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Using what we know about threat reactivity models to understand mental health during the COVID-19 pandemic

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ABSTRACT

The COVID-19 pandemic has been accompanied by unprecedented levels of stress and threats in a variety of domains (e.g., health, livelihood). Individual differences in threat reactivity may explain why some individuals are at elevated risk for the development or maintenance of psychopathology during the COVID-19 pandemic. This article describes several prominent models, mechanisms, and components of threat reactivity (e.g., appraisals, intolerance of uncertainty, avoidance) and discusses how they might help improve understanding of changes in psychopathology during and following the COVID-19 pandemic.

The COVID-19 pandemic is an unprecedented global public health crisis. Hundreds of millions of people worldwide have been infected with COVID-19 and millions have died and continue to die from this unrelenting virus. Furthermore, many COVID-19 survivors experience a post-COVID-19 condition (often termed "long COVID"; Huang et al., 2021) involving prolonged symptoms (e.g., fatigue, shortness of breath, cognitive dysfunction) that last for at least 2 months and cannot be explained by an alternative diagnosis (Soriano, Murthy, Marshall, Relan, & Diaz, 2021). The pandemic has also been associated with increased rates of suicidal thoughts and behaviors (Dubé, Smith, Sherry, Hewitt, & Stewart, 2021) and intimate partner violence (Richards, Nix, Mourtgos, & Adams, 2021). Researching the mental health consequences of the COVID-19 pandemic is an urgent research priority (Holmes et al., 2020). Preliminary studies suggest that psychological distress and mental health symptoms generally increased in the early months of the pandemic (e.g., March–April 2020), largely returned to pre-pandemic levels in the ensuing months (Aknin et al., 2021; Robinson, Sutin, Daly, & Jones, 2021; Santomauro et al., 2021), and have wavered during the arrival of new variants of the virus (Cohen, 2021). However, there has been substantial heterogeneity in the mental health consequences of COVID-19 (Gloster et al., 2020) and it is important to understand individual differences that may increase risk for psychopathology during the COVID-19 pandemic.

Individual differences in *threat reactivity* may play a critical role in identifying who might be at particular risk for mental health difficulties during and following the COVID-19 pandemic. Threat reactivity refers to a cross-species set of processes and sensitivities that have been implicated in numerous internalizing and externalizing psychopathologies, most notably post-traumatic stress disorder, substance use, and various anxiety disorders (Lieberman et al., 2020; Stevens et al., 2021; Williams et al., 2016). The transdiagnostic nature and clinical importance of threat reactivity has made it a particularly important set of factors/mechanisms given the increased interest in alternative psychiatric nomenclatures proposed in recent years –e.g., NIMH's Research Domain Criteria (RDoC; Funkhouser et al., 2021; Zalta & Shankman, 2016), the Hierarchical Taxonomy of Psychopathology (Kotov et al., 2017), and the ability to study (and ultimately treat) threat reactivity across multiple units of analyses (Shankman & Gorka, 2015; Young et al., 2021). The goal of this paper is therefore to describe the role that different aspects and mechanisms of threat reactivity may play in the occurrence or risk for psychopathology during and/or following the COVID-19 pandemic.

Several "disclaimers" and caveats should be noted. First, the purpose of this paper is *not* to argue that threat reactivity is universally maladaptive. Like most psychological constructs, individual differences in threat reactivity are likely to be normally distributed. A *certain amount* of heightened threat reactivity (and its emotional concomitants, fear and anxiety; Daniel-Watanabe & Fletcher, 2021; Klumpp & Shankman, 2018) during COVID-19 is a healthy response to a worldwide pandemic as it promotes adaptive safety behaviors such as hand washing, social distancing, and mask wearing (Harper, Satchell, Fido, & Latzman, 2020; Knowles & Olatunji, 2021). However, both excessive *and* insufficient

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levels of threat reactivity may lead to maladaptive behaviors in response to COVID. For example, low levels of threat reactivity may, in part, lead to behaviors that increase risk for COVID-19 infection and transmission, and high levels of threat reactivity might lead to excessive distress and maladaptive risk-averse behaviors (e.g., refusal to leave home; excessive handwashing). In other words, the 'right amount' of threat reactivity is adaptive – analogous to the evolutionary advantages of reacting with fear if confronted with a present and unambiguous threat (Lang, 2010).

Second, COVID-19 is associated with different types of threats, including catching the virus oneself, having a loved one catch the virus, economic consequences, and social isolation (Coelho, Suttiwan, Arato, & Zsido, 2020). These threats also likely played different roles at different stages of the pandemic given the ever-changing landscape of case rates, mitigation strategies, virus variants, etc. Relatedly, there have been other sources of stress concurrent with the pandemic (e.g., political and racial tensions, protests) that have contributed to the mental health crisis during the last two years. Distinguishing the sources of threats/stress during the COVID-19 pandemic is beyond the scope of this paper and will be addressed, in part, by other articles in this special issue (see McLaughlin article). This paper will therefore only focus on within-individual mechanisms, processes, and features of threat reactivity and how they may play a role in COVID-related psychopathology. However, it is important to note that these within-person aspects of threat reactivity likely interact with particular sources of threat/stress in different ways in predicting psychopathology, thus creating different *vulnerability-stress interactions* (Monroe & Simons, 1991).

Third, threat reactivity may change as a result of chronic stress exposure during the COVID-19 pandemic (see McLaughlin et al., this issue for further discussion of mechanisms linking chronic stress to psychopathology). The effects of chronic or repeated stressors on threat reactivity specifically are poorly understood. Many of the aspects of threat reactivity discussed in this paper have been largely studied by averaging threat responses elicited during relatively short laboratory paradigms (Denson, Spanovic, & Miller, 2009; Duits et al., 2015; Grillon, 2002). Examining the *time course* of threat reactivity (a series of constructs often referred to as affective chronometry; Davidson, 1998) during these laboratory paradigms may provide insights into the impacts of chronic stressors on threat reactivity (Klumpp & Shankman, 2018). However, the extent to which these laboratory paradigms generalize to the chronic stressors commonly experienced during the COVID-19 pandemic is unclear.

1. Different aspects of threat reactivity could lead to adverse mental health outcomes during COVID-19

1.1. Threat appraisals

Appraisal, or the process of detecting and assessing environmental features with regard to one's well-being (Moors, Ellsworth, Scherer, & Frijda, 2013), is an important driver of emotions and behavior (Sheeran, Harris, & Epton, 2014). Threat appraisals evaluate (a) whether a stimulus or situation is potentially harmful to one's well-being, (b) the likelihood of the dangerous or negative event, (c) the severity of the event if it were to occur, and (d) the ability to cope and access resources if necessary (Carr, 1974; Lazarus, 1991; Salkovskis, 1996). Individuals with anxiety symptoms or disorders tend to display biases in each of these domains such that they tend to overestimate the likelihood of a negative event, overestimate the negative impact of the event if it were to happen, and underestimate the availability of coping resources (Salkovskis, 1996). Cognitive behavioral interventions for anxiety disorders are thought to reduce anxiety by helping patients develop more realistic and adaptive threat appraisals (Clark & Beck, 2010), and empirical studies suggest that cognitive behavioral therapy improves threat reappraisal (Draheim & Anderson, 2021), which may mediate reduction in anxiety symptoms (Smits, Julian, Rosenfield, & Powers, 2012).

Threat appraisals have played an important role in shaping thoughts, emotions, and behaviors related to COVID-19. Greater appraisals of the risk and/or severity of contracting COVID-19 have been associated with greater COVID-19-related fear and distress (Mertens, Gerritsen, Duijndam, Salemink, & Engelhard, 2020; Taylor, Landry, Paluszek, & Asmundson, 2020), intention to get vaccinated (Caserotti et al., 2021), and adherence to social distancing and avoidance of public places (Al-Hasan, Khuntia, & Yim, 2020; Taylor et al., 2020). These findings corroborate data from previous disease outbreaks suggesting that greater perceptions of the likelihood and/or severity of infection were associated with pandemic-related anxiety and safety behaviors (Rudisill, 2013). Importantly, COVID-19-related worry and protective behaviors are more strongly predicted by *perceived* COVID-19 threat than *actual* COVID-19 threat (Schmidt et al., 2021), highlighting the importance of threat appraisals in shaping emotions and behavior during the pandemic. In addition to perceived health-related threats, perceived risk of suffering personal economic losses due to COVID-19 is associated with preventative health behaviors and support for policies to mitigate COVID-19 across the globe (Nisa et al., 2021).

Considering the influence of threat perceptions on COVID-19 protective behaviors (e.g., social distancing, wearing masks, vaccination), it is worth examining how COVID-19 threat perceptions are formed. Of course, the presence or absence of known risk factors for contracting COVID-19 (e.g., number of cases in one's community) or experiencing severe COVID-19 symptoms (e.g., having chronic medical conditions) influence many people's COVID-19 threat perceptions. These known risk factors are only moderately correlated with COVID-19 risk perceptions, however (e.g., b = 0.24; Ahuja et al., 2021). The COVID-19 pandemic has been accompanied by an overabundance of information and misinformation (Naeem & Bhatti, 2020), and risk perceptions are generally influenced by what information is most salient or available (Tversky & Kahneman, 1973). Information and misinformation have been most commonly received from government agencies or officials, news media, social media, family, and/or friends. Interestingly, several studies have shown that trust in government, science, and medical professionals as information sources was associated with greater COVID-19 risk perception and greater COVID-19 knowledge (e.g., Roozenbeek et al., 2020), whereas individuals whose most trusted COVID-19 information source was other news sources or social media were less knowledgeable about COVID-19 (Sakya et al., 2021). Relatedly, the politization of the COVID-19 pandemic and associated policies in the United States has likely influenced the amount of trust placed in government officials and agencies relative to other information sources. Indeed, political affiliation was associated with COVID-19 risk perceptions and protective behaviors in the United States (Bruine de Bruin, Saw, & Goldman, 2020), and individuals may be more likely to trust government officials whose political affiliation matches their own. Reliance on unreliable information sources is likely to continue due to confirmation bias (i.e., the tendency to favor information in a way that supports one's prior beliefs; Nickerson, 1998), thereby minimizing opportunities to generate more accurate reappraisals of COVID-19 threats.

1.2. Attentional bias

Attentional bias to threat, or the preferential allocation of attention to threat-related stimuli over neutral stimuli, is adaptive for the early detection of threats. However, attentional bias to threat is heightened in individuals with or at risk for anxiety disorders (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007), and numerous cognitive theories implicate elevated attentional bias to threat in the etiology of fear- and anxiety-related psychopathology (e.g., Beck & Clark, 1997). For instance, individuals high in trait anxiety may exhibit vigilance toward threat during an early stage of immediate threat processing, followed by a later attentional allocation stage characterized by avoidance (Cisler & Koster, 2010).

There is preliminary evidence that, on average, individuals have exhibited attentional bias to COVID-19-related stimuli relative to neutral stimuli during the COVID-19 pandemic (Albery, Spada, & Nikčević, 2021; Cannito et al., 2020). More importantly, COVID-19-related attentional bias was associated with more frequent symptoms of COVID-related anxiety (Albery et al., 2021) and health anxiety (Cannito et al., 2020), suggesting that attentional bias to threat may be involved in the development of anxiety specifically regarding the COVID-19 pandemic.

Assessing, and ultimately intervening on, attentional bias is likely to require novel methods given that traditional methods of assessing attentional bias index have questionable psychometric properties and often conflate multiple distinct processes, e.g., orientation toward threat (i.e., vigilance) and disengagement from threat (Koster, Crombez, Verschuere, & De Houwer, 2004; MacLeod, Mathews, & Tata, 1986; Pettit et al., 2020). Metrics aiming to capture distinct attentional bias components may have superior psychometric properties to traditional metrics (Evans, Walukevich, Seager, & Britton, 2018), are elevated in individuals with or at risk for anxiety disorders (Evans, Walukevich, & Britton, 2016; Meissel et al., 2021), and may be differentially associated with COVID-related anxiety (Albery et al., 2021; Nasiry & Ameli, 2021). These findings from laboratory studies of attentional bias are generally consistent with results from self-report studies. Greater COVID-19 news exposure was associated with increased state anxiety (Nekliudov et al., 2020) and depressive symptoms (Olagoke, Olagoke, & Hughes, 2020), and individuals reporting greater threat-related cognitive biases perceived COVID-19 infection as being more likely and were more likely to use maladaptive emotion regulation strategies (e.g., suppression; Schudy, Żurek, Wiśniewska, Piejka, Gawęda, & Okruszek, 2020).

1.3. Avoidance

Avoidant behavior is characterized as a conscious or unconscious effort to avoid a stressor or threat, often to minimize negative thoughts and emotions brought on by the stressor (Barlow, 2004). As a behavioral response, although effective in the short-term (but see Krypotos, Effting, Kindt, & Beckers, 2015), avoidance serves to maintain fears and worries, often resulting in decreased well-being and onset of depression and anxiety disorders (Hofmann & Hay, 2018; Krypotos et al., 2015). The COVID-19 pandemic reflects significant stressors that interact with avoidant responses, resulting in decreased psychological well-being.

Avoidance behaviors can lead to psychopathology during COVID-19 through multiple pathways. Many people have gone to significant lengths to avoid exposure to the virus by significantly limiting their pre-pandemic activities (e.g., exercising, socializing with friends). While avoiding these activities can be adaptive in reducing COVID-19 risk, they can also increase risk for psychopathology by removing adaptive coping strategies and sources of social support (Solomou & Constantinidou, 2020). Another pathway through which avoidant behaviors can lead to psychopathology is when individuals disregard the threat posed by the virus (i.e., "disengagement coping"; Skinner, Edge, Altman, & Sherwood, 2003; Taha, Matheson, Cronin, & Anisman, 2014), as this could lead to maladaptive avoidance of unpleasant feelings related with the pandemic. "Disengagement coping" could also account for the significant increased frequency of binge drinking during COVID-19, findings that are especially pronounced in those with depression (Greenglass, Chiacchia, & Fiskenbaum, 2021; Weerakoon, Jetelina, & Knell, 2021). Avoiding recognition of the seriousness of the threat of COVID-19 is also risky as this can lead to unsafe behavior that can contribute to the virus spread (e.g., socializing in close physical proximity to others, refusal to wear masks in public spaces, neglecting handwashing). In sum, avoidance behaviors are multifaceted and identifying the function of the specific individual's behaviors is of the utmost importance (Hofmann & Hay, 2018). Moreover, given the transmissibility of COVID-19, avoidance behaviors likely require a "goldilocks" approach to identify the "just right" amount of avoidance behaviors.

1.4. Fear acquisition and extinction

Rachman's (1977) three-pathway model of fear acquisition suggests that fear can be acquired through either fear learning (i.e., the process by which a neutral conditioned stimulus elicits fear over time following repeated pairing with an aversive unconditioned stimulus), information transmission (i.e., being informed that a stimulus is dangerous), or modeling (i.e., observing a fearful response to a stimulus in others). Fear learning has received the most attention as a potential mechanism of pathological fear (e.g., anxiety disorders) and can be elicited by classic Pavlovian conditioning paradigms. Individuals with an anxiety disorder display elevated conditioned responding during fear learning compared to healthy controls (Lissek et al., 2005), supporting its putative etiological role in phobic anxiety disorders (Field, 2006; Grillon, 2008). Patients with anxiety disorders also exhibit difficulty inhibiting a fear response when presented with a safety cue (Lissek et al., 2005), suggesting that fear overgeneralization or impaired safety learning may also be involved (Jovanovic, Kazama, Bachevalier, & Davis, 2012). As discussed previously, fear responses are often accompanied by behaviors (e.g., safety behaviors, avoidance) that temporarily reduce distress, but may contribute to the maintenance of fear in the long term (Lovibond, Davis, & O'Flaherty, 2000). On the other hand, fear extinction is the process by which a fear response gradually decreases following repeated exposure to a feared stimulus in the absence of an associated aversive event (Myers & Davis, 2007). Fear extinction is thought to be driven by inhibition learning (Craske et al., 2008) or habituation processes (Foa & Kozak, 1986), and is impaired in individuals with anxiety disorders compared to healthy controls (Duits et al., 2015; Lissek et al., 2005). As such, fear extinction is widely studied in the context of exposure therapy, which itself is a clinical proxy of fear extinction (Craske et al., 2008).

Widespread fear learning has taken place during the COVID-19 pandemic. Previously neutral stimuli (e.g., the word "coronavirus") became conditioned stimuli and elicited a fear response (Presti, Mchugh, Gloster, Karekla, & Haye, 2020). There are a variety of aversive outcomes that might act as unconditioned stimuli in the context of COVID-19 (e.g., loss of employment, hospitalization, death of loved ones). Additionally, overgeneralized fear learning in the context of COVID-19 (e.g., exhibiting a fear response to a stimulus that is not associated with COVID-19 risk) may increase vulnerability for maladaptive COVID-19-related anxiety. As COVID-19 cases declined, many communities gradually reduced mitigation policies and allowed individuals to resume pre-pandemic activities and reduce or discontinue protective behaviors (e.g., mask-wearing, social distancing). This process resembles that of fear extinction. For example, if someone had previously avoided certain activities to minimize COVID-19 risk (e.g., dining in a restaurant) and gradually resumes those activities without experiencing any negative outcomes, they may form new beliefs about the likelihood of negative COVID-related outcomes associated with those activities. Impaired inhibitory learning could lead to the maintenance of COVID-19 fear even as COVID-19 becomes less threatening (i.e., poor inhibitory learning still prevents them from dining out in restaurants). Of course, negative outcomes may still occur when COVID-19-related threats are decreasing, which could induce rapid fear reacquisition regarding COVID-19-related threats (Woods & Bouton, 2007). Indeed, many parts of the world have experienced substantial fluctuations in COVID-19 cases and associated threats and preventative policies. Calibrating one's fear to changes in environmental threats is adaptive, and elevated fear responses during fear learning or impaired inhibitory learning during extinction may increase risk for excessive COVID-19 fear and associated mental health problems (Craske, Hermans, & Vervliet, 2018).

Although less studied than fear learning in the traditional anxiety literature, information transmission and modeling may also partially explain COVID-19 fear acquisition. For example, many people sought out information at the beginning of the pandemic to help them more accurately assess COVID-19 threats and modify their behavior accordingly (Bento et al., 2020). Modeling has also likely played a role in shaping fears associated with COVID-19, especially considering that behaviors are more likely to be influenced by modeling in times of uncertainty (Smith, Hogg, Martin, & Terry, 2007). For instance, the phenomenon of 'panic buying' (i.e., excessively stockpiling food and goods) in the initial stage of the pandemic may have resulted from many people modeling a relatively small group of over-anxious, high IU individuals (Arafat et al., 2020; Taylor, 2021). Additionally, consistent with modeling playing a role in COVID-19 fear acquisition, college students' perceptions of their peers' adherence to preventative guidelines and COVID-19 vaccination intentions were positively associated with their own behaviors and vaccination intentions (Graupensperger, Abdallah, & Lee, 2021; Graupensperger, Lee, & Larimer, 2021). The impact of modeling is also evidenced by the role of celebrities and other public figures in encouraging (or discouraging) COVID mitigation strategies (Martinez-Berman, McCutcheon, & Huynh, 2021).

1.5. Neural correlates of threat reactivity

There is a large literature of human and animal studies examining the neuroanatomy and neural circuitry involved in threat reactivity in clinical samples and in healthy populations. An extensive discussion of this literature is beyond the scope of this article and has been reviewed in other papers (e.g., Grupe & Nitschke, 2013), some of which focus on a specific component of threat processing such as fear learning (Ohman & Mineka, 2001), extinction learning (Myers & Davis, 2007), or threat attention and appraisal (Britton, Lissek, Grillon, Norcross, & Pine, 2011). Broadly, threat responses are generated in regions in the limbic system (e.g., the amygdala) and modulated by areas such as the prefrontal cortex (Marek, Strobel, Bredy, & Sah, 2013). Other regions have been implicated in reactivity to certain kinds of threats. For example, the anterior insula is involved in the anticipatory processing of uncertain threats (Shankman et al., 2014; Walker, Toufexis, & Davis, 2003). Functional neuroimaging studies suggest that individuals with anxiety and traumatic disorders often show amygdala and anterior insula hyperactivation and hypoactivation in prefrontal regions involved in emotion modulation (Etkin & Wager, 2007).

Few (if any) neuroimaging studies to date have examined neural reactivity to threatening stimuli specifically related to COVID-19. However, several studies have examined whether neural reactivity to other threats (e.g., fearful faces) assessed before the COVID-19 pandemic predicted mental health outcomes during the pandemic. For example, pre-pandemic amygdala activation to threat predicted internalizing symptoms during the pandemic and moderated the association between COVID-19-related stressors and internalizing symptoms (Weissman et al., 2021). Additionally, higher prefrontal activity during emotion regulation predicted lower stress burden during the COVID-19 pandemic (Monninger et al., 2021) and anterior insula reactivity to uncertain threat predicted negative affect during the COVID-19 pandemic (Khorrami, Manzler, Kreutzer, & Gorka, 2021). Taken together, these studies suggest that neural markers of threat reactivity may play a prognostic role in COVID-19-related psychopathology.

1.6. Neuroendocrine correlates of threat reactivity

The neuroendocrine system plays a central role in stress and emotion (dys)regulation (McEwen & Akil, 2020) and dysregulation in this system has been implicated in a variety of psychological disturbances including depression, PTSD, and anxiety (Ehlert, Gaab, & Heinrichs, 2001). Within the neuroendocrine system, acute or chronic stressors induce a psychological and physiological response to maintain homeostasis, which activates the hypothalamic-pituitary-adrenal (HPA) axis. A detailed description of the functioning of the HPA axis is beyond the scope of this paper, though it is important to note that this system is responsible for secreting cortisol which ultimately operates as a negative feedback mechanism within this system (Stokes, 1995). Subjective threat appraisals influence the neuroendocrine response (Schlotz, Hammerfald, Ehlert, & Gaab, 2011). Accordingly, threat appraisals may impact the neuroendocrine system and its role in emotion regulation during COVID-19.

COVID-19 threats have also led many to self-quarantine during the pandemic, thus increasing social isolation and feelings of loneliness (Hoffart, Johnson, & Ebrahimi, 2020). Loneliness is associated with neuroendocrine abnormalities (e.g., HPA axis activation; Doane & Adam, 2010) and internalizing psychopathologies (Shevlin, McElroy, & Murphy, 2015). Together, this suggests that the self-quarantine behavior associated with virus-related threat detection may contribute to a neuroendocrine response that underlies emotional dysregulation and potential psychopathology.

1.7. Intolerance of uncertainty

Another critical component of threat reactivity is how individuals respond to uncertainty. Uncertainty itself can be perceived as threatening (Dugas, Letarte, Rhéaume, Freeston, & Ladouceur, 1995), even in the context of reward (Nelson, Shankman, & Proudfit, 2014). Individuals with elevated intolerance of uncertainty (IU) – the dispositional inability to endure the aversive response triggered by perceived uncertainty (Carleton, 2016) – are more likely to experience anxiety and worry and engage in uncertainty-reducing behaviors in response to uncertainty (Badia, Harsh, & Abbott, 1979; Freeston, Tiplady, Mawn, Bottesi, & Thwaites, 2020; Ladouceur, Gosselin, & Dugas, 2000). IU is associated with increased risk for anxiety and depressive disorders (Correa, Liu, & Shankman, 2019; Funkhouser et al., 2021; Gentes & Ruscio, 2011) and may connote vulnerability for psychopathology due to increased contextual uncertainty during COVID-19. IU also may be a process of change in multiple cognitive behavioral psychotherapies. IU decreases during cognitive behavioral therapy (CBT) and reductions in IU are associated with reductions in anxiety disorder symptoms (Khakpoor, Mohammadi Bytamar, & Saed, 2019; Mahoney & McEvoy, 2012; McEvoy & Erceg-Hurn, 2016), suggesting that IU may be a good target for psychotherapy during the COVID-19 pandemic (Dugas & Ladouceur, 2000; van der Heiden, Muris, & van der Molen, 2012).

Preliminary studies conducted during the COVID-19 pandemic suggest that IU was associated with greater health anxiety, pandemic-related anxiety, appraisals of pandemic-related threat severity, use of maladaptive emotion-focused coping strategies, and conspiratorial thinking (Larsen, Donaldson, Liew, & Mohanty, 2021; Mertens et al., 2020; Satici, Saricali, Satici, & Griffiths, 2020; Tull et al., 2020). These results corroborate findings from a study conducted during the H1N1 pandemic (Taha, Matheson, Cronin, & Anisman, 2014). IU has also been associated with uncertainty-reducing behaviors related to health anxiety such as seeking medical information online and 'panic buying' or stockpiling supplies (Taylor, 2021). Although information-seeking regarding COVID-19 can be helpful for informing personal choices, frequent consumption of COVID-related news was associated with *greater* uncertainty (Yoon et al., 2021) and can exacerbate worry and anxiety (Soroya, Farooq, Mahmood, Isoaho, & Zara, 2021). The effect of information-seeking on COVID-19 fear and anxiety may be especially strong in individuals with high IU (Baerg & Bruchmann, 2022; Bottesi, Marino, Vieno, Ghisi, & Spada, 2021). For example, suppose a person high in IU is worried that they had contracted COVID-19 because they experienced a headache and sore throat. To attempt to reduce uncertainty, they may search for information about the likelihood of this outcome on the internet, where they would likely encounter a variety of diagnostic and prognostic explanations and probabilities, which will further trigger their intolerance of uncertainty. This would result in an escalation in worry and health anxiety (Fergus, 2013), a phenomenon termed 'cyberchondria' (White & Horvitz, 2009). Consistent with this vicious cycle, recent studies found that IU partially accounted for the associations between health anxiety/obsessive compulsive symptoms and fear of COVID-19 (Wheaton, Messner, & Marks, 2021) and between anxiety-related coping styles and compulsive buying behavior (Çelik & Köse, 2021).

Interestingly, the temporal course of COVID-19-related uncertainty coincided with the changes in symptoms of internalizing disorders (e.g., Major Depression, anxiety disorders) during the COVID-19 pandemic. The early months of the COVID-19 pandemic in the spring of 2020 were characterized by salient yet poorly understood (i.e., uncertain) threats, and this increase in uncertainty may have been involved in the development of internalizing symptoms in individuals high in IU during this time. Some COVID-related threats (e.g., COVID-19 infection) have become better understood over the course of the pandemic, thereby reducing uncertainty. On the other hand, there is ongoing uncertainty regarding other threats associated with COVID-19. For example, uncertainty regarding COVID-19 vaccines' effectiveness and potential adverse effects have been cited as reasons for vaccine hesitancy (Solís Arce et al., 2021). Individuals high in IU may be especially distressed by this ongoing elevated uncertainty, leading to especially high levels of psychopathology in these individuals. That said, IU may not impact everyone's beliefs about COVID-19. For instance, some individuals may be 100% certain in their beliefs related to COVID-19 (e.g., regarding vaccine efficacy), and IU would have little impact on mental health for these individuals.

2. How different aspects of threat reactivity might work together

Aspects of threat reactivity have largely been discussed separately thus far, but threat-related psychopathology likely arises from complex and dynamic relationships involving multiple aspects of threat reactivity (Fried & Robinaugh, 2020; Robinaugh et al., 2019). Understanding how processes such as these relate to each other both within and across biobehavioral systems (e.g., neural circuits, behavior) is a central goal of the RDoC initiative (Insel et al., 2010) and has been examined in numerous studies. For example, if an individual engages in adaptive threat reappraisals, this can accelerate extinction learning and reduce threat-related attentional bias (Blechert et al., 2015; Van Damme, Crombez, Hermans, Koster, & Eccleston, 2006). Alternatively, avoidance of feared situations prevents opportunities for extinction learning and threat reappraisal (Craske et al., 2018; Lovibond, Mitchell, Minard, Brady, & Menzies, 2009). In fact, studies have shown that individuals may infer danger from the use of avoidance behaviors even when the avoided situations are nonthreatening (Blakey & Abramowitz, 2016; Engelhard, van Uijen, van Seters, & Velu, 2015; van Uijen, Leer, & Engelhard, 2018). This in turn may reinforce potentially inaccurate threat appraisals and contribute to the persistence of attentional biases and fear (Britton et al., 2011; Heeren & McNally, 2016).

Individuals with high IU may be especially reactive to threats. In uncertain situations, individuals with high IU are prone to greater threat appraisals (Pepperdine, Lomax, & Freeston, 2018), avoidance (Flores, López, Vervliet, & Cobos, 2020; San Martín, Jacobs, & Vervliet, 2020), and neural reactivity to threat in regions including the amygdala and anterior insula (Tanovic, Gee, & Joormann, 2018). High IU is also associated with poorer threat extinction learning (Morriss, Wake, Elizabeth, & van Reekum, 2021; Morriss, Zuj, & Mertens, 2021), greater sensitivity to instructions about safety (Gorka, Lieberman, Nelson, Sarapas, & Shankman, 2014; Mertens & Morriss, 2021; Morriss, Bennett, & Larson, 2021; Morriss & van Reekum, 2019), greater threat generalization (Bauer et al., 2020), and heightened attentional biases to uncertainty (Morriss, McSorley, & van Reekum, 2018; Morriss & McSorley, 2019). These findings collectively suggest that individuals with high IU may exhibit deficits in other aspects of threat reactivity and thus be more sensitive to COVID-19 threats and struggle to adjust to changing information about COVID-19 threats and safety guidelines.

3. Conclusions

The COVID-19 pandemic has increased contextual threats worldwide and mechanisms and aspects of threat reactivity may help explain why some individuals were (and are) at increased risk for developing mental health problems during this time. Some of these threat processes may be more distal risk factors for psychopathology, whereas others are thought to be more proximally involved in etiology. Additionally, although discussed independently above, the different components and mechanisms of threat reactivity likely interact and relate in important ways (e.g., appraisals affecting avoidance behaviors; Hofmann & Hay, 2018). A common theme across threat reactivity models is that excessive threat reactivity may contribute to the development of mental health problems such as maladaptive anxiety. On the other hand, insufficient threat reactivity may lead to behaviors that increase risk for negative outcomes related to COVID-19.

Fortunately, processes involved in threat reactivity can be reduced through evidence-based interventions (e.g., exposure therapy, selective serotonin reuptake inhibitors) and federal governments in many countries have allocated funding for expanding access to mental health resources (e.g., the Consolidated Appropriations Act, 2021 in the United States). Increasing the scalability of these interventions will be important to support wider dissemination.

It is also worth noting that existing mental health interventions largely aim to *reduce* threat reactivity, but some individuals underestimate COVID-19 threats and might benefit from increased COVID-19 threat reactivity. Although comparatively less likely to contribute to internalizing mental health problems, underestimations of COVID-19 threats are associated with less engagement in recommended protective behaviors (Taylor et al., 2020) and may interfere with ongoing efforts to mitigate COVID-19 transmission. Increasing threat perceptions regarding COVID-19 remains an ongoing public health challenge (Ali, 2020). Many interventions occur at the level of the individual, but societal-level interventions (e.g., clear and consistent messaging) can also effectively modulate COVID-19 threat reactivity. Individuals with maladaptively low COVID-19 threat perceptions tend to distrust government officials and scientists (Roozenbeek et al., 2020), and delivering interventions through alternative, more trusted information sources may be more effective for modifying this group's COVID-19 threat perceptions and related behavior.

In sum, the 'right amount' of threat reactivity is adaptive for detecting and responding to threats related to COVID-19, but insufficient or excessive levels of COVID-19 threat reactivity can increase risk for mental or physical health problems. Interventions that help individuals 'calibrate' their COVID-19 threat sensitivity in accordance with available (and constantly changing) information about COVID-19 are critical for preventing these negative outcomes.

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CRediT authorship contribution statement

Carter J. Funkhouser: Conceptualization, Writing – original draft, Writing – review & editing. **David M. Klemballa:** Writing – original draft, Writing – review & editing. **Stewart A. Shankman:** Conceptualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

None.

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