Simulating Thoughts to Measure and Study Internal Attention in Mental Health

Running Head: INTERNAL ATTENTION

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# ABSTRACT

Our mind’s eye and the role of internal attention in mental life and suffering has intrigued scholars for centuries. Yet, experimental study of internal attention has been elusive due to our limited capacity to control the timing and content of internal stimuli. We thus developed the Simulated Thoughts Paradigm (STP) to experimentally deliver own-voice thought stimuli that simulate the content and experience of thinking and thereby experimental study of internal attentional processes. In independent experiments (N=122) integrating STP into established cognitive-experimental tasks, we found and replicated evidence that emotional reactivity to negative thoughts predicts difficulty disengaging internal attention from, as well as biased selective internal attention of, those thoughts, which predict cognitive vulnerability (e.g., negative repetitive thinking), which predicts anxiety and depression. Reported findings may have exciting implications for the study of internal attention broadly, models of internal attentional (dys)control in cognitive vulnerability and mental health more specifically.

Key Words: Anxiety, Attention Bias, Cognitive Control, Cognitive Vulnerability, Depression, External Attention, Internal Attention, Repetitive Negative Thinking, Rumination

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# INTRODUCTION

To adapt, survive and thrive, our minds are continuously challenged to process and respond to events in our external (i.e., sensory) and internal (i.e., mental) environments (Klinger, 1978; V. Menon & Uddin, 2010; Zabelina & Andrews-Hanna, 2016). The brain’s solution to this ever-present challenge is attention – the selection and modulation of sources and objects of external and internal information (Chun, Golomb, & Turk-Browne, 2010; Desimone & Duncan, 1995). Accordingly, dysregulation of attentional processes has long been implicated in information processing theories of prevalent mental disorders such as mood and anxiety disorders (Harvey, Watkins, & Mansell, 2004; Mogg & Bradley, 2018; Williams, Watts, MacLeod, & Mathews, 1988). Yet research to-date has focused almost exclusively on dysregulation of *external* attention (Mogg & Bradley, 2018; Van Bockstaele et al., 2014). Much less research has focused on dysregulation of *internal* attention broadly or in mental health specifically (Klinger, 1978; Zabelina & Andrews-Hanna, 2016). We argue that (dys)regulation of *internal* attention as well as the dynamic interplay between *internal* and *external* attention, may be fundamentally important to (mal)adaption and mental health. Furthermore, we argue that efforts to more directly study *internal* attention may prove critical to long-sought basic and clinical science of information processing in mental health.

## External Attention (Dys)Regulation

*External attention* is the processing of perceptual-sensory information incoming from a source external to the mind/brain such as the peripheral nervous system, originating from outside and/or within the body (e.g., visual information incoming via the eyes, proprioceptive sensations originating from the muscles) (Chun et al., 2010; Dixon, Fox, & Christoff, 2014; Gazzaley & Nobre, 2012). Theory and data suggest that external attentional processes are governed by two interacting yet distinct attentional systems – the stimulus-driven (bottom-up) and goal-directed (top-down) systems (Chun et al., 2010; Corbetta & Shulman, 2002). Dysregulation in the goal-directed system is theorized to drive (maladaptive) strategic avoidance of- or difficulties in disengaging from- emotionally evocative information (Mogg & Bradley, 2018). Dysregulation in the stimulus-driven system is theorized to drive initial orienting biases toward- and increased disruption of goal-directed behavior by- motivationally relevant, but task irrelevant, information.

## Internal Attention (Dys)Regulation

*Internal attention* is the processing of information stored in the mind, recalled from long-term or active in working memory (Chun et al., 2010). Emerging work indicates that the goal-directed/stimulus-driven systems which govern *external-perceptual* processing may also subserve processing of *internal* events (e.g., memories, thoughts) (Chun et al., 2010; Dixon et al., 2014; Gazzaley & Nobre, 2012). Executive control processes, such as working memory and response selection, are by definition *internal and goal-directed* processes (Chun & Johnson, 2011), whereas other forms of cognitive processes and states may be characterized as *internal and stimulus-driven* processes. For example, unwanted memories or involuntary remembering have been conceptualized as an automatic reflexive bottom-up process dependent on stimulus-driven forms of internal attention, or any interesting memory that enters consciousness and takes over attentional resources (Cabeza, Ciaramelli, Olson, & Moscovitch, 2008; van Schie & Anderson, 2017). Similarly, spontaneous thought has been characterized as *undirected* and often without awareness of its ontogeny (see (Fox, Spreng, Ellamil, Andrews-Hanna, & Christoff, 2015)). We propose that much like how goal-directed and stimulus-driven attentional systems may subserve external attention and its dysregulation over motivationally-relevant information (Amir, Zvielli, & Bernstein, 2016; Mogg & Bradley, 2018), goal-directed/stimulus-driven systems may also subserve internal attention and its dysregulation (e.g., difficulty disengaging from thoughts, attentional capture by unwanted memories, etc.).

## Internal Attention Dysregulation, Cognitive Vulnerability, & Mental Health

Internal attentional processes are theorized to be functionally important to mental health (Harvey et al., 2004; Huijser, van Vugt, & Taatgen, 2018; Koster, De Lissnyder, Derakshan, & De Raedt, 2011; Marchetti, Koster, Klinger, & Alloy, 2016; van Vugt, 2017). Specifically, dysregulated internal attentional processes may subserve a variety of higher-order cognitive processes which have long been implicated in anxiety and depression such as repetitive negative thinking (e.g., rumination, worry), emotional (dys)regulation, and self-focused attention (Ehring & Watkins, 2008; Goldin, Manber, Hakimi, Canli, & Gross, 2009; Gross & Jazaieri, 2014; Harvey et al., 2004; Ingram, 1990). It has been theorized, for example, that internal attention processes contribute to rumination and depression via the narrowing scope of attention to mood congruent thoughts (Whitmer & Gotlib, 2013), impaired disengagement from self-referential information (Koster et al., 2011) and subsequent difficulty inhibiting no-longer relevant information from working memory (Joormann, 2010).

Empirical, albeit indirect, evidence for these ideas may be found in working memory (WM) bias research. WM and attention are closely related processes (Awh, Vogel, & Oh, 2006; Engle, 2002; Gazzaley & Nobre, 2012; Kiyonaga & Egner, 2013) – both characterized by the selective allocation of limited-capacity processing resources between competing objects (information) (Chun et al., 2010). Recent meta-analyses report that anxiety and worry are associated with reduced performance in attentionally-demanding (but emotionally-neutral) WM tasks (Moran, 2016). Similar effects have been found for depression, although these effects are more likely observed when attention is not entirely constrained to the WM task, providing opportunity for spontaneous task-unrelated thoughts and negative repetitive thought to impair performance (Hertel, 1997; LeMoult & Gotlib, 2018). In addition, mounting evidence suggests that persons with elevated levels of repetitive negative thinking (Ehring & Watkins, 2008) also show impaired inhibition or disengagement from no-longer relevant information in WM (independent of the emotional valence of the information) (Zetsche, Bürkner, & Schulze, 2018). This body of work provides important albeit indirect evidence as to the specific or unique role(s) of internal attentional processes (e.g., biased selection, impaired disengagement) in cognitive vulnerability and mental health. Although strong and important effects, they provide only indirect evidence with respect to internal attention per se. Indeed, WM tasks by design also rely on memory processes (e.g., encoding, storage, proactive interference) affecting task performance and make inferences regarding the role(s) of internal attentional processes based on the cognitive operations required to complete these tasks (Atkinson et al., 2018; Baddeley, 2011).

## Gaps in the Study of (Dys)Regulated Attention: Theory & Method

Despite the theorized importance of dysregulated internal attention for cognitive vulnerability and mental health problems (Ehring & Watkins, 2008; Harvey et al., 2004; Joormann, 2010; Koster et al., 2011; Whitmer & Gotlib, 2013), decades of research focused on external attention and its dysregulation (Mogg & Bradley, 2018). This may be, in large part, explained by key constraints of the methodological paradigm through which (external) attention has long been measured and quantified. To measure (external) attention, methods require the capacity to experimentally control the timing, the content (or features), and the location (for spatial attention) of stimuli (Neisser, 1976; Posner, Snyder, & Davidson, 1980; Treisman, 1960). Thus, unlike readily experimentally controlled external sensory-perceptual stimuli, similar experimental control over the timing and content of a person’s thoughts may be the stuff of science fiction. We thus have no direct behavioral or cognitive-experimental task designed to measure and quantify internal attention and its dysregulation (Klinger, 1978; Mansell, Clark, & Ehlers, 2003).

Instead, to-date, we have relied on tasks such as the Sternberg and n-back designed to measure working memory proces­ses thought to rely upon or indirectly reflect internal attentional processing (Joormann & Gotlib, 2008; Kane, Conway, Miura, & Colflesh, 2007). We argue that the field may benefit from the development of a novel experimental approach to more directly measure and quantify internal attentional processing and its dysregulation. We propose that one promising means to do so is to experimentally *manipulate the phenomenology* of what are, in fact, external stimuli so that they are functionally processed and experienced as if they were internal events (i.e., one’s own thoughts). In other words, the experimental study of internal attention could be significantly advanced through the capacity to deliver stimuli that are phenomenologically-valid simulations of experience such as one’s own thoughts.

## Simulated Thoughts Paradigm & Studies Overview

We therefore developed the Simulated Thoughts Paradigm (STP). The STP is designed to deliver idiographic stimuli that simulate the *content* and the *experience* of one’s own verbal thoughts. First, we select a unique set (see Method section) of emotionally negative self-referential sentences (e.g., "I'm so alone.") and emotionally neutral self-referential sentences (e.g., "I have class soon.") per participant. Second, we audio record participants saying these selected self-referential thoughts out loud. With these simulated thought stimuli, we are able to experimentally control the timing, idiographic content (Klinger, 1978; McVay & Kane, 2013), emotional valence and intensity of participants’ own thoughts. The premise and rationale for this approach is that the idiographically-relevant content, timbre and tempo of one’s own internal voice is designed to elicit a phenomenological sense of ownership, authorship and identification with the experimentally controlled simulated thought-like stimuli that parallels similar phenomenology of one’s own spontaneous thoughts (Aldao, 2013; Hadash, Plonsker, Vago, & Bernstein, 2016; Varela, Thompson, & Rosch, 1991). Thus, the STP is designed to elicit an experience that *feels* like thinking one’s thoughts. These STP stimuli thus become phenomenologically-valid simulations of experiencing one’s thoughts. Consequently, the STP methodology is designed to phenomenologically trick brain source localization – to mis-experience (external) audio stimuli that we experimentally control, with their own internally-generated mental events.

Own-voice thought stimuli as a means to simulate verbal thought is grounded in work on behavioral and phenomenological accounts of inner speech (Alderson-Day & Fernyhough, 2015; Perrone-Bertolotti, Rapin, Lachaux, Baciu, & Lœvenbruck, 2014) and cognitive neuroscience of own-voice perception and self-representations (Kaplan, Aziz-Zadeh, Uddin, & Iacoboni, 2008). Hearing one’s own voice activates right prefrontal brain regions implicated in abstract self-representations and self-referential processes (not activated for example when hearing others’ voices) (Candini et al., 2018; Kaplan et al., 2008; Nakamura et al., 2001) nor when simply reading text (Joubert et al., 2004). Furthermore, our approach to simulated thought through one’s voice is also informed by *embodied* or *simulated* accounts of cognition (Barsalou, 2008). Broadly, mental representations or cognition are internally generated through simulation (activation) of the same modality-specific brain systems that sub-serve the encoding of perception, action and interospection. Accordingly, verbal thought is internally generated through simulation (activation) of left inferior frontal gyrus language-processing systems thought to sub-serve language production and comprehension (Aziz-Zadeh, Cattaneo, Rochat, & Rizzolatti, 2005; Nalborczyk et al., 2017). Thus, own-voice thought stimuli provide a powerful means to simulate verbal thought due to the shared neural substrate between internal thought - and external speech- production and comprehension.

**Figure 1**. Experimental Procedure. STP = Simulated Thoughts Paradigm. 1Instructions and practice trials for the Digit Categorization Task were completed before the Schema Activation procedure.

**STP Stimuli Selection and Mental Health Related Questionnaires**

Participants review 100 self-referential sentences and rate each sentence on its *frequency* and *emotional valence*. Participants also complete a battery of mental health related questionnaires.

**STP Stimuli Recording**

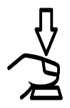
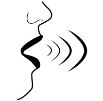
Participants are recorded speaking idiographically selected unique subset of emotionally negative and emotionally neutral self-referential sentences.

**Schema Activation**

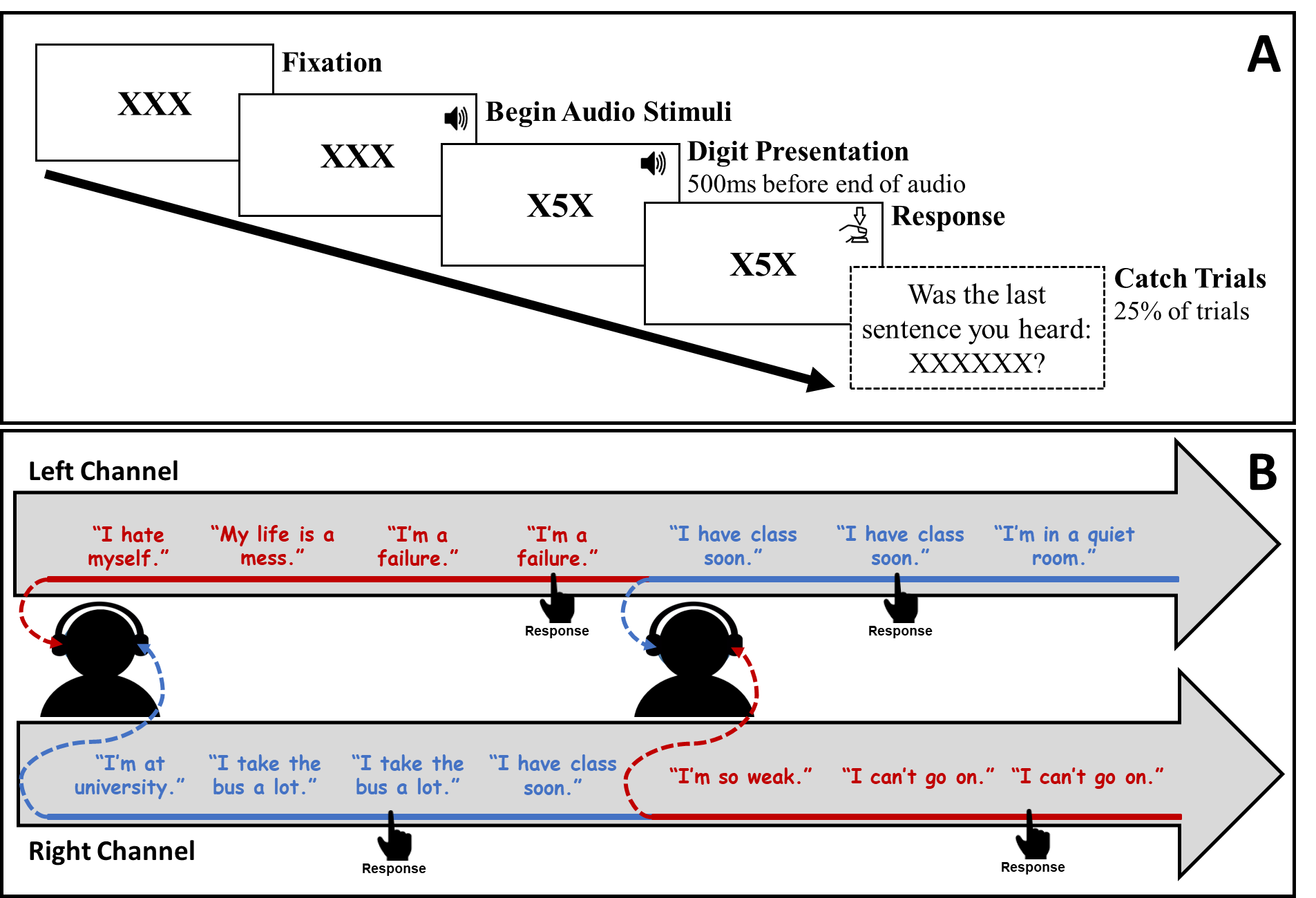
Participants rate their subjective positive and negative affect before and then after listening to their own simulated-thought stimuli.

**Attentional (dys)regulation task**

STP stimuli are presented as part of a digit categorization task1 (Study1) or dichotic 1-back task (Study 2).



In Study 1, we used the STP to test and measure (1) subjective emotional reactivity to the experience of one’s own negative self-referential thoughts; and (2) internal attentional processing of those thoughts and, more specifically, difficulty disengaging internal attention from negative self-referential thoughts to external visual stimuli and task (visual digit categorization; (Sudevan & Taylor, 1987)). First, we quantified emotion reactivity by measuring individual differences in degree of change in subjective ratings of positive and negative affect in response to the experience of one’s own self-referential thought (see Figure 1 for experimental procedure) as well as activating participants’ negative self-referential schema via exposure to their negative self-referential simulated thought stimuli. Then, STP stimuli were presented as part of an established experimental task (digit categorization - odd or even; See Figure 2A;(Sudevan & Taylor, 1987)). By integrating STP into this adapted digit categorization task, we control the content and timing of both internal thought-like STP stimuli and external-perceptual task-response-relevant target. We thereby measure and quantify difficulty disengaging internal attention *from* simulated personalized negative self-referential thought (vs personalized emotionally-neutral self-referential thought) *to* task-relevant external information. Finally, prior to the lab session, participants completed a self-report battery including measures of negative repetitive thinking (repetitive negative thinking, brooding, worry) (Ehring et al., 2011; Meyer, Miller, Metzger, & Borkovec, 1990; Treynor, Gonzalez, & Nolen-Hoeksema, 2003) as well as depression and anxiety symptoms (Beck, Epstein, Brown, & Steer, 1988; Spitzer, Kroenke, & Williams, 1999). See Method section below for additional details. In Study 2 we ran a conceptual replication of Study 1 and similarly measured emotional reactivity as well as repetitive negative thinking, rumination, worry and depression and anxiety symptom levels. Critically, in Study 2 we examined the role of selective internal attention to negative (vs. neutral) self-referential thoughts (see Figure 2B). To guard against p-hacking and inflation of family-wise alpha, all variables and analyses tested in studies 1 and 2 are reported in this manuscript; no additional measures or variables, beyond those reported here and in the Supplemental Materials (SM), were analyzed.



B

A

**Figure 2. (A)** **Digit Categorization Task.** Each trial begins with three Xs (horizontally aligned) presented at the center of the screen. After 1000 ms, participants hear an auditory negative self-referential or neutral self-referential sentence. Five-hundred ms before the endof the auditory stimulus the central X is replaced by a single visualtarget stimulus digit number (from 1 to 8) until response. Participants are instructed to press one of two keys categorizing the target digit as odd or even After response to the target digit participants were randomly (25% of trials) probed regarding the content of the sentence they heard during that trial. On 50% of catch-probe trials, the sentence presented (‘XXXXXX’ in the figure) was the same sentence heard, and on 50%, a different (incorrect) sentence was presented. Accuracy of catch trials: M(SD) = 99.46(1.99)%. **(B)** **Dichotic 1-Back Task.** Participants hear two separate lists of auditory stimuli, one list in each channel (ear). Stimuli lists are randomly mixed into intra-block sequences (i.e., 12 STP stimuli/sequence) of negative and neutral self-referential thoughts. When one channel (e.g., left side) delivers a negative stimulus the opposite channel (i.e., right side) delivers a neutral stimulus. At pseudo-random intervals, the simulated thought stimulus in one of the channels is presented sequentially (i.e., specific STP recording is repeated). Participants are asked to, as accurately and quickly as possible, press one of two buttons corresponding to the channel (LEFT/RIGHT) in which the stimulus was repeated sequentially. Biased selective internal attention is computed by subtracting accuracy in responding to repetitions in neutral stimuli from accuracy in negative stimuli. A positive bias score reflects greater selective attention to negative vs. concurrent neutral stimuli.

## Studies 1 and 2

## Aims

Using the STP, we sought to study key predictions of central models of cognitive vulnerability of depression and anxiety implicating internal attention and its dysregulation in (Ehring & Watkins, 2008; Joormann, 2010; Koster et al., 2011; Whitmer & Gotlib, 2013; Wisco, 2009). In Study 1, we hypothesized that degree of emotional reactivity (i.e., elevated negative or reduced positive emotions) to experiencing (simulated) negative self-referential thoughts will predict degree of difficulty disengaging internal attention from these thoughts (vs. emotionally-neutral thoughts) to (emotionally-neutral) task-relevant external (visual) information (Sheline et al., 2009; Wisco, 2009). Second, we hypothesized that degree of difficulty disengaging internal attention from negative self-referential thoughts will be associated with elevated levels of negative repetitive or perseverative thought, maladaptive rumination (brooding) and worry, as well as depression and anxiety symptoms (Joormann, 2010; Koster et al., 2011; Whitmer & Gotlib, 2013). Finally, per major models of cognitive vulnerability, we expected that these associations will function in a serial multiple mediation process. Emotional reactivity to negative self-referential thoughts will lead to difficulty disengaging from negative self-referential thoughts, this difficulty in disengaging will drive problems with negative repetitive self-referential thought processes (e.g., brooding), which will contribute to degree of depression and anxiety symptom levels (Ehring & Watkins, 2008; Joormann, 2010; Koster et al., 2011; Wisco, 2009) (See Figure 3). In Study 2, we aimed to replicate the predicted findings in Study 1. Specifically, we hypothesized that the same pattern of associations and serial mediation will be observed with respect to biased selective internal attention. Indeed, we expected emotion reactivity to negative self-referential thoughts would similarly contribute to biased selective attention to negative information and, in turn, drive cognitive vulnerability and thereby symptoms (Donaldson, Lam, & Mathews, 2007; LeMoult & Gotlib, 2018; Mathews & MacLeod, 1994; Susan Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008).

**Predictor**

Negative emotional reactivity

**Outcome**

Depression symptom levels (PHQ-9)

**Mediator 1**

Difficulty disengaging / Biased selective attention

**Mediator 2**

Repetitive negative thinking (PTQ)

**Figure 3.** Diagram of serial mediation Model 1 in Study 1 and Study 2. Serial indirect effect of predictor on outcome through mediators 1 & 2 = *a*1**·***d*21**·***b*2. PHQ-9 = Public Health Questionnaire, PTQ = Perseverative Thinking Questionnaire. **Study 1:** *Interference scores* were entered as the first mediator (Mediator 1) to estimate difficulty disengaging internal attention from negative self-referential thoughts and Perseverative Thinking Questionnaire scores to estimate repetitive negative thinking as second mediator (Mediator 2). In this Model 1, depression symptom levels (PHQ-9) were entered as an outcome variable and anxiety symptom levels (Beck Anxiety Inventory) as an outcome in Model 2. In addition to these two primary serial mediation models, alternative mediator 1 and 2 and predictors were tested. First, to contrast the differential functional role(s) of negative and positive emotion reactivity, we tested a model wherein the predictor was change (reduced levels of) positive affect (emotion reactivity) to one’s negative self-referential thoughts as opposed to change in negative affect. Second, to examine the hypothesized specificity of attentional *interference* scores, we also tested the serial mediation models wherein dynamic *facilitation* scoresas well as the *aggregated difference* scores were entered as mediator 1. Third, to examine the generalizability of the effects beyond a single construct and measure of cognitive vulnerability (i.e., repetitive negative thinking), we tested additional models wherein brooding or worry were entered as mediator 2. **Study 2:** Implemented the same design with *biased selective internal attentional score* as the first mediator.

d21

c'

a1

a2

b1

b2

# STUDY 1

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# METHOD

## Participants

Forty-eight participants were recruited from a university community in Israel (*M(SD)age* = 24.46(6.11) years-old, rangeage 18-39; 74% female). Potential participants were excluded from the study if they were: (a) < 18 years-old; (b) report hearing or speech difficulties; or (c) mother tongue other than Hebrew (to reflect their native internal language-of-thought), not fluent in Hebrew, or report thinking in a language other than Hebrew ("In what language do you typically think? For example, when recalling a phone number.").

## Measures and apparatus

Simulated Thought Paradigm (STP): Stimulus Selection. The STP methodology is designed to deliver idiographic stimuli that simulate the *content* as well as the *experience* of one’s own verbal thoughts. Briefly, participants reviewed a list of 100 self-referential verbal thought-like sentence items, of which 67 items were derived from established questionnaires (see SM) and classified apriori as negatively valenced (e.g., "I'm so alone.") and 33 as emotionally neutral (e.g., "I have class soon."). Participants rated (1) how *frequently* they have thoughts similar to each item, on a 5-point scale (1 = "Never have this thought" to 5 = "Think about it a lot"; (Hollon & Kendall, 1980)) and (2) to what *degree* the item/thought elicits negative or positive emotion on 7-point scale (*valence level*; -3 = "Very negative", 0 = "Neither positive nor negative", 3 = "Very positive."). For each participant, we selected the 20 negative self-referential items with highest frequency (*M(SD)* = 2.114(.892)) and negative valence (*M(SD)* = -2.262(.740)) ratings, and 20 neutral self-referential items with highest frequency (*M(SD)* = 2.450(1.126)) and nearest to neutral valence (i.e., smallest absolute value; *M(SD)* = .078(1.126)) ratings (i.e., ratings nearest to 0). Participants were then recorded speaking each sentence aloud, and these recordings where used as simulated thought stimuli within the Schema Activation and Digit Categorization tasks (below). STP methodology included modification of simulated thought stimuli using a low-pass filter. This was done to more closely simulate the perceptual sonics of hearing one’s own voice – an approach that has been previously demonstrated to increase subjective ratings of the likeness of these voice stimuli to hearing one’s own voice (Kaplan et al., 2008; Shuster & Durrant, 2003). We observed a significant difference in mean duration of negative (*M(SD)* = 1.529(.348) seconds) and neutral (*M(SD)* = 1.456(.286) seconds) stimuli in a paired samples t-test (*t(47)* = 5.052, *p* < .001). See SM for analysis ruling out duration difference scores in explaining the observed effects. See SM for additional details of specific instructions, equipment and software used for the STP recording and delivery.

Simulated Thought Paradigm (STP): Schema Activation.Participants were instructed to listen to the simulated thought stimuli “as if they were thoughts passing through your mind”. Participants reported their subjective positive and negative affect (Subjective Emotional State; see Questionnaires below) immediately after listening to the sentences (Time 1) as well as when initially arriving at the lab (Time 0). Negative emotional reactivity (NER) was calculated from subjective state emotion ratings by subtracting participants mean ratings of *negative* emotions (guilt, anxiety, anger, sadness, embarrassment, distress) before and after listening to their own simulated-thought stimuli (Time 1 - Time 0). Scores > 0 reflect elevation in negative emotion following exposure to their simulated thoughts. Positive emotional reactivity (PER) was similarly computed based on mean rating of *positive* emotions (interest, joy, amusement) before and after listening to their own simulated-thought stimuli (Time 1 - Time 0). Scores < 0 reflect reduction in positive emotion in response to the simulated thoughts.

**Simulated Thought Paradigm: Digit Categorization Task (DCT).** See Figure 2. STP stimuli were presented via an established experimental task augmented to measure and quantify difficulty disengaging internal attention *from* simulated personalized negative self-referential thought (vs personalized emotionally-neutral self-referential thought) *to* task-relevant external information. Specifically, the DCT was designed to measure attentional disengagement from stimulated thoughts (negative and neutral self-referential) stimuli to a digit categorization (odd or even) task (Sudevan & Taylor, 1987). The task consisted of 80 trials with trial type determined by the auditory stimulus (40 negative self-referential trials, 40 neutral self-referential trials; randomly presented). During each trial, three Xs (horizontally aligned) were presented at the center of the screen. After 1000 ms, participants heard an auditory negative self-referential or neutral self-referential sentence. Five-hundred ms before the endof the *auditory* stimulus the central X was replaced by a single *visual* target stimulus digit number (from 1 to 8) until response. Participants were instructed to press one of two keys categorizing the target digit as odd or even. Dependent measure was RT, reflecting time to disengage from (negative and neutral self-referential) stimuli and respond to digit target. Catch trials were used to ensure that participants processed the content of each and every simulated thought stimulus; and to motivate participants to attend to the auditory negative/neutral self-referential stimuli in a goal-directed manner so that we could help ensure that RT to external visual digit stimuli reflect speed of internal attentional disengagement from the simulated thought stimuli. Specifically, randomly following 25% of trials and immediately following participants’ response to the digit, one of the 40 negative/neutral self-referential sentences was presented on the monitor. On these catch trials, participants were instructed to indicate whether the presented sentence was or was not the last simulated thought. On 50% of these catch trials the correct answer was YES. Accuracy on catch trials was high (*M(SD)* = 99.46(1.99)%) indicating that participants indeed attended to simulated thought stimuli.

***Digit Categorization Task (DCT): Mean aggregated difference scores.*** The mean RT of neutral self-referential trials were subtracted from the mean RT of negative self-referential trials, such that a greater positive score reflects slower disengagement or greater interference aggregated across negative self-referential trials, and greater negative score reflects faster disengagement or greater facilitation.

***Digit Categorization Task (DCT): Dynamic scores.***The above noted *aggregated difference score* represents the traditional computation from similar cognitive-experimental tasks of external attention (Amir et al., 2016; Mansell et al., 2003). It has, however, also been the subject of extensive criticism and debate in recent years (Price et al., 2015; Rodebaugh et al., 2016; Zvielli, Bernstein, & Koster, 2015). Accordingly, we computed two dynamic scores in line with recent efforts to develop time-sensitive dynamic indices of attentional processing using cognitive-experimental task data (Amir et al., 2016; Evans & Britton, 2018; McNally, 2018; Price et al., 2015; Rodebaugh et al., 2016; Zvielli et al., 2015). *Attentional interference.* A running mean (9 trials window: current trial (n) and 4 trials forwards (n+4) and 4 trials backwards(n-4)) and 95% confidence interval (95%CI; RTs are log transformed for normality prior to calculation of CI) were calculated for neutral trials, and then linearly interpolated across the rest of time points (i.e., negative self-referential trials) that occurred between neutral self-referential trials. In other words, a mean and 95%CI of neutral trials RT is modelled in time for negative self-referential trials, such that each negative trial has both its "actual" RT (participant’s response time on that trial) and an estimation of RT and 95%CI of that estimation were, at that point in the task, a neutral self-referential occurred. We then (1) identify negative self-referential trials whose RT is greater – i.e., *slower* – than the 95%CI of neutral self-referential trials of that respective time-point; then (2) compute a trial-level difference score by subtracting the neutral running mean RT from that (negative) target trial's RT; finally, (3) divide that difference score by one standard deviation of neutral trials within the time window. A mean average score (of steps 2 and 3) is then calculated for all identified negative self-referential trial RTs. See Figure 4. *Attentional facilitation.* Like the dynamic interference score, a similar procedure was used to compute attentional facilitation. For facilitation, however, mean RT time is calculated only from negative self-referential trials *faster* than their respective neutral CI, and the trial-level difference score is calculated by subtracting the negative self-referential trial RT from the neutral trials running mean RT. Magnitude scores thus provide an estimation of interference and facilitation on negative self-referential trials whose RTs are likely (95% confidence) outside of the distribution of neutral trials at that specific moment in the task.

## Questionnaires

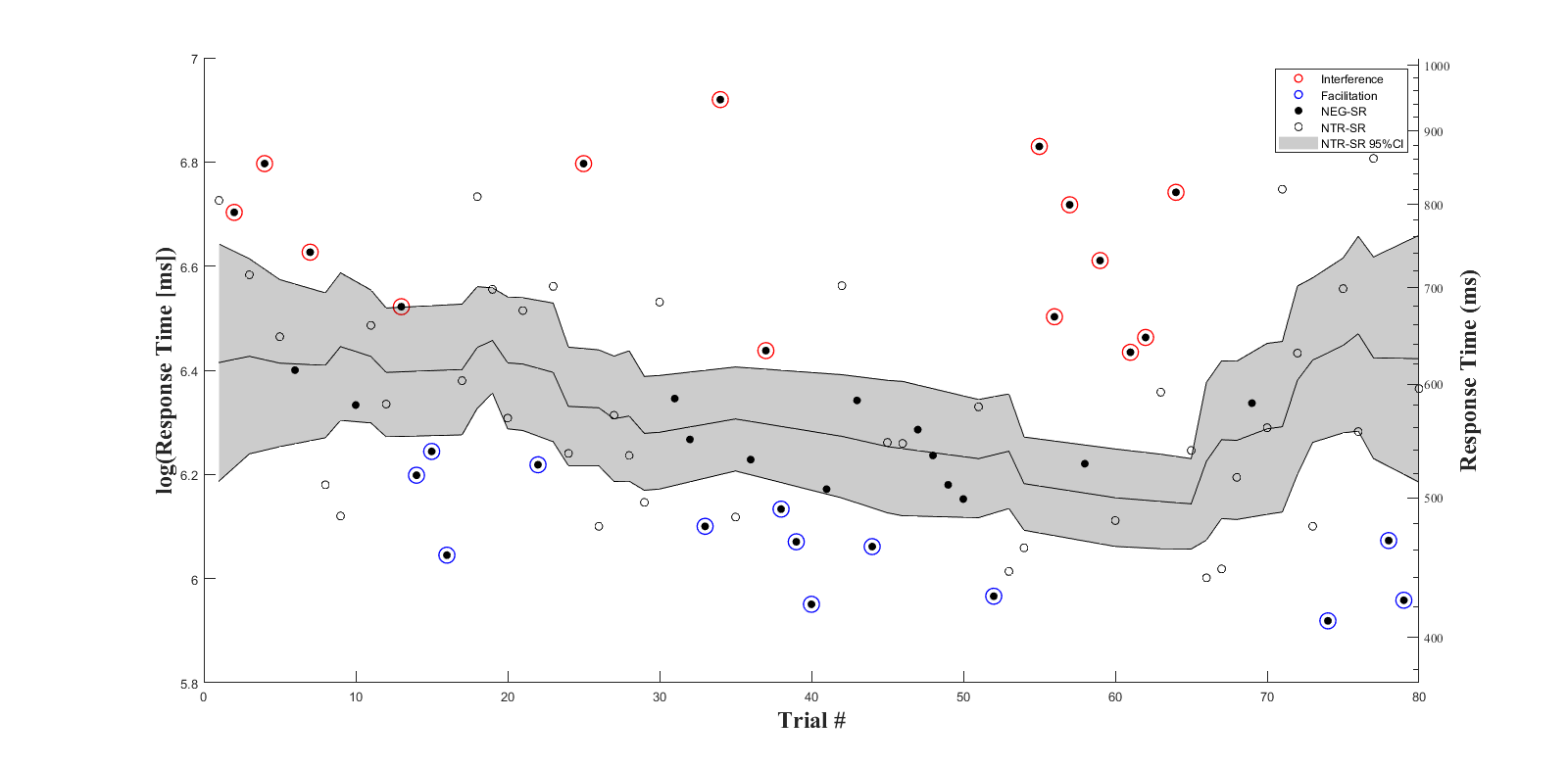
Self-report questionnaires included mental health-related measures of repetitive negative thinking (Perseverative Thinking Questionnaire (PTQ)(Ehring et al., 2011)), brooding – a maladaptive form of rumination (Rumination Response Scale (RRS) (S Nolen-Hoeksema & Morrow, 1991; Treynor et al., 2003)), worry (Penn State Worry Questionnaire (PSWQ) (Meyer et al., 1990)), as well as symptom levels of depression (Public Health Questionnaire-9 (PHQ9) (Spitzer et al., 1999)), and anxiety (Beck Anxiety Inventory (BAI) (Beck et al., 1988)) as well as momentary subjective positive and negative affect ratings (Subjective Emotional States (SES) (Plonsker, Gavish Biran, Zvielli, & Bernstein, 2017)) for negative and positive emotional reactivity.

## Procedure

Prior to the lab session, participants completed an on-line survey in which they provided initial consent and completed a battery of questionnaires – including the stimuli selection process of the STP. In the lab, participants again provided consent for the experimental lab session, rated their baseline subjective state negative and positive affect (SES), and then completed the STP stimuli recording (see SM). Participants began the practice phase (8 trials of STP stimuli) of the DCT. Following these practice trials, and before continuing to the 80 trials of the DCT, we delivered the Schema Activation via the STP – participants passively listened to their own simulated thought stimuli and again rated their negative and positive subjective state affect (SES). After completing the experiment, participants were compensated.

## **Analytic plan**

We tested study aims and predictions by examining specific paths within serial mediation models (see Figure 3). Serial multiple mediator models (Hayes, 2013) were estimated with bias-corrected and accelerated (BCa) bootstrapped confidence intervals (Preacher & Hayes, 2008; Verstynen, 2013). To aid in interpretation of individual paths within the serial mediation model we also report zero-order Pearson correlations where possible (see Table 1). All significance tests are two-tailed.

**Figure 4**. Example of response times across trials of the Digit Categorization Task. Black dots reflect RT on negative trials relative to white dots which reflect RT on emotionally neutral trials. Red circles around dots reflect trials slower than the upper-bound (+1.96SEs) of confidence of interval based on the RTs of a running window of 9 emotionally neutral trials (gray area). Blue circles around dots reflect trials faster than the lower-bound (-1.96SEs) of that running confidence of interval. Interference/facilitation scores are calculated by taking the mean of absolute difference scores (RT of each negative trial minus the running mean of neutral trials at that point in time [black line in gray area]) of interference/facilitation trials and dividing by that window’s running 1 SD. Aggregated mean bias scores are calculated by subtracting mean RT of all neutral self-referential trials (white dots) from mean RT of all negative self-referential trials (black dots).

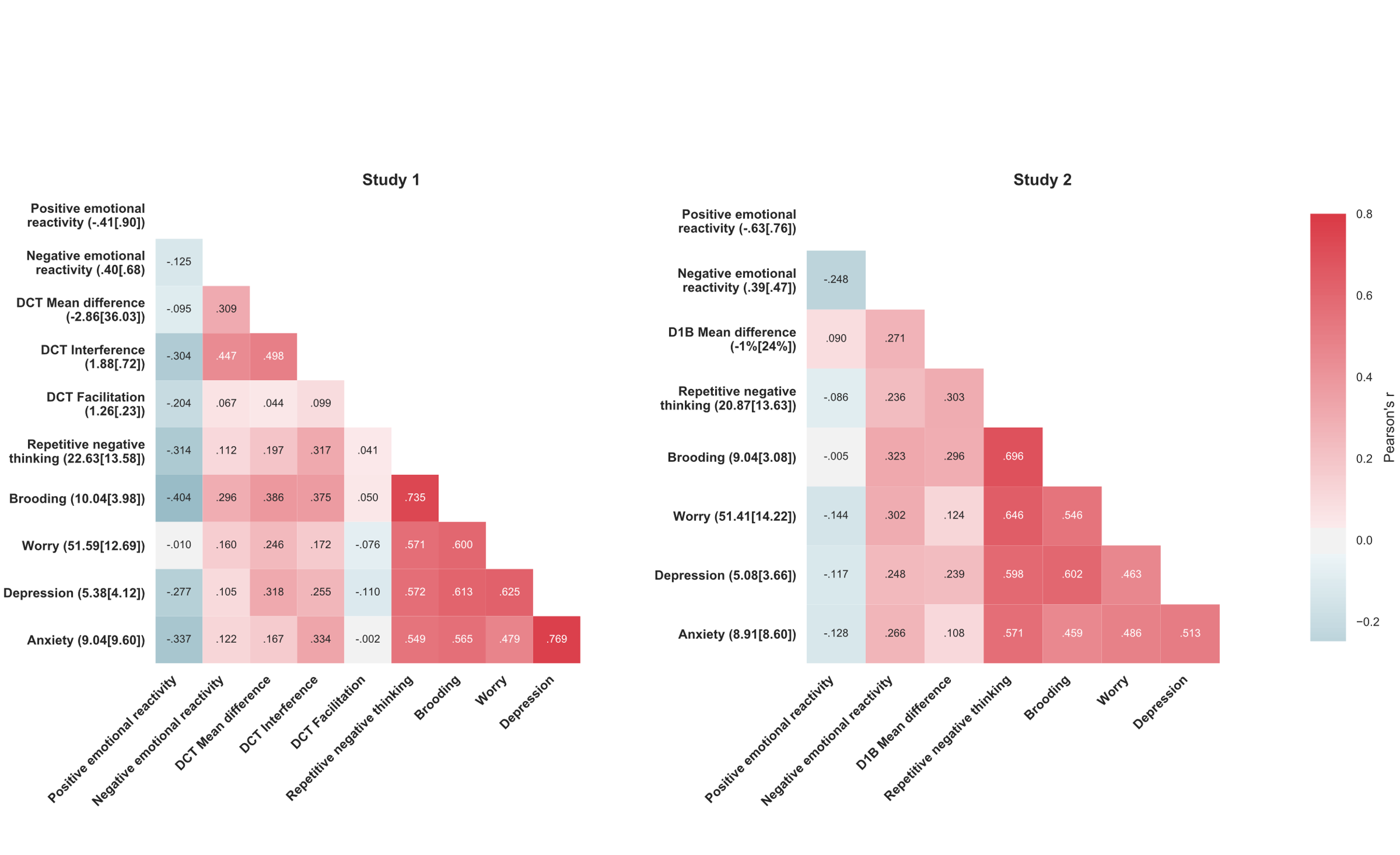
# RESULTS

## **Digit Categorization Task: Reliability**

The observed split-half reliability (based on the average of 1000 random split halves of the task) (Waechter, Nelson, Wright, Hyatt, & Oakman, 2014) was acceptable for the (1) dynamic *interference* (*r*(48) = .637, *95%CI* = .631 to .643) and (2) *facilitation* (*r*(48) = .524, *95%CI* = .516 to .532) scores, but low for the (3) *aggregated difference* score (*r*(48) = .291, *95%CI* = .282 to .301). Scores are Spearman-Brown prophecy corrected.

## **Association between emotional reactivity to- and difficulty disengaging internal attention from- negative self-referential thoughts**

We first tested the hypothesized association between emotional reactivity to one’s negative self-referential thought and difficulty disengaging internal attention from those thoughts to an external visual task. To do so, we examined the association between the predictor (negative or positive) emotional reactivity scores and first mediator (M1) attentional interference, and separately (as alternate M1s) dynamic facilitation and aggregated bias scores scores – i.e., path *a*1 in the serial mediation model (see Figure 3). As predicted, negative emotional reactivity scores were associated with interference scores (*Coeff* = .472, *BootSE* = *.172*, *BCa95%CI* = .050 to .745) (*r*(48) = .447, *p* = .001) but not facilitation scores (*Coeff* = .023, *BootSE* = .048, *BCa95%CI* = -.063 to .125) (*r*(48) = .067, *p* = .650). Likewise, negative emotional reactivity scores were associated with aggregated differencescores (*Coeff* = 16.398, *BootSE* = 6.234, *BCa95%CI* = 3.832 to 29.014) (*r*(48) = .309, *p* = .033). In contrast to negative emotional reactivity, positive emotional reactivity scores were not significantly associated with interference scores (under bias-corrected and accelerated bootstrapped confidence intervals; *Coeff* = -.244, *BootSE* = *.152*, *BCa95%CI* = .081 to -.513) (*r*(48) = -.304, *p* = .035), facilitation scores (*Coeff* = -.053, *BootSE* = .046, *BCa95%CI* = -.153 to .031) (*r*(48) = .204, *p* = .165), nor aggregated differencescores(*Coeff* = -3.845, *BootSE* = 5.436, *BCa95%CI* = -18.247 to 3.231) (*r*(48) = -.095, *p* = .519).

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**Figure 5.** Heatmaps of zero-order Pearson correlations and descriptive statistics of variables (Mean [Standard Deviation]) in y-axis labels of Studies 1 & 2. DCT = Digit categorization task, D1B = Dichotic 1-back.

## **Association between difficulty disengaging internal attention from negative self-referential thoughts and cognitive vulnerability**

We next tested the hypothesized association between difficulty disengaging internal attention from negative self-referential thoughts and problems with negative repetitive thinking. We examined the association between M1 attentional interference, and separately dynamic facilitation and aggregated difference scores (alternate M1s), and second mediator (M2) repetitive negative thinking, and separately brooding, worry (alternate M2s) – i.e., path *d*21. Negative emotional reactivity was the predictor in the model. As predicted, internal attentional interference scores were significantly associated with repetitive negative thinking (*Coeff* = 6.330, *BootSE* = 2.940, *BCa95%CI =* .775 to 12.393) (*r*(48) = .317, *p* = .028). Similar significant associations were observed for brooding (*Coeff* = 1.687, *BootSE* = .833, *BCa95%CI =* .073 to 3.385) (*r*(48) = .375, *p* = .009) but not worry (see SM). Moreover, all models with worry as the second mediator showed non-significant associations in path *d*21 as well indirect effects (path *a*1*d*21*b*2; see below). Thus, for brevity, we do not further report on worry here (but see Figure 5 and SM for details). Additionally, we tested the same associations when positive emotional reactivity was the predictor and attentional interference as M1 – no significant associations were observed (see SM for details).

As predicted, facilitation scores were not associated with repetitive negative thinking (*Coeff* = 1.983, *BootSE* = 9.507, *BCa95%CI =* 25.413 to -13.910) (*r*(48) = .041, *p* = .780) nor brooding (*Coeff* = .512, *BootSE* = 2.362, *BCa95%CI =* -4.742 to 4.681) (*r*(48) = .050, *p* = .738). Aggregated difference scores were also associated with repetitive negative thinking (*Coeff* = .068, *BootSE* = .046, *BCa95%CI =* .008 to .196) (*r*(48) = .197, *p* = .180) as well as brooding (*Coeff* = .036, *BootSE* = .013, *BCa95%CI =* .011 to .062) (*r*(48) = .386, *p* = .007).

## **Association between difficulty disengaging internal attention from negative self-referential thoughts and depression and anxiety symptoms**

We next tested the hypothesized association between difficulty disengaging internal attention from negative self-referential thoughts and depression and anxiety symptoms. To do so we examined the association between M1 attentional interference, and separately dynamic facilitation and aggregated bias scores (alternate M1s), and the outcome depression and anxiety– i.e., path *b*1 (see Figure 3). Inconsistent with prediction, there was no direct significant association between attentional interference scores and depression (*Coeff* = .445, *BootSE* = .711, *BCa95%CI =* -.856 to 1.977) (*r*(48) = .255, *p* = .081) or anxiety symptoms (*Coeff* = 2.483, *BootSE* = 2.107, *BCa95%CI =* -1.042 to 7.452) (*r*(48) = .334, *p* = .020). Furthermore, no direct associations were observed between attentional facilitation or aggregated mean differencescores and depression or anxiety.

## **Serial mediation of emotional reactivity and depression and anxiety by difficulty disengaging attention from negative thoughts and negative repetitive thinking**

Finally, we tested the hypothesized serial multiple mediating mechanism linking negative emotional reactivity, difficulty disengaging internal attention, repetitive negative thinking, and symptom outcomes. Accordingly, we examined the serial indirect paths of the estimated models – i.e., the cross product of paths *a*1, *b*2 and *d*21. See Figure 3. Results indicated a significant positive serial indirect path of M1 attentional interference and M2 repetitive negative thinking mediating the relations between negative emotional reactivity and depression (*Effect* = .495, *BootSE* = .356, *BCa95%CI*: .060 to 1.660). A similar pattern of indirect effects or evidence for serial mediation was observed with respect to anxiety symptoms (*Effect* = 1.040, *BootSE* = .828, *BCa95%CI*: .121 to 3.881). Notably, similar serial indirect effects were observed when brooding (rumination) was tested as M2, with outcomes of depression (*Effect* = .511, *BootSE* = .389, *BCa95%CI*: .058 to 1.819) and anxiety (*Effect* = 1.017, *BootSE* = .883, *BCa95%CI*: .092 to 4.490). No significant serial indirect effects were observed in models wherein positive emotional reactivity was the predictor (see SM for details). Furthermore, consistent with observed evidence of specificity of interference scores, we found no evidence of serial indirect effects for the dynamic attentional facilitation scores for either depression (*Effect* = .008, *BootSE* = .079, *BCa95%CI*: -.090 to .292) or anxiety (*Effect* = .018, *BootSE* = .168, *BCa95%CI*: -.216 to .599). Finally, when aggregated mean difference scores were entered as M1, similar effects to those observed for dynamic interference scores were observed, including significant serial mediation paths for repetitive negative thinking and brooding (M2) for depression and anxiety outcomes (see SM for details).

## **Sensitivity analysis: Ruling out alternative accounts of observed effects**

We ran additional analyses to examine the possibility that observed results were accounted for by some unexplained general slowing of RT, some artifactual RT variability, or a general neurocognitive dysfunction affecting the ability to sustain attention over time reflected in RT. In these data, such an artifact or confound, for example, could generate instability or variability of RT that is *unrelated* to differential internal attentional processing of the negative vs. neutral stimuli in the digit categorization task (Kruijt, Field, & Fox, 2016; Zvielli et al., 2015). Accordingly, we computed *pseudo-interference scores*, replacing the RT from the negative self-referential trials in the computation with RT from the neutral self-referential trials (Zvielli et al., 2015). Accordingly, for these pseudo-score analyses, participants’ scores reflect their mean RT of *neutral* self-referential trials which are *slower/longer* than the upper-bound (+1.96 *SE*) of a confidence interval of the mean of an interpolated running window of 9 neutral self-referential trials and divided by that neutral window’s running 1 SD. If effects are due to variability unrelated to attentional processing of negative self-referential thought content per se, then the pseudo-scores would have the same likelihood of catching an effect as a score based on the experimental data. Accordingly, we examined the serial mediation models reported for dynamic interference scores and traditional aggregated scores but with the pseudo-interference scores as the first mediator (M1). In both of these pseudo-interference score models, there is no evidence of serial indirect paths for depression (*Effect* = -.003; 95%CI: -.254 to .030) or anxiety (*Effect* = -.008.; 95%CI: -.254 to .030) nor a trend for such an effect. These findings indicate that observed serial multiple mediation model effects reported above are not likely accounted for by some artifactual or confounding source of RT slowing or variability or a general neurocognitive dysfunction affecting the ability to sustain attention over time that may be related to cognitive vulnerability or depression/anxiety. Thus, as theorized, the observed serial mediation model effects are more likely accounted for by difficulty disengaging internal attention from negative self-referential simulated thought stimuli in order to attend to an external stimulus and task.

# STUDY 2

# METHOD

## Participants

Seventy-four participants were recruited from a university community in Israel (*M(SD)age* = 25.24(4.63) years-old, rangeage 18-43; 70% female). Exclusion criteria was similar to Study 1 with the addition that individuals did not participate in the previous study.

## Measures and apparatus

Simulated Thought Paradigm (STP): Stimulus Selection. See Study 1.

Simulated Thought Paradigm (STP): Schema Activation. Schema Activation procedure was identical to Study 1 with one difference. Participants heard the 20 neutral STP stimuli and then immediately reported their subjective positive and negative affect immediately (Time 0), and then continue to hear the 20 negative STP stimuli and again reported their positive and negative affect ratings (Time 1). Negative/positive emotional reactivity (NER) was by subtracting participants mean ratings of negative/positive emotions at Time 0 from those at Time 1 (Time 1 - Time 0). This was done so that we could further disentangle the effects of emotionally neutral from negative self-referential simulated thoughts on emotion reactivity observed in Study 1.

**Simulated Thought Paradigm: Dichotic 1-Back Task (D1B).** This task is a novel integration of the established Dichotic Listening and 1-back experimental paradigms (Foa & McNally, 1986) designed to more closely reflect selective attention between concurrent thought-like stimuli. Participants heard two separate lists of STP stimuli, one list in each channel (ear). Stimuli lists were randomly mixed into intra-block sequences of 12 negative or neutral self-referential thoughts. When the one channel (e.g., left side) delivered a negative stimulus the opposite channel (i.e., right side) deliverred a neutral stimulus. At pseudo-random intervals the stimuli in one of the channels was presented twice sequentially (i.e., specific STP stimuli is repeated) and participants were instructed to, as accurately and quickly as possible, press one of two buttons corresponding to the channel (LEFT/RIGHT) in which the same stimuli was repeated sequentially (see Figure 2).

More specifically, intra-block sequences consisted of ten unique STP stimuli of similar valence, with two stimuli randomly repeated, accordingly for a total of 12 stimuli per chunk. The rationale behind using intra-block sequences was to allow time for participants to recognize the content of stimuli in each channel and accordingly reorient their attention towards or away from that channel – potentially affecting their identification of a repetition (see below). For example, a participant may be attending to their left channel, where a neutral stimulus is presented. Participant may then reorient their attention to examine what stimulus is concurrently presented in the right channel. A negative stimulus in the right ear may capture, or maintain, their attentional focus on the right channel. Intra-block sequences and individual stimuli onset and offsets were not temporally matched between channels, meaning that (except for the very beginning of the task) stimuli in one channel may begin (once the previous stimuli in the same channel ended) while stimuli from the opposite channel is still on-going. The task consisted of 3 blocks with a brief self-timed rest period between blocks.

***Dichotic 1-Back Task: Mean accuracy difference scores.*** A *biased selective attention score* was calculated by subtracting the accuracy for neutral stimuli from the accuracy for negative stimuli. An accurate response (for each stimulus) was the correct left/right button press for the according left/right channel in which a repetition occurred – i.e., the stimuli delivered at trial *n-1* was repeated on trial *n* (in the same channel); or the correct withholding of a response if no repetition was present (see Figure 2B). To simplify interpretation, accuracy difference scores are presented in percentages (i.e. from -100% to +100% accuracy difference).

## Questionnaires

See Study 1.

## Procedure

The procedure was divided into 3 stages – one home stage and two lab sessions. Prior to the first lab session, participants completed an on-line survey in which they provided initial consent and completed a battery of questionnaires, as well as assessment necessary for idiographic STP stimuli selection. In the first lab session, participants provided consent for the experimental lab sessions, and then completed the STP stimuli recording stage. In the second lab session, participants first completed the Schema Activation via the STP – participants passively listened to their own simulated thought stimuli and rated their negative and positive subjective state affect (SES) first after hearing the neutral stimuli and again after hearing the negative stimuli. Participants then completed the Dichotic 1-Back Task practice and test task trials. After completing the experiment, participants were compensated.

## **Power analysis**

Monte Carlo simulated power analysis (Schoemann, Boulton, & Short, 2017), based on the correlation matrix from Study 1, determined that 75 participants were needed to replicate serial mediation findings with 80% power.

## **Data scoring and analytic plan**

Identical to Study 1, we tested study aims and predictions by examining specific paths within serial mediation models.

(Hedge, Powell, & Sumner, 2018; Waechter et al., 2014)(Hedge et al., 2018; Parsons, Kruijt, & Fox, 2018)

(Hayes, 2013)

(LeMoult & Gotlib, 2018; Mathews & MacLeod, 1994)

(Goldin et al., 2009; Joormann, 2010; Koster et al., 2011; Thayer & Lane, 2000; Whitmer & Gotlib, 2013)(Donaldson et al., 2007; LeMoult & Gotlib, 2018; Mathews & MacLeod, 1994)

(Goldin et al., 2009; Lang, 1995; Lang, Bradley, & Cuthbert, 1990; Marchetti et al., 2016; Sheline et al., 2009)(Ehring et al., 2011; Koster et al., 2011)

(Joormann, 2010; Koster et al., 2011; Mathews & MacLeod, 1994; Whitmer & Gotlib, 2013)(Ehring & Watkins, 2008; Joormann, 2010; Koster et al., 2011; Whitmer & Gotlib, 2013; Zetsche et al., 2018)(Donaldson et al., 2007; Harvey et al., 2004)(Koster & Bernstein, 2015)

(Koster et al., 2011; Marchetti et al., 2016)(Joormann, 2010; Koster et al., 2011)(Amir et al., 2016; Evans & Britton, 2018; Kruijt et al., 2016; McNally, 2018; Price et al., 2015; Rodebaugh et al., 2016; Zvielli et al., 2015)(Price et al., 2015; Rodebaugh et al., 2016; Zvielli et al., 2015)(Price et al., 2015; Rodebaugh et al., 2016; Waechter et al., 2014)

(Gallagher et al., 2015)

(Zetsche et al., 2018)(Ehring & Watkins, 2008)(Fresco, Frankel, Mennin, Turk, & Heimberg, 2002)(Borkovec, Alcaine, & Behar, 2004)(Harvey et al., 2004)(Borkovec et al., 2004)(Harvey et al., 2004)

(Kaplan et al., 2008)(Varela et al., 1991)(Christoff, Irving, Fox, Spreng, & Andrews-Hanna, 2016; Lutz, Slagter, Dunne, & Davidson, 2008; Raichle et al., 2001)(Klinger, 1978; Smallwood & Schooler, 2015)(McVay & Kane, 2013; Smallwood & Schooler, 2015)(Raichle et al., 2001; Sheline et al., 2009)(A. Bernstein, Hadash, & Fresco, 2018)(Beck, 1991; Hollon & Kendall, 1980)(Aupperle, Melrose, & Paulus, 2012)(Stopa & Clark, 1993)(Fradkin, Eitam, Strauss, & Huppert, 2018)

(Koster et al., 2011)(Tang, Hölzel, & Posner, 2015)(Lutz et al., 2008; Tang et al., 2015)(Harvey et al., 2004; Shapero et al., 2018)(Amit Bernstein & Zvielli, 2014; Zvielli, Amir, Goldstein, & Bernstein, 2016)

(Meyer et al., 1990; Spitzer et al., 1999; Treynor et al., 2003)(Alderson-Day & Fernyhough, 2015; Perrone-Bertolotti et al., 2014)(Joormann, 2010; Koster et al., 2011; Susan Nolen-Hoeksema et al., 2008)(Alderson-Day & Fernyhough, 2015; Barsalou, 2008; Candini et al., 2018; Kaplan et al., 2008)

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## Author Contributions

I.A., L.R., and A.B. conceived and designed Study 1. I.A. and L.R. collected the data on Study 1. I.A. and A.B. conceived and designed Study 2. I.A. collected the data on Study 2. I.A. and A.B. analysed the data in Studies 1 & 2. I.A. and A.B. wrote the manuscript.

## Competing interests statement

A.B. has a patent application under review related to training of attention. He declares no conflict of interest related to the findings or publication of this study.