > 0.05$).

The time course of startle within and between sessions is plotted in Fig. 1. The multilevel growth curve model explained 71.2% of the variance in startle responding. There was significant variation in mean levels of startle responding across people and across sessions as evidenced by significant person-level and day-level random intercepts ($ps < 0.001$). There was also significant variation in within-session startle slopes across sessions within people ($p < 0.001$). In addition to these random effects, results revealed (1) a negative linear effect of within-session time, $b = -0.41$, $p < 0.001$, indicating within-session habituation, (2) a quadratic effect of within-

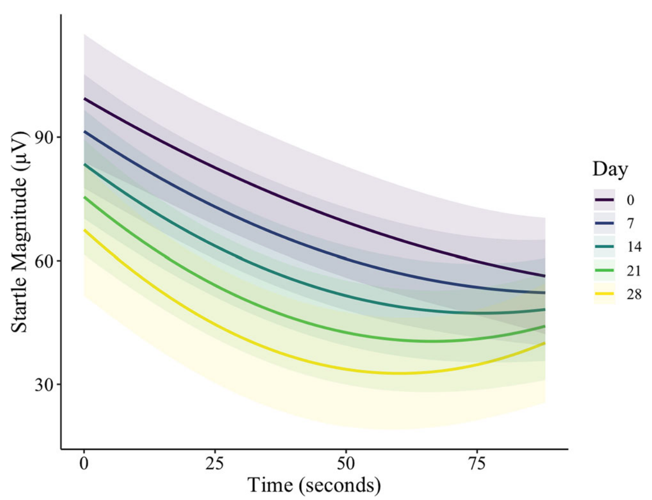

Fig. 1 Within-session habituation curves across days. Ribbons represent 95% CIs. Within-session habituation curves are plotted for days 0, 7, 14, 21, and 28 because the mean interval between successive sessions was 7 days

session time, $b = 0.01$, $p < 0.001$, indicating that the rate of within-session habituation decreased over the course of the task, and (3) a negative effect of day, $b = -1.34$, $p < 0.001$, indicating between-session habituation. Day marginally moderated the linear effect of within-session time, $b = 0.01$, $p = 0.074$, and significantly moderated the quadratic effect of within-session time , $b < 0.01$, $p = 0.033$, such that the quadratic effect of within-session time was nonsignificant from days 0 to 3.1, but was significant at all other days. Re-centering within-session time at either the first or last startle probe of the task revealed that reactivity to the first startle probe, $b = -1.17$, $p < 0.001$, and last startle probe, $b = -0.56$, $p = 0.030$, decreased across sessions.

Results of the model testing the time course of self-reported anxiety are presented in Table 3 and plotted in Figure S1 in the supplementary materials. The model explained 62.1% of the variance in self-reported anxiety ratings. Examination of the random effects indicated that mean levels and between-session slopes of self-reported anxiety varied significantly across individuals ($ps < 0.001$). There was also (1) a negative linear effect of day, $b = -0.04$, $p < 0.001$, indicating that anxiety decreased across sessions, and (2) a quadratic effect of day, $b < 0.01$, $p < 0.001$, such that the between-session habituation rate was greater across earlier sessions compared to later sessions, and (3) a main effect of rating time point, $b = 0.73$, $p < 0.001$, such that anxiety was on average greater during the habituation task than before it. This anxiety "potentiation" during the habituation task serves as a manipulation check, validating the aversiveness of the startle probes. The effect of rating time point was marginally moderated by the linear effect of day, $b = -0.01$, $p = 0.070$, and was significantly moderated by the quadratic effect of day, $b < 0.01$, $p = 0.044$, indicating that within-session differences in anxiety before versus during the habituation task decreased slightly across sessions, and decreased more rapidly across earlier sessions compared to later sessions.

Associations Between RNT and Habituation of Startle Responding

The main effect of RNT was nonsignificant, $b = 5.91$, $p = 0.371$, and RNT did not moderate the linear, $b = 0.01$, $p = 0.768$, or quadratic, $b = 0.00$, $p = 0.986$, effects of within-session time. This indicates that RNT was unrelated to within-session habituation or startle responding at the mid-point of the task at the mean value of day (i.e., day ~14). RNT also did not moderate the effect of day, $b = 0.02$, $p = 0.952$. However, RNT significantly moderated the interaction between the linear (but not quadratic; $p = 0.656$) effect of within-session time and day in predicting startle responding (see Table 2 and Fig. 2), $b = 0.01$, $p = 0.027$. Tests of the within-session time by day interaction at low (−1 SD) or high (+1 SD) RNT levels indicated that within-session habituation slopes did not significantly change across sessions in individuals with low RNT, $b = 0.00$, $p = 0.706$, but became significantly less steep across sessions in individuals with high RNT, $b = 0.01$, $p = 0.011$. Johnson-Neyman analyses of the within-session time by day interaction at low or high levels of RNT indicated that within-session habituation slopes were significantly negative across all days in individuals with low RNT, but became statistically nonsignificant at day 25.1 in those with high RNT (see Figure S2 in the supplementary materials).

Consistent with these results, rerunning the model with day uncentered instead of mean-centered indicated that RNT was not related to within-session habituation (i.e., the linear or quadratic effects of within-session time; $p > 0.148$) or initial ($p = 0.295$) or final ($p = 0.959$) startle reactivity at the first session. In fact, final startle reactivity estimates at the first session were virtually identical in individuals with low (56.8 μV) versus high (56.7 μV) RNT. RNT was unassociated with initial ($p = 0.821$) or final ($p = 0.185$) startle reactivity at day 28.

RNT also was unrelated to between-session changes in initial startle reactivity, as evidenced by a nonsignificant RNT by day interaction when rerunning the model with within-session time uncentered, $b = -0.24$, $p = 0.465$. However, RNT marginally moderated the effect of day on final reactivity when within-session time was re-centered at the final startle probe, $b = 0.48$, $p = 0.073$. Simple slopes revealed that final startle reactivity significantly decreased across sessions in those with low RNT, $b = -1.05$, $p = 0.002$, but not in those with high RNT, $b = -0.08$, $p = 0.846$.

Associations Between RNT and Habituation of Self-Reported Anxiety

RNT significantly moderated both the linear, $b = -0.02$, $p = 0.001$, and quadratic, $b < 0.01$, $p = 0.001$, effects of day in predicting self-reported anxiety (see Table 3 and Fig. 3). Contrary to hypotheses, simple slopes analyses indicated that the linear decrease in anxiety across sessions was steeper in individuals with high RNT, $b = -0.06$, $p < 0.001$, compared to those with low RNT, $b = -0.02$, $p = 0.034$. Similarly, the quadratic effect of day was significant in those with high, $b < 0.01$, $p = 0.001$, but not low, $b < 0.01$, $p = 0.223$, RNT. The main effect of RNT, its two-way interaction with rating time point, and its three-way interaction with rating time point and the linear or quadratic effects of day were all nonsignificant ($ps > .354$). Uncentering day revealed that higher levels of RNT were associated with greater self-reported anxiety (averaged across the two rating time points [before and during]) at the first session, $b = 0.44$, $p = 0.003$. Anxiety at the first session (averaged across the two rating time points) was strongly correlated with between-session habituation slopes, $r = -0.69$, $p < 0.001$.

Table 2 Results from the model examining the moderating effect of repetitive negative thinking on within- and/or between-session habituation of startle responding

Predictor	Unstandardized estimate	Interpretation
(Intercept)	54.93***	
Within-session time	−0.41***	Startle ↓ within sessions
Within-session time^2	0.01***	Startle ↓ at the beginning of sessions more than at the end
Day	−1.34***	Startle ↓ across sessions
Sex	25.11*	Females > males
Age	−0.64	
Within-session time × day	0.01	Within-session startle decline is similar across sessions
Within-session time × sex	−0.01	
Within-session time × age	0.01	
Within-session time^2 × day	< 0.01*	Within-session startle decline becomes less curvilinear across sessions
Day × sex	−0.82	
Day × age	0.02	
Within-session time × day × sex	< 0.01	
Within-session time × day × age	< 0.01	
RNT	5.91	
Within-session time × RNT	0.01	
Within-session time^2 × RNT	< 0.01	
Day × RNT	0.02	
Within-session time × day × RNT	0.01*	RNT ➔ greater between-session change in within-session startle decline
Within-session time^2 × day × RNT	< 0.01	
Random effects		
σ^2	1958.81	Residual variance
$\tau_{00\ \text{day}}$	1343.35***	Day-level random intercept variance
$\tau_{00\ \text{ID}}$	2586.59***	Person-level random intercept variance
$\tau_{11\ \text{within-session time}}$	0.18***	Within-session time random slope variance
ρ_{01}	−0.68***	Correlation between day-level random intercept and within-session time random slope

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. *RNT* repetitive negative thinking

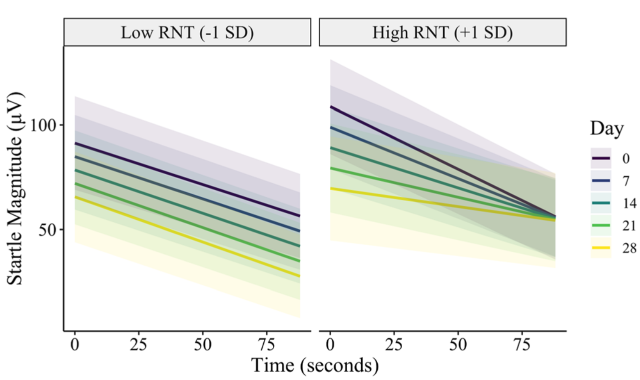

Fig. 2 The linear effect of within-session time (i.e., within-session habituation slopes) across days at low or high levels of repetitive negative thinking (RNT). Ribbons represent 95% CIs. Within-session habituation slopes are plotted for days 0, 7, 14, 21, and 28 because the mean interval between successive sessions was 7 days

Associations Between Startle Responding and Self-Reported Anxiety

To test whether self-reported anxiety was associated with the intercept or habituation of startle responding within or between sessions, three self-reported anxiety variables were entered as level 2 fixed effect predictors of startle responding in separate models: (1) self-reported anxiety before the habituation task, (2) self-reported anxiety during the habituation task, and (3) their difference (anxiety during – anxiety before). Regardless of whether within-session time and/or day were mean-centered or uncentered, the main effects of these anxiety variables and their interactions with within-session time and/or day were all nonsignificant (*ps* > 0.05). This indicates that self-reported anxiety was not associated with within- and between-session slopes of startle responding or estimated startle reactivity at various points within and across sessions.

Table 3 Results from the model examining the moderating effect of repetitive negative thinking on between-session habituation of self-reported anxiety

Predictor	Unstandardized estimate	Interpretation
(Intercept)	2.12***	
Rating time point (before vs. during the task)	0.73***	Anxiety ↑ during the task
Day	−0.04***	Anxiety ↓ across sessions
Day^2	< 0.01***	greater anxiety ↓ across earlier sessions versus later sessions
Sex	0.21	
Age	−0.01	
Rating time point × day	−0.01	
Rating time point × day^2	< 0.01*	Greater anxiety ↑ during the task at early sessions
Rating time point × sex	0.22	
Rating time point × age	−0.02*	Greater anxiety ↑ during the task in younger participants
Day × sex	< 0.01	
Day × age	< 0.01	
Day × rating time point × sex	−0.02	
Day × rating time point × age	0.00	
RNT	0.05	
Rating time point × RNT	0.08	
Day × RNT	−0.02***	RNT ➔ steeper ↓ in anxiety across sessions
Day^2 × RNT	< 0.01**	RNT ➔ more curvilinear anxiety ↓ across sessions
Rating time point × day × RNT	0.01	
Rating time point × day^2 × RNT	< 0.01	
Random effects		
σ^2	0.78	Residual variance
$\tau_{00\ ID}$	0.73***	Person-level random intercept variance
$\tau_{11\ Day}$	< 0.01***	Day random slope variance
ρ_{01}	−0.38*	Correlation between person-level random intercept and day random slope

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. *RNT* repetitive negative thinking

Discussion

RNT is a transdiagnostic risk factor for internalizing psychopathology and theoretical models suggest RNT may serve a cognitive avoidance function and impair habituation or inhibitory learning. This study examined associations between RNT and patterns of within- and between-session habituation of startle responding and self-reported anxiety. RNT was unrelated to within- or between-session habituation overall, but was associated with between-session changes in within-session habituation slopes. Follow-up analyses revealed that individuals with higher RNT exhibited less steep within-session habituation slopes at later (but not earlier) sessions. RNT also predicted the between-session time course of self-reported anxiety such that individuals with higher RNT reported greater anxiety at the first session and exhibited steeper, more curvilinear between-session habituation curves than those with lower RNT. These results are generally consistent with avoidance models of RNT and highlight the benefits of examining affective chronometry within and between sessions.

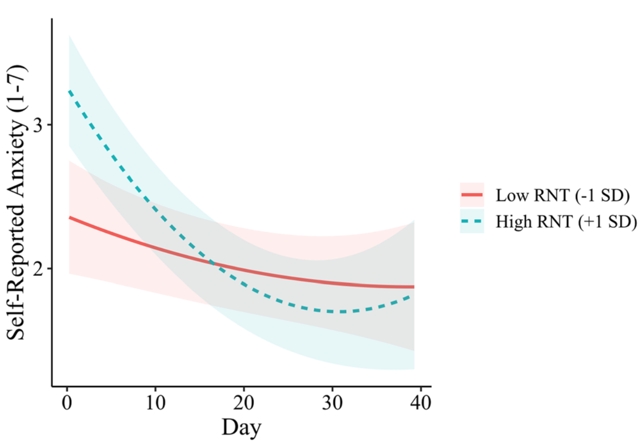

Fig. 3 Between-session habituation curves of self-reported anxiety at low and high levels of RNT. Ribbons represent 95% CIs

The lack of association between RNT and within-session startle habituation at either the mean value of day (i.e., day ~14, corresponding to session ~3) or the first session was unexpected. However, further analyses revealed that within-session habituation "stopped" after several sessions in participants with high RNT, but continued across all study sessions in those with low RNT. This effect was driven by a lack of a between-session decrease in reactivity to the final startle probe in participants with high RNT rather than differential between-session decreases in initial reactivity. Stated differently, these results suggest that participants with greater RNT have a higher startle asymptote or "floor" and may have reached this floor at the end of the first session. Those with low RNT ended the first session at the same startle magnitude as those with high RNT, but their startle responding continued to decline across all subsequent sessions due to consistent within-session and between-session habituation. As many as 13 startle probes were required to reach a startle asymptote in a previous single-session study (Lane et al., 2013), but only six probes were examined in the present study because a potential confound (the application of anxiogenic shock electrodes) was introduced after the first block of six startle probes. The number of startle probes per session and multi-session design therefore may have contributed to this pattern of results.

When evaluated alongside these methodological considerations, the startle results suggest that RNT was associated with both a higher floor and reduced within-session habituation of startle responding. This is consistent with hypotheses and theoretical models proposing an avoidant function of RNT. These models posit that RNT may be a form of cognitive avoidance of threat or aversiveness (Borkovec et al., 2004) and maintain negative affect, physiological arousal, and internalizing symptoms by interfering with emotional processing and/or inhibitory learning (Craske et al., 2008; Foa & Kozak, 1986). These results are also consistent with the contrast avoidance model of worry (Newman & Llera, 2011). This hypothesis is supported by evidence that RNT increases average startle responding (Steinfurth et al., 2017) and reduces the likelihood of a negative emotional contrast in daily life by increasing anxious arousal (Newman et al., 2019).

Regarding self-reported anxiety, we found that individuals higher in RNT reported elevated anxiety at the first session and exhibited a curvilinear decrease in anxiety between sessions, whereas individuals with lower RNT had lower anxiety at the first session and did not habituate between sessions. The finding that RNT was associated with greater between-session habituation was unexpected, but can be attributed to baseline anxiety differences at the first session and a floor effect in individuals low in RNT. In other words, anxiety in individuals higher in RNT "started" higher and thus had "farther to fall" across sessions. The positive association between RNT and self-reported anxiety at the first session is inconsistent with the startle results. This divergence is relatively unsurprising considering startle and self-reported anxiety were assessed with different frequencies and timings within each session (e.g., one of the two anxiety ratings assessed anxiety before the habituation task, whereas startle responses reflected defensive responding during the task) and the generally weak correlations between self-reported affect and physiological reactivity (Mauss & Robinson, 2009). Consistent with these considerations and divergent results, self-reported anxiety was unrelated to mean levels and within- and between-session habituation of startle responding.

These findings have several important treatment implications should they generalize to clinical samples. First, the purported avoidant function of RNT indicates that it may be helpful to target RNT alongside other maladaptive avoidance behaviors (Salters-Pedneault et al., 2004). Second, mindfulness-based interventions that support increased present-focused awareness are well-suited for reducing RNT considering RNT is typically past- or future-oriented. Third, individuals with higher RNT are more likely to drop out and psychologically disengage from treatment (Banerjee et al., 2018; Crane & Williams, 2010). The startle results suggest that within-session reductions in physiological activation may plateau after several sessions in individuals with high RNT, which may subsequently lead to disengagement and/or dropout. Assessing RNT could therefore be used to identify individuals who are more likely to have difficulty implementing mindfulness skills, perceive treatment to be less helpful, and disengage or drop out.

Strengths, Limitations, and Constraints on Generalizability

This study examined multiple features of affective chronometry (e.g., habituation slopes, initial reactivity, final reactivity) both within and across five sessions, and revealed numerous insights that would have been obfuscated in a single-session design. For example, the examination of within-session habituation at five separate sessions was crucial for elucidating the association between RNT and within-session habituation in this study, perhaps due to the habituation task containing fewer startle probes than in other studies. Other notable strengths include the examination of both physiological and self-report measures of defensive responding and higher statistical power than other studies on between-session physiological habituation.

There are several limitations that warrant further discussion. First, the sample consisted of unselected community members. Testing mechanisms associated with the time course of emotional responding in nonclinical samples is an important step toward the development and refinement of experimental models of internalizing symptoms (Grillon et al., 2019), and future studies should assess the generalizability of these results to clinical populations. Second, the two measures that were averaged to index RNT assessed trait-like tendency to engage in RNT, and it is unclear whether individuals who reported tendencies to engage in RNT actually engaged in RNT during or between study sessions. Third, we were unable to examine within-session habituation of self-reported anxiety because self-reported anxiety was only assessed twice per session. Fourth, it is possible that the observed associations are not specific to RNT and instead are due to related constructs like negative affectivity. Fifth, these findings may not generalize to studies examining responses to more prolonged aversive experiences or affect- or context-modulated startle. Sixth, these findings might be confounded by factors such as perceived stress and negative or traumatic events. These constructs were not assessed in this study, but are important to consider in future research.

Conclusion

Theoretical models highlight RNT as a potential form of cognitive avoidance involved in the maintenance of negative affect, physiological activation, and internalizing symptoms. This study found that RNT was associated with (a) a higher floor (i.e., asymptote) of startle responding as evidenced by blunted within-session startle habituation at later sessions, and (b) greater self-reported anxiety at the first session. These results provide some support for avoidance models of RNT.

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Material and/or Code Availability Data and materials are available here: https://osf.io/8j3mw/.

Ethics approval Approval was obtained from the Institutional Review Board of the University of Illinois at Chicago. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication Patients signed informed consent regarding publishing their data.

Competing interests The authors declare no competing interests.

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