AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Personality and Social Psychology:
Interpersonal Relations and Group Processes

ISSN: 0022-3514

https://doi.org/10.1037/pspi0000487

Stress Reactivity and Sociocultural Learning: More Stress-Reactive Individuals Are Quicker at Learning Sociocultural Norms From Experiential Feedback

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When interacting with others in unfamiliar sociocultural settings, people need to learn the norms guiding appropriate behavior. The present research investigates an individual difference that helps this kind of learning: stress reactivity. Interactions in an unfamiliar sociocultural setting are stressful, particularly when the actor fails to follow its rules. Although stress is typically considered a liability, more stress-reactive individuals may be more motivated to improve and, thus, quicker to learn these rules. Consistent with this idea, a pilot study found that people genetically inclined to stress reactivity, as computed by a genetic profile score across 59 single-nucleotide polymorphisms on 10 different genes, learned unfamiliar sociocultural norms from experiential feedback at a faster rate (i.e., exhibited a greater increase in accuracy across trials). Study 1 found that participants with higher acute cortisol reactivity in response to a physical stressor were faster at learning unfamiliar sociocultural norms. Study 2 conceptually replicated these results using a self-report measure of dispositional stress reactivity. Study 3 found that self-reported dispositional stress reactivity similarly predicted the rate of learning in a sociocultural task and a nonsocial task. Study 4 provided evidence for the underlying mechanism—participants higher on dispositional stress reactivity experienced more stress early in the sociocultural norm learning task, which predicted faster learning overall and lower stress later on in the task. These findings indicate that more stress-reactive individuals get more stressed out from the negative feedback that they receive in social interactions in unfamiliar settings, which motivates them to learn the relevant norms.

Keywords: stress reactivity, culture, learning, norms, cortisol

Supplemental materials: https://doi.org/10.1037/pspi0000487.supp

Jennifer Kubota served as action editor.

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All data, analysis code, and materials are available at https://osf.io/yb4ga/. This research was approved by the National University of Singapore Institutional Research Board (IRB) reference number 14-083 and approval number NUS-2222, Nanyang Technological University IRB protocols IRB-2013-09-021 and IRB-2016-05-019, the Hong Kong Polytechnic University IRB protocol HSEARS20220506001-01, and the Singapore Management University IRB protocol IRB-23-211-A144(1223).

This research was partially supported by a start-up grant provided by The Hong Kong Polytechnic University to Krishna Savani, funds provided by the Singapore Management University to Shilpa Madan, Singapore Ministry of Education Social Science Research Thematic Grant MOE2016-SSRTG-006 awarded to Krishna Savani, and Singapore Ministry of Education ACRF Tier 1 Grants RG52/15 and RG7/13 and ACRF Tier 2 Grant MOE2012-T2-1-051 awarded to Ying-Yi Hong. Parts of this research were conducted when Shilpa Madan, Krishna Savani, Desiree Y. Phua, and Ying-Yi Hong were at the Nanyang Technological University. The authors are grateful to Velvetina Lim, Ee Hwee Lau, Dayana Bulchand, Andrea Low, Samantha Seah, Gulshan Fathima, Xin Yi Lim, Sze-Ann Chong, Tricia Khoo, and Tiffany Tan for invaluable research assistance.

Shilpa Madan played a lead role in data curation, formal analysis, investigation, validation, visualization, and writing–original draft and an equal role in conceptualization and methodology. Krishna Savani played a lead role in funding acquisition, project administration, resources, supervision, and writing–review and editing, a supporting role in writing–original draft, and an equal role in conceptualization and methodology. Pranjal H. Mehta played a supporting role in conceptualization, methodology, and writing–review and editing. Desiree Y. Phua played a supporting role in data curation and writing–review and editing. Ying-Yi Hong played a supporting role in funding acquisition, methodology, and writing–review and editing. Michael W. Morris played a supporting role in conceptualization and methodology and an equal role in writing–review and editing.

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Psychological science increasingly recognizes that cognition and social interaction occur in the context of sociocultural diversity. Rather than experiencing a monolithic sociocultural environment, most people traverse diverse sociocultural settings that are characterized by people from different nations, regions, religions, ethnicities, sexual orientations, and gender identities (Morris, 2024). More people than ever before face the challenge of learning diverse norms prevalent in various settings, norms that are often tacit rather than explicitly stated—whether it is how to greet people when overseas or which pronouns to use to refer to new interaction partners. Learning the approved behaviors in unfamiliar sociocultural settings requires gleaning the correct situated actions from the feedback that social interactions provide. Past research finds that sociocultural learning hinges on different cognitive processes (i.e., implicit learning, explicit learning, and metacognition), depending on various features of the task, including how explicitly the feedback is presented (Morris et al., 2019; Savani et al., 2022). We submit that in addition to these cognitive mechanisms, learning the appropriate interaction norms in a new sociocultural setting is likely to involve psychophysiological mechanisms, which have not yet been examined in past research on this topic. Extensive research links both intercultural interactions (Berry, 2006; Rudmin, 2009) and interracial interactions to stress (Trawalter et al., 2009). Although this body of work has demonstrated that the experience of stress has numerous negative psychological consequences (Boyer et al., 2015; Trawalter et al., 2009), in the present research, we ask whether the stress induced by interpersonal interactions in unfamiliar sociocultural settings can propel more stress-reactive individuals to learn the relevant norms faster.

Stress in Unfamiliar Sociocultural Settings

Stress occurs when a person perceives a threat to their internal or external equilibrium (de Kloet et al., 2005; Wolf, 2019). This equilibrium is referred to as *homeostasis*. Stressors are triggers that disrupt homeostasis, such as physical or psychological events, and the stress response is the evolved cascade of psychological, physiological, and behavioral responses aimed at restoring homeostasis. *Stress* is a broad term used to capture these homeostatic processes, including stressors and the stress response.

Extensive research has found that people experience stress when interacting with individuals from backgrounds that are different from their own (e.g., cross-race interactions; Boyer et al., 2015; Richeson & Shelton, 2007; Trawalter et al., 2009). Such interactions are associated with stress in both majority and minority group members (Clark et al., 1999; Richeson & Shelton, 2003). For example, after being exposed to individuals with stigmatized characteristics (e.g., those with facial birthmarks, Black individuals, and poor people), nonstigmatized individuals exhibit physiological signatures of threat (Blascovich et al., 2001). Minority group members experience even greater stress from intergroup interactions if they expect the majority group member to be prejudiced (Sawyer et al., 2012). In a similar vein, people who interact with individuals in an unfamiliar cultural group also experience stress (e.g., Ward et al., 2005, 2009; Ward & Geeraert, 2016).

Prior research has identified several negative consequences of the stress induced through social interactions in unfamiliar settings. For instance, after a cross-race interaction, participants from the majority group performed worse on a task that required executive control, and this effect was particularly pronounced among people who had more prejudiced views about minority groups (Richeson et al., 2003; Richeson & Shelton, 2003, 2007; Richeson & Trawalter, 2005). The authors theorized that these effects were driven by the stress of the cross-race interactions, which placed a strain on people's mental resources, resulting in impaired executive function. Other work has shown that cross-race interactions are linked to poorer physical health outcomes and lower well-being, particularly among minority group members who anticipate prejudice from majority group members (Berger & Sarnyai, 2015; Goosby et al., 2018; Sawyer et al., 2012).

This prior work suggests that the stress of intergroup interactions has disadvantages for cognition, health, and well-being. But could this stress also have an upside in intergroup contexts? Some research indicates that the stress experienced in intercultural interactions can have positive outcomes. For example, acculturative stress, defined as a "stress reaction in response to life events that are rooted in the experience of acculturation" (Berry, 2006, p. 47), can foster effective coping (Ward, 1997) and cognitive flexibility (Crisp & Turner, 2011). However, this research focused on the general acculturative stress that individuals experienced in the new culture, which is a combination of stress from multiple sources. For example, a commonly used inventory of acculturative stress includes four items about interpersonal interactions along with 10 items about general adjustment in the new culture (e.g., living conditions, housing conditions, food, shopping, cost of living, health care, and entertainment; Black & Stephens, 1989). Thus, the role of stress experienced specifically in intercultural social interactions remains unclear. Additionally, when exposed to a stressor, people vary in the amount of acute stress that they experience; this individual difference is captured by the construct of *dispositional stress reactivity* (Zänkert & Kudielka, 2019). However, past research has not distinguished individual differences in stress reactivity from the extent to which intercultural interactions are perceived as stressful.

Research on biomarkers of stress provides hints that stress and intercultural learning are associated. A meta-analysis of 125 studies of immigrants to Western societies found that higher blood pressure, which is associated with more stress (Vrijkotte et al., 2000), was associated with greater acculturation, even after controlling for body mass index and cholesterol (Steffen et al., 2006). Similarly, a review concluded that "language-based proxy measures of acculturation were related to higher levels of stress-related inflammatory and endocrine biomarkers and to lower levels of allostatic load scores" (Scholaske et al., 2021, p. 1). Although these correlational relationships have usually been interpreted as reflecting the effect of acculturation on stress, another interpretation is that individuals who feel more stressed acculturate faster. According to this account, the stress immigrants experience has an upside: It facilitates learning and adaptation to a new culture. This interpretation aligns with evolutionary theorizing on stress—the stress response should facilitate an animal's ability to adapt to changes in their environment, promoting survival and reproduction (Del Giudice et al., 2011). Of course, the correlations may also be due to a third variable that influences both stress and acculturation.

Although consistent with our thesis, past research on stress and acculturation has several methodological shortcomings. Most of the studies are cross-sectional and, thus, do not permit clear inferences about the role of stress in intercultural learning. Specifically, if intergroup interactions are a source of stress (Richeson et al., 2003), how does this stress affect people's ability to learn the norms guiding such interactions? Furthermore, past research has focused on baseline levels of stress rather than stress reactivity. As such, this work on baseline levels of stress biomarkers is not well-suited for studying the potential benefits of stress reactivity for intercultural interactions.

Another challenge is that previous work on stress has relied on self-reported measures of acculturation rather than behavioral measures. Acculturation involves two distinct aspects: sociocultural adaptation (i.e., "the ability to fit in or execute effective interactions in a new cultural milieu") and psychological adjustment (i.e., "feelings of well-being or satisfaction"; Ward, 1997, p. 414). Past research has tended to conflate the two; however, our specific interest is in sociocultural adaptation, not in psychological adjustment. To that end, we first measure participants' stress reactivity and then expose all participants to the same intercultural task in which we measure behavioral responses indicative of sociocultural learning. We then test whether stress reactivity serves as an antecedent of sociocultural learning and also assess whether the acute stress experienced acts as an underlying mechanism.

Individual Differences in Stress Reactivity

The last decade has seen significant advances in basic research on human stress reactivity and its physiological substrates (e.g., Crum et al., 2013; Knight & Mehta, 2017; Schultheiss & Mehta, 2019). We leverage this work to examine stress reactivity as an antecedent of sociocultural learning in different ways.

The physiological stress response includes two primary systems: the sympathetic nervous system (SNS) and the hypothalamic-pituitary-adrenal (HPA) axis (de Kloet et al., 2005). When people perceive a threat in the environment, their SNS is activated rapidly and facilitates bodily changes, such as increased heart rate and blood pressure. The perceived threat also activates the HPA axis, which operates on a relatively slower timeline (Wolf, 2019). Neural stimulation in the hypothalamus triggers the release of corticotropin-releasing hormone (CRH) into the hypophyseal portal system, a network of blood vessels connecting the hypothalamus to the anterior pituitary gland in the brain. In the anterior pituitary gland, CRH initiates the release of adrenocorticotropin hormone (ACTH) into the bloodstream. ACTH travels to the adrenal glands, located on top of the kidneys, and stimulates the secretion of cortisol from the adrenal cortex into the bloodstream (Zänkert & Kudielka, 2019).[1]

Although unfamiliar situations and uncomfortable interactions trigger HPA axis responses for most people, people differ in their HPA axis reactivity. That is, the magnitude of the acute stress response evoked by the same stressor is larger for some individuals than others (Zänkert et al., 2019). This insight has led researchers to pinpoint biological and psychological attributes that contribute to factors that drive variation in HPA axis stress reactivity. Genetics is one source of this variation. In particular, single-nucleotide polymorphisms (SNPs) on genes that regulate different components of the HPA axis, including genes related to the functioning of CRH, glucocorticoid, and mineralocorticoid receptors, influence HPA axis stress reactivity (Hartling et al., 2019; Mahon et al., 2013; Plieger et al., 2018; Zänkert et al., 2019). This work suggests that genetic markers linked to HPA axis activity can be valuable for testing the hypothesis that stress reactivity is an antecedent of sociocultural learning.

Another line of work has identified a psychological factor implicated in the stress response, referred to as dispositional stress reactivity (Schlotz, Hammerfald, et al., 2011; Schlotz, Yim, et al., 2011). Dispositional stress reactivity is defined as a person's stable tendency to experience heightened stress responses following exposure to acute stressors, including physiological and psychological stress responses (Schlotz, Yim, et al., 2011). Dispositional stress reactivity shows temporal stability over several weeks and predicts both acute HPA axis stress responses, assessed with changes in cortisol levels, and situation-specific perceived stress following exposure to well-validated laboratory stressors (Schlotz, Hammerfald, et al., 2011; Schlotz, Yim, et al., 2011). Situation-specific perceived stress also mediates the association between higher dispositional stress reactivity and increased HPA axis stress reactivity (Schlotz, Hammerfald, et al., 2011). Thus, the psychological construct of dispositional stress reactivity can also be valuable for studying stress reactivity as an antecedent of cultural learning.

Sociocultural Learning

Although people can learn the norms of a new sociocultural setting through instruction and studying, as social norms are often implicit, much of this learning likely happens through experiential feedback—people try different behaviors and learn about their appropriateness from the positive or negative reactions they receive. By *experiential learning* (or *reinforcement learning* and *trial-and-error learning*), we mean "learning what to do—how to map situations to actions—so as to maximize a numerical reward signal. The learner is not told which actions to take … but instead must discover which actions yield the most reward by trying them" (Sutton, 1992, p. 1). This form of learning is relevant to social interactions; for example, when in a new sociocultural setting, people need to learn the locally appropriate greetings and conversational norms (e.g., Hwang & Hughes, 2000; Pierce & Schreibman, 1995). Importantly, experiential learning is particularly relevant to the norms of interpersonal interactions that are tacit, probabilistic, and multiply determined (Gluck & Bower, 1988; Savani et al., 2022).

Based on the idea that agents learn rules by interacting with the environment and receiving feedback, studies measure learning by asking participants to make choices in situations with various cues and providing them with feedback about whether they made the correct choice (Foerde et al., 2006; Knowlton et al., 1996; Poldrack et al., 2001; Shohamy et al., 2004). Drawing on this literature, we define learning as participants' increased frequency of making choices that conform to the unstated, underlying rule. As the

[1] Cortisol is a catabolic hormone whose primary function is to mobilize glucose (energy; Stachowicz & Lebiedzińska, 2016). For example, cortisol stimulates gluconeogenesis in the liver. Cortisol also promotes vigilance to threats in the environment and downregulates other physiological systems less relevant to immediate threats, including the immune system (de Kloet et al., 2005). Cortisol crosses the blood–brain barrier and influences cognitive processes, such as learning and memory, by binding to glucocorticoid and mineralocorticoid receptors in the brain (Wolf, 2019). The effects of cortisol on target issues occur through relatively slower-acting genomic mechanisms of action, on the order of minutes to hours, as well as faster-acting nongenomic mechanisms (Wolf, 2019). The HPA axis stress response is terminated through a negative feedback loop, whereby elevated cortisol levels suppress the secretion of CRH in the hypothalamus and ACTH secretion in the anterior pituitary gland (Zänkert & Kudielka, 2019).

relationship between cues and outcomes is probabilistic, participants use the response-contingent feedback in each trial to update their mental representation of the rule. The better people are at updating, the more quickly their choice accuracy will improve (Foerde & Shohamy, 2011; Poldrack et al., 2001).

Stress Reactivity and Sociocultural Learning

When entering culturally unfamiliar settings, people typically do not know the unwritten rules that guide various kinds of social interactions. They have to learn the appropriate response contingencies from trial-and-error experimentation and feedback. Positive feedback may come from an interactant's nod or smile. Negative feedback may come from their expressions of discomfort or disapproval. Negative feedback indicates a need for improvement and a lack of cultural fluency (Lin et al., 2019; Mourey et al., 2015; Oyserman, 2011). Although stress is typically perceived as a negative state, we posit that people with higher stress reactivity would experience more subjective stress when they receive frequent negative feedback in social interactions, which would motivate them to learn the underlying norms, which would, in turn, reduce the frequency of negative feedback and, therefore, reduce their level of experienced stress (e.g., Dickerson & Kemeny, 2004; Shirtcliff et al., 2014).

Past research has found that stress reactivity plays an important role in directing people's attention to social cues (Shirtcliff et al., 2014). For example, individuals with higher stress reactivity are more responsive to others' distress (Roozendaal, 2000) and feel more empathy (Shirtcliff et al., 2009). Similarly, individuals with higher stress reactivity are more vigilant to negatively valenced social stimuli (Roelofs et al., 2007). For instance, police officers with higher cortisol reactivity to a social stressor made fewer errors in choices about how to respond in dangerous situations, presumably because higher stress reactivity heightens attention and vigilance (Akinola & Mendes, 2012), but likely also because stress reactivity increases people's sensitivity to negative social cues (Roelofs et al., 2007; Shirtcliff et al., 2009). Drawing on these findings, we posit that more stress-reactive people would experience greater acute stress from the negative feedback that they receive in sociocultural interactions, which would motivate them to learn the relevant norms faster to avoid additional negative feedback. Thus, we hypothesize that people with greater stress reactivity will be faster at learning sociocultural norms from experiential feedback.

From this perspective, the role of stress reactivity may not be the same when learning analogous nonsocial rules. Past research on stress and learning (which exclusively focused on nonsocial rules) typically compares an acute stress condition (in which stress is induced through an exogenous task) against a nonstress control condition. These studies have found that acute stress increases people's attention to positive feedback and aids performance (Lighthall et al., 2013). However, this finding does not hold when the learning tasks require working memory or sophisticated choice strategies (Otto et al., 2013). Induced stress was associated with enhanced performance on a procedural memory task but worse performance on a rule-based hypothesis testing task (Ell et al., 2011). Overall, this body of research suggests that in nonsocial domains, the relationship between stress and learning is complex and likely depends on numerous contextual factors (Mather & Lighthall, 2012). Hence, the advantage of stress reactivity that we propose may be specific to social learning. However, as these mixed findings were derived from studies manipulating induced stress rather than studies measuring stress reactivity, it is also possible that individual differences in stress reactivity similarly predict learning in social and nonsocial contexts.

A final issue relevant to our proposal is the form of the relationship between stress reactivity and learning. Previous research has focused primarily on linear relationships between stress reactivity and cognition, but some work has found curvilinear relationships (Lupien & McEwen, 1997). For example, one study found an inverted U-shape between cortisol levels and memory, whereby moderate levels of cortisol resulted in better memory recall compared to low or high cortisol (Schilling et al., 2013). Although cortisol levels were manipulated rather than measured in this study, the authors suggest that their results may have implications for the role of stress in learning because cortisol levels increase following exposure to acute stressors. In addition, research on stress and social processes has largely overlooked nonlinearity (von Dawans et al., 2021). Thus, beyond testing our primary hypothesis for a linear relationship between stress reactivity and sociocultural learning, we also explored curvilinear associations.

Overview of Studies

We conducted five studies to investigate the relationship between individuals' stress reactivity (the independent measure), acute stress experienced during the learning task (a potential underlying mechanism), and the rate at which they learn sociocultural norms of an unfamiliar setting (the dependent measure). Specifically, we test whether people who have higher stress reactivity (as assessed by their HPA genetic profile score [GPS], cortisol reactivity to an exogenous physical stressor, and self-reported dispositional stress reactivity) experience more perceived stress during the sociocultural norm learning task, which, in turn, predicts faster learning during the task.

As stress reactivity can be affected by people's life experiences (Rao et al., 2008), there remains the possibility that people's ability to learn diverse norms influences their stress reactivity and not the other way around. It is also possible that some other aspect of life experience influences both of these variables. Clearer evidence would come from biomarkers that are truly exogenous to a person's life experiences. These can be found in gene variants people are born with that predispose them to greater or lesser stress reactivity. Thus, in a pilot study, we assess HPA axis GPSs, which have been previously shown to predict HPA axis stress reactivity following exposure to a stressor (Hartling et al., 2019; Zänkert et al., 2019).

In Study 1, we assess participants' acute cortisol reactivity in response to a physical stressor (i.e., the cold pressor) and test whether this reactivity predicts the rate at which they learn novel sociocultural norms. The next three studies use a validated self-report measure to assess individuals' dispositional stress reactivity; this measure has been known to predict both cortisol reactivity and the subjective experience of acute stress following exposure to a social stressor (Schlotz, Hammerfald, et al., 2011; Schlotz, Yim, et al., 2011). Specifically, Study 2 tested whether people scoring high on dispositional stress reactivity are faster at learning unfamiliar sociocultural norms through trial and error. Study 3 compared the relationship between dispositional stress reactivity and people's ability to learn parallel social versus nonsocial norms. Finally, Study 4 tested the underlying mechanism—individuals higher in dispositional stress reactivity experience more stress in the initial phase of the norm learning task, which predicts faster learning later in the task. This multimethod approach with three complementary measures of stress reactivity (two of which are not self-reported, and all of which have been linked to the HPA axis) allows us to provide convergent tests of our key hypothesis that stress reactivity is associated with faster sociocultural learning.

We measured people's rate of learning diverse sociocultural norms in lab-based tasks, simulating the experience of navigating social interactions with people from different communities. Following past research (Morris et al., 2019; Savani et al., 2022), participants made behavioral choices in multiple interactions and received feedback on their accuracy. Following past research in the learning and memory literature (e.g., Ashby & Maddox, 2011; Maddox et al., 2004) and in the social norm learning literature (Morris et al., 2019; Savani et al., 2022), we operationalize learning as the change in participants' probability of making the culturally appropriate choice across successive trials (i.e., the slope of the change in accuracy across successive trials).

Data Analysis Approach

For each trial of the sociocultural norm learning task, participants made either the normatively correct decision or the normatively incorrect decision as per American norms. We assessed how participants' accuracy changed across the 50 trials. We would expect participants to be at near-chance levels in the beginning, but as they receive feedback, their accuracy is likely to increase as they encounter more trials. We thus modeled the slope of each participant's learning curve and assessed whether this slope varied as a function of their GPS.

Across all studies in the current research, we followed past research on learning (Bogaerts et al., 2018; Morris et al., 2019; Savani et al., 2022) to model the slope of participants' learning curves (i.e., the change in their accuracy across successive trials) in the sociocultural learning task using a multilevel model (Raudenbush & Bryk, 2002), treating the trials as nested within participants. We used a hierarchical logistic regression because our dependent variable was at the trial level, that is, whether participants' response on a given trial was consistent or inconsistent with the predetermined rule that served as the basis for the feedback; this was binary in nature (incorrect = 0, correct = 1). The predictor variables were trial order (coded such that the first trial = 0 and the last trial = 1),[2] participants' stress reactivity score, and interaction between trial and stress. Given this coding, the effect of trial represents participants' change in accuracy from the first trial to the last trial, that is, their learning *rate over the entire length of the learning task.* The slope of the trial order was treated as varying across participants, and the covariance between participants' average accuracy and the slope was estimated. Simply stated, this model first runs a logistic regression for each participant to estimate the participants' learning curve slope (in the *log odds* unit) and then assesses how participants' slope varies as a function of their stress reactivity (see Raudenbush & Bryk, 2002, Chapter 10, for details).

Transparency and Openness

Following the Transparency and Openness guidelines, all materials, anonymized data, and analysis code for this research are publicly available at https://osf.io/yb4ga/. Any additional variables and analyses are reported in the Supplemental Materials. Studies 3 and 4 were preregistered.

Pilot Study

The goal of this study was to provide a preliminary test of the hypothesis that stress reactivity is an antecedent of sociocultural learning. Specifically, we measured a GPS that taps into individual variability in HPA functioning, including genes related to the functioning of glucocorticoid receptors, mineralocorticoid receptors, and CRH. We tested whether people with a GPS indicating increased HPA axis stress reactivity are faster at learning the norms of an unfamiliar culture.

GPSs are calculated using large sample genome-wide association studies and have been used to predict educational attainment (Rietveld et al., 2013), depressive symptoms (Okbay et al., 2016), alcoholism (Salvatore et al., 2014), and their general risk of developing psychiatric disorders (Cross-Disorder Group of the Psychiatric Genomics Consortium, 2013), among many other outcomes. The GPS we calculated has been associated with differences in reactivity to stressors in the environment (e.g., Hartling et al., 2019; Mehta & Binder, 2012; Pagliaccio et al., 2014; Wasserman et al., 2010).

Method

Participants

In earlier research, Phua et al. (2017) sampled 820 Singaporean undergraduate students. At the time of the present study, 477 of these students had completed all measures that were part of the primary project and were thus available for us to recruit for the present study. After repeated invitations, only 73 students participated in the present study. Of these, 59 students were successfully genotyped (Phua et al., 2017). This comprised our final sample (40 women, 19 men; M_{age} = 22.32 years; 53 citizens of Singapore, six citizens of China; 54 ethnic Chinese, three Malays, and two Indians). Although our sample size is very small, we sought to maximize statistical power in two ways. First, we used a precise measure of participants' genetic tendency toward a more reactive stress system, which was assessed by a weighted average of 63 different genetic variations. Second, we measured participants' sociocultural norm learning using a 50-trial task, which gave us a relatively precise measure of the slope of participants' learning curve. A repeated-measures design such as this, with many data points per participant, has a much higher statistical power than a between-subjects design with one data point per participant because it controls for between-subjects error variance (McClelland, 2000).

[2] For ease of interpretation, we used the formula "trial_recoded = (trial_original − 1)/49," which converted the original trial numbers ranging from 1 (first trial) to 50 (last trial) to new trial numbers ranging from 0 (first trial) to 1 (last trial).

Genotyping

Participants' buccal cells were collected using MasterAmp Buccal Swabs (Epicenter Technologies). Genomic DNA was extracted from these buccal swabs using MicroElute Genomic DNA (OMEGA Bio-Tech). These DNA samples were genotyped using the Illumina Infinium PsychArray BeadChip, which resulted in the successful extraction of 277,383 SNPs (see Phua et al., 2017, for details). Following Phua et al. (2017), we selected genes based on past research that examined the effects of genetic variations related to the stress system on psychiatric disorders (Arnett et al., 2016; Leszczyńska-Rodziewicz et al., 2013; Schatzberg et al., 2014). Specifically, we examined all single-nucleotide variations across 10 different genes, including glucocorticoid receptor genes NR3C1 and NR3C2, CRH receptor genes CRHR1 and CRHR2, immunophilin protein gene FKBP5, serotonin-related genes SLC6A4 and TPH1, opioid receptor gene OPRM1, and GABA receptor gene GABRA6.

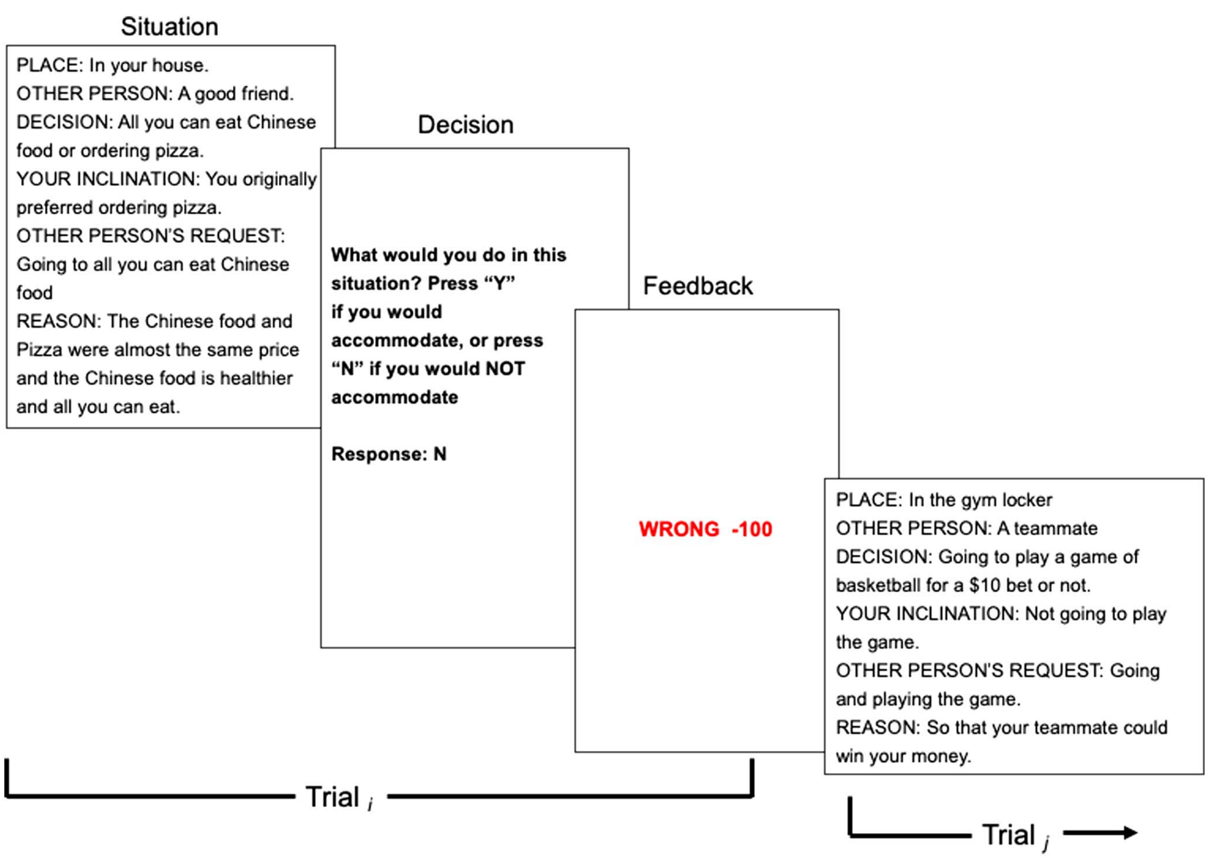
Of these, 73 SNPs were included in the genome-wide association study (GWAS) conducted by the Cross-Disorder Group of the Psychiatric Genomics Consortium (2013), which was used as the reference study for the current research. Of these 73 SNPs, only 63 SNPs associated with the risk of developing psychiatric disorders in the GWAS with p values below 0.5 were used to calculate the GPS (please see the Supplemental Materials, pp. 2–3, for the list of SNPs and their associated weights). Such a lenient threshold is common in GWAS because many SNPs may not have statistically significant effects, but the cumulative effects of a large number of nonsignificant SNPs combined can be substantial (Evans et al., 2007). The odds ratio of these SNPs in the GWAS was log-transformed and used as weights to compute each participant's stress system GPS.

Sociocultural Norm Learning Task

The sociocultural norm learning task in this study was a social influence task that presented participants with 50 unique interpersonal situations that detailed the nature of an interaction between an *influencer* and an *influencee* that had occurred in the United States (Morris et al., 2019, Study 1). Our Singaporean participants had to learn when to accommodate and when not to accommodate in the American influence situations.

Specifically, participants were informed that the situations were sampled from the United States, and their goal was to learn to make decisions like Americans. In each trial (see Figure 1), we presented participants with a brief description of an interpersonal influence interaction sampled from the everyday experiences of U.S. college students (Savani et al., 2011, Study 2). In each trial, we described

Figure 1
Example Trial From the Task in the Pilot Study



Note. See the online article for the color version of this figure.

(a) the relationship between the influencer and the person being influenced (the *influencee*), (b) the options that the influencee faced, (c) the influencee's initial inclination, (d) the influencer's request, and (e) the influencer's motive for the influence (see Figure 1).

In a previous study (Savani et al., 2011, Study 4), American students rated whether accommodating the influencer's request would have positive or negative consequences for the influencee in each of these situations. Based on these participants' average responses, we assigned a "culturally correct decision" to each of the 50 situations. Across the 50 trials, no situations were repeated, and there was no uniform correct response—accommodating the influencer's request was the normatively correct decision in 48% of the situations, whereas declining the influencer's request was the normatively correct decision in the remaining 52% of the situations. Thus, our Singaporean participants had to learn when to accommodate the influencer and when to resist the influencer in American influence situations. Any practice effects (e.g., participants learn to give the same response across multiple trials) would necessarily result in chance accuracy over successive trials as neither accommodation nor resistance is uniformly the correct response; instead, participants need to discriminate the types of situations in which they should accommodate (48% of the trials) versus in which they should resist (52% of the trials).

To maintain participants' attention in the face of a relatively long and tedious task, we informed them that the best-performing participant would receive a bonus of $50 Singapore dollars (approximately U.S.$40 at the time of the study). Participants were presented with the 50 U.S.-sourced influence situations in random order. Each situation was displayed on the screen for a minimum duration, depending on the paragraph length (400 ms per word). Thereafter, participants had to decide whether or not to accommodate the influencer's request. Immediately after participants made a response, they received feedback based on whether they made the normatively correct decision as per American norms. Specifically, participants saw either "CORRECT +100 points" or "WRONG −100 points" displayed in either green- or red-colored font, respectively, for 2 s, followed by the next situation. This task was administered using the DirectRT software.

Results

The dependent variable was the participant's accuracy on each trial (incorrect = 0, correct = 1), which indicated whether our Singaporean participants' response was consistent with what a majority of American participants in a previous study perceived as the culturally appropriate action. The predictor variables were trial order, participants' HPA axis GPS (standardized), and a Trial Order × GPS interaction. The slope of the trial order was treated as varying across participants, and the covariance between participants' average accuracy and the slope was estimated. Participants' average accuracy on the sociocultural norm learning task was 55.10% (SD = 8.58%).

The main effects of trial order and HPA axis GPS were nonsignificant. However, as predicted, there was a significant interaction between trial order and HPA axis GPS (see Table 1). The positive sign of the beta coefficient indicates that as the HPA axis score increased, the slope of the trial order also increased. In particular, one standard deviation increase in participants' genetic propensity toward a more reactive stress system increased their total improvement in accuracy over the course of the experiment by 34%.

Table 1
Detailed Hierarchical Logistic Regression Results for the Pilot Study and Studies 1 and 2

Independent variable	Pilot study	Study 1	Study 2
Main effect: Trial order	N.S.: B = .02, 95% CI [−.23, .27], SE = .13, OR = 1.02, z = .14, p = .89	N.S.: B = .08, 95% CI [−.17, .33], SE = .13, OR = 1.01, z = .66, p = .51	SIG.: B = .37, 95% CI [.24, .50], SE = .07, OR = 1.45, z = 5.72, p < .001
Main effect: Stress reactivity (operationalized differently across studies)	N.S.: B = −.06, 95% CI [−.22, .10], SE = .08, OR = .94, z = .80, p = .42	N.S.: B = −.17, 95% CI [−.56, .23], SE = .20, OR = .85, z = .81, p = .42	N.S.: B = −.22, 95% CI [−.62, .50], SE = .21, OR = .81, z = 1.05, p = .29
Stress Reactivity × Trial Order	SIG.: B = .29, 95% CI [.04, .54], SE = .13, OR = 1.34, z = 2.30, p = .022 (A genetic vulnerability toward greater HPA axis stress reactivity was associated with faster learning across trials)	SIG.: B = .59, 95% CI [.18, 1.01], SE = .21, OR = 1.81, z = 2.79, p = .005 (A stronger increase in cortisol levels following exposure to the cold pressor was associated with faster learning across trials)	SIG.: B = .50, 95% CI [.09, .19], SE = .21, OR = 1.65, z = 2.37, p = .018 (Higher scores on a self-report measure of dispositional stress reactivity were associated with faster learning across trials)
Constant	SIG.: B = .19, 95% CI [.03, .34], SE = .08, OR = 1.21, z = 2.40, p = .016	SIG.: B = .67, 95% CI [.43, .91], SE = .12, OR = 1.96, z = 5.53, p < .001	SIG.: B = .67, 95% CI [.55, .80], SE = .06, OR = 1.96, z = 10.51, p < .001

Note. N.S. = nonsignificant; CI = confidence interval; SE = standard error; OR = odds ratio; SIG. = significant; HPA = hypothalamic-pituitary-adrenal.

We conducted simple slopes analyses to decompose the interaction at one standard deviation above and below the mean on the HPA axis GPS. At one standard deviation below the mean, the main effect of trial order was directionally negative, $B = -.28$, 95% CI [−.63, .08], $SE = .18$, $OR = .76$, $z = 1.53$, $p = .13$. However, at one standard deviation above the mean on the HPA axis GPS, the main effect of trial order was directionally positive, $B = .31$, 95% CI [−.04, .66], $SE = .18$, $OR = 1.36$, $z = 1.73$, $p = .084$. An examination of Figure 2 indicates that in early trials, Singaporean participants' likelihood of selecting the culturally appropriate response in U.S. situations is about 50%. However, as they receive feedback over successive trials, this accuracy increases for participants with high-stress reactivity. As participants were instructed to "learn to make decisions like Americans," this increase in accuracy (or increased likelihood of making culturally appropriate choices) reflects learning by definition (i.e., "the acquisition of knowledge or skills through experience"; Pivec & Kearney, 2007, p. 268). We did not find evidence for a relationship between HPA axis GPS and trial order on learning (please see the Supplemental Materials for scatter plots and detailed analysis, pp. 7, 13).

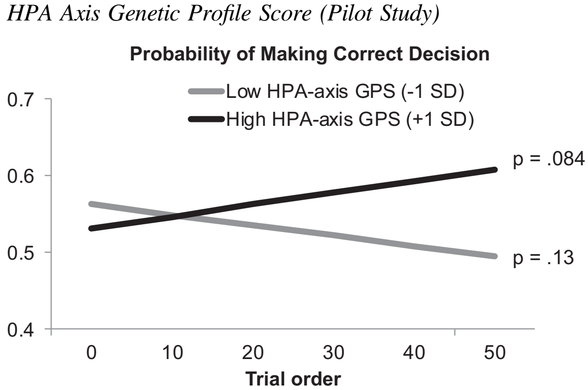
Discussion

This pilot study found a positive relationship between participants' genetic vulnerability toward HPA axis reactivity, as computed by a GPS, and their rate of learning how to act appropriately in particular types of situations sampled from the United States. Singaporean participants predisposed to low HPA axis reactivity did not learn to handle American influence situations the way American locals do. However, those predisposed to high-stress reactivity did manage to learn the American norms from trial-and-error feedback, even though all trials were unique in terms of the stimuli presented. Figure 1 shows that participants who had the GPS predisposing them to a more reactive HPA axis improved from about 50% (chance accuracy) to over 60% accuracy over 50 trials. An important limitation of this study is that the sample size was very small for a genetics study.

Importantly, we designed the cultural norm learning task to rule out practice or sensitization effects. Any practice effects (e.g., participants learning to give the same response across multiple trials) would necessarily result in chance accuracy (48% or 52%) over successive trials (as neither accommodation nor resistance was uniformly the correct response); instead, participants learn to distinguish situations in which they should accommodate from situations in which they should resist (Savani et al., 2011). Similarly, there is little possibility of sensitization as the 50 situations were unique and diverse in their content (see the OSF at https://osf.io/yb4ga/ → "Scripts" → "Pilot Study" → "Input for DirectRT.csv" for the complete list of the stimuli). Moreover, any practice or sensitization effects would alter the main effect of trial order; there is no reason to assume that practice or sensitization effects would only occur for participants scoring high on the HPA axis GPS but not for those scoring low on the HPA axis GPS.

Figure 2

Participants' Average Accuracy (Y-Axis) for Every 10 Trials (X-Axis), by HPA Axis Genetic Profile Score (Pilot Study)



Note. HPA = hypothalamic-pituitary-adrenal; GPS = genetic profile score.

Study 1

The goal of Study 1 was to conceptually replicate the results from the pilot study by first measuring HPA axis stress reactivity using the change in cortisol concentrations following exposure to a physical stressor. We then asked participants to complete a sociocultural learning task. This design also enabled us to test the hypothesis that stress reactivity (as assessed by changes in cortisol following exposure to a physical stressor) is an antecedent of sociocultural learning. We tested whether people with greater cortisol reactivity in response to an exogenous physical stressor would be faster at learning the norms of a new culture. Two tasks are commonly used to measure the reactivity of the stress system: the Trier Social Stress Test (Kirschbaum et al., 1993), wherein people perform a stressful public speaking task, and the cold pressor task (Lovallo, 1975), wherein people immerse their hand in nearly freezing water. We used the cold pressor task because its implementation could be more easily standardized across participants.

Method

Participants

Existing multilevel power analysis tools that we were aware of at the time of the study (i.e., Bosker et al., 1999; Raudenbush et al., 2011) did not provide a method to decide the sample size based on the effect size of cross-level interactions and desired power within a logistic framework. We decided on a sample size of 52 based on two considerations. First, this was 30% more than the sample size in recent research using similar methods and designs (Savani et al., 2022, Studies 1 to 3). Second, our sample size was partly determined by the number of cortisol saliva enzyme-linked immunosorbent assay wells available, which were four plates containing 78 wells each. As we measured each person's saliva at three time points, each of which was assayed in duplicate; this meant that we could recruit only 52 participants. A total of 60 participants took part in the study, but eight of them provided less than 1 ml of saliva, so their samples were not sent to the vendor for assaying. We stopped data collection once we had usable saliva samples from 52 participants.

Our final sample size was 52 Singaporean men ($M_{age} = 23.88$ years, all Singapore citizens; 48 ethnic Chinese, three ethnic Malays, and one ethnic Indian). Similar to past research, we recruited only male participants to avoid any possible effects of the menstrual cycle and hormonal birth control (Kirschbaum et al., 1992).[3] We did not

[3] We address this shortcoming of our sample in this study in the subsequent studies.

recruit any individuals who reported using cigarettes, steroids, or long-term medication. Individuals were also not recruited if they were diagnosed with any specific illnesses, such as hormonal or immune system–related disorders, psychological disorders, cardiovascular diseases, diabetes, coronary artery issues, or tingling or numbness in the hands (Lighthall et al., 2013). Participants' eligibility was ascertained through an online prescreening survey and confirmed through subsequent email correspondence. Although our sample size is relatively small in terms of the number of participants, we sought to maximize statistical power by using a carefully controlled task to induce stress (i.e., immersing the hand in a temperature-controlled cold water bath), which all participants are likely to experience similarly; by measuring participants' stress reactivity in terms of their change in cortisol in response to an external physical stressor, which was measured three times, and assayed in duplicate each time, leading to a relatively precise measure of stress reactivity; and by measuring participants' sociocultural norm learning using an 80-trial task, which gave us a relatively precise measure of the slope of participants' learning curve.

Procedure

In line with the established protocol, all sessions for this study were conducted between 2 p.m. and 6 p.m. to minimize the influence of diurnal variations in cortisol levels (Kudielka et al., 2004). We instructed participants to refrain from certain activities before the commencement of the study, including consumption of alcohol (24 hr before), consumption of caffeine (3 hr before), sleep (2 hr before), exercise (1 hr before), and consumption of food and drinks, including water (1 hr before; Lighthall et al., 2013). Figure 3 illustrates the timeline of the study procedure.

At the start of each session, participants completed a screening checklist to confirm that they fulfilled the above screening requirements and had refrained from engaging in the above activities. They also provided informed consent. Participants then rinsed their mouths with water. Although the cold pressor is a physical stressor, participants also experience a subjective sense of stress during the task (Lighthall et al., 2013). To verify that this is the case in the present study, we asked participants to provide baseline pain and stress ratings, followed by a saliva sample (t_0). These activities ensured that participants waited about 15 min to provide the resting baseline saliva sample. Thereafter, participants completed the cold pressor task, after which we obtained the second pain and stress ratings using identical measures. Afterward, they completed a set of questionnaires that served as filler tasks, followed by a second saliva sample (t_1; M = 22.37 min, SD = 1.27 from the start of the cold pressor task). Participants then completed the sociocultural norm learning task and provided their demographic information. Finally, participants provided a third saliva sample (t_2; M = 56.39 min, SD = 5.33 from the start of the cold pressor task). Participants were then debriefed.

Stress Induction: Cold Pressor Task. Participants were asked to immerse their nondominant hand in ice water inside a temperature-controlled (0–5 °C or 32–41 °F) bath. Participants were asked to keep their hand in the water for as long as possible, up to a maximum of 3 min. An experimenter was present when the participants immersed their hand in cold water and informed them when 3 min had elapsed if they had not removed their hand until then (M = 60.97 s, SD = 57.02).

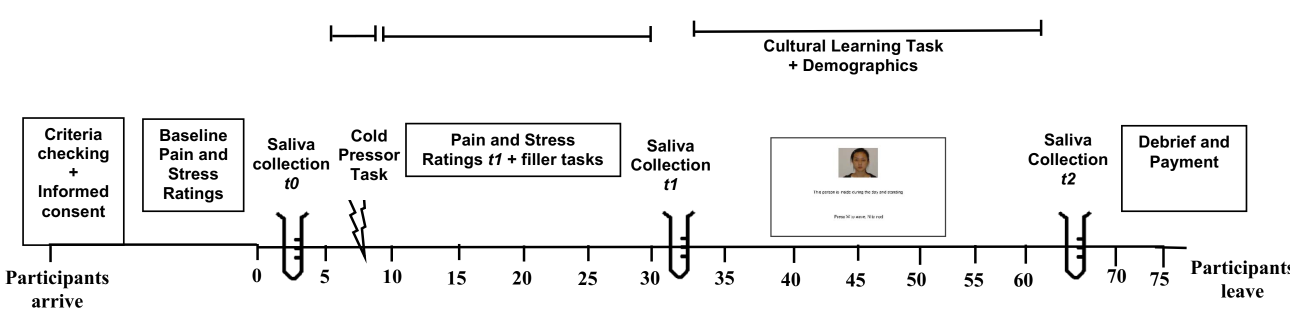
Cortisol Measure: Salivary Collection and Assay. We measured participants' physiological stress responses to the stress induction task through their salivary cortisol levels. Participants provided passive drool samples (1 ml each) at three time points, which were later assayed for cortisol. We collected the first sample right before the cold pressor task (t_0), the second sample before the sociocultural norm learning task (t_1), and the third sample after the sociocultural norm learning task was completed (t_2). The samples were immediately stored at −80 °C or −112 °F after each session. At the end of the collection, samples were transported frozen and subjected to a cortisol level analysis by an external laboratory using enzyme-linked immunosorbent assay kits. For each sample at each of the three time points, duplicate assays were conducted. The mean of the resulting two values was used in the final analysis.

Pain and Stress Ratings. Participants completed pen and paper–based pain and stress ratings on a three-item, 11-point scale immediately before and after the cold pressor task. In the first set of ratings before the cold pressor task, we asked participants to report how they felt at that current moment: "How painful/stressful/unpleasant do you feel right now?" (0 = *not at all* to 100 = *very much*, in 10-point increments). For the second set of ratings after the cold pressor task, participants were presented with three questions about how they felt during the cold pressor task: "How painful/stressful/unpleasant was this experience?" (0 = *not at all* to 100 = *very much*, in 10-point increments).

Sociocultural Norm Learning Task. Participants then completed a different sociocultural norm learning task, adapted from Morris et al. (2019, Study 2). Specifically, we asked participants

Figure 3

Timeline of the Study Procedure (Study 1)



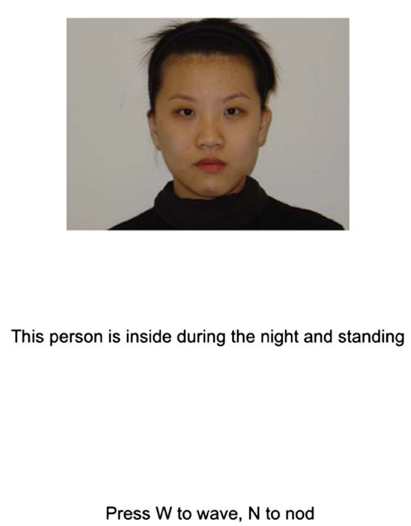
Note. Facial image are from Asian Face Database (Wong & Cho, 2007a, 2007b). The owner of the database gave us permission to use the face in our publication. See the online article for the color version of this figure.

to learn the greeting norms of a new culture using people's faces accompanied by a single line of information. We asked the participants to imagine that they had moved to Kyrgyzstan, a country in central Asia, and they needed to learn from experience how to appropriately greet people in the new country. Participants were told that they would meet a series of locals, simulated by a face and some words about the context in which they met the other person. Based on this information, participants had to choose between two ways of greeting the individual (a wave or a nod).

Specifically, all trials were unique in that they featured a different individual (represented by a photograph) along with multiple pieces of information about the context of the interaction, including time of day, whether the individual was indoor or outdoor, and standing or sitting. Following these instructions, each participant went through 80 trials of greeting interactions with different people in Kyrgyzstan (randomly presented for each participant, 40 female and 40 male pictures taken from the Asian Emotions Database; Wong & Cho, 2007a, 2007b). Each picture was accompanied by a sentence describing the context, that is, daytime or nighttime, indoors or outdoors, and sitting or standing (e.g., "This person is inside during the day and sitting"). Two seconds after the stimuli were presented, the participants were asked, "How would you greet this person? Press W to Wave and N to Nod" (see Figure 4 for an illustration). As soon as the participants indicated their response (i.e., *W* or *N*), they received feedback on their choice, "correct" or "wrong," displayed in either green- or red-colored font, respectively, for 2 s, depending on whether their response agreed with the underlying rule used to decide the appropriate way to greet in Kyrgyzstan. We increased the number of trials to 80 in this study compared to 50 trials in the pilot study because the trials in this study were much simpler—they only included a picture and a single descriptive sentence compared to the long paragraphs used to describe each situation in the pilot study.

The correct greeting norm that all participants had to learn was based on location (i.e., wave if outside and nod if inside). Through

Figure 4
Example Trial From the Task in Study 1



Note. Facial image are from Asian Face Database (Wong & Cho, 2007a, 2007b). The owner of the database gave us permission to use the face in our publication. See the online article for the color version of this figure.

trial and error, participants had to figure out which cue to use and which to ignore when deciding how to greet the individual. To increase the complexity of the learning task and to mimic the inconsistency of real-world social interactions, we added noise to the feedback in 20% of the trials. Specifically, in these 20% of the trials, participants received "wrong" feedback if their response complied with the underlying rule and "correct" feedback if their response was actually incorrect, that is, not in agreement with the underlying rule. This task was administered using the Inquisit software. Given that Inquisit crashes occasionally, participants were asked to indicate if they encountered any technical problems during the task, along with demographic information.

This sociocultural norm learning task was validated in an unrelated study with 91 Singaporean students who were going abroad for a semester-long exchange program. The participants completed this task before they went abroad. Their speed of learning on this task significantly predicted their self-reported social adjustment abroad, thus providing evidence for the ecological validity of the task (S. M. Madan et al., 2018, as cited in Savani et al., 2022).

Results

As this was a lengthy experimental session, we included an attention check question as part of the filler task administered between the cold pressor task and saliva collection at t_1. Specifically, participants were asked not to respond to a question and just leave it blank. We excluded four participants who failed this attention check. Further, five participants experienced technical difficulties with the Inquisit program while completing the sociocultural norm learning task (including program crashes) and were thus excluded, leaving 43 participants in the data set.

Participants reported feeling greater pain, $M_{pre} = 1.16$, $SD = 3.91$; $M_{post} = 55.81$, $SD = 21.96$, $t(42) = 17.09$, $p < .001$, and stress after the cold pressor task, $M_{pre} = 9.30$, $SD = 17.65$; $M_{post} = 29.30$, $SD = 23.74$, $t(42) = 5.58$, $p < .001$. This result indicates that the cold pressor task leads not only to physical pain but also to a subjective psychological experience of stress. See the Supplemental Materials (p. 8) for similar results on perceived unpleasantness. Cortisol values were measured in µg/dL ($M_{t0} = 0.22$, $SD = 0.20$; $M_{t1} = 0.39$, $SD = 0.27$; $M_{t2} = 0.22$, $SD = 0.11$). As the cortisol values were right-skewed, we log-transformed them prior to analyses (Lighthall et al., 2013). We calculated the change in cortisol due to the cold pressor task by subtracting the individual log-transformed baseline levels (t_0) from the log-transformed cortisol levels at t_1 (immediately after the cold pressor task). The mean change in cortisol was .57 log µg/dL ($SD = 0.59$). This variable served as the index of the reactivity of participants' stress system; importantly, it was assessed before the sociocultural norm learning task.

Similar to the pilot study, we analyzed the data using a hierarchical logistic regression with trials nested within participants. The dependent measure was accuracy, that is, whether, on each trial, participants chose the greeting that complied with the underlying rule, that is, wave if outside and nod if inside (coded as 0 = inaccurate, 1 = accurate). Participants' average accuracy on the sociocultural norm learning task was 65.55% ($SD = 13.35\%$). The predictor variables were the trial order (first trial = 0, last trial = 1), change in cortisol from t_0 to t_1 (mean-centered), and their interaction (see Table 1 for the results). The main effects of trial order and cortisol reactivity were nonsignificant. However, as predicted, there was a significant interaction between trial order and the increase in cortisol. A one standard deviation increase in participants' cortisol reactivity enhanced their overall improvement in accuracy across 80 trials by 48.66%.

Next, we conducted simple slopes analyses to assess variation in learning at one standard deviation above and below the mean on cortisol reactivity. At one standard deviation below the mean (−1 *SD*), the main effect of trial order was nonsignificant, $B = -.27$, 95% CI [−.61, .08], $SE = .17$, $OR = .77$, $z = 1.52$, $p = .13$. However, at one standard deviation above the mean (+1 *SD*), the main effect of trial order was positive and significant, $B = .43$, 95% CI [.07, .79], $SE = .18$, $OR = 1.54$, $z = 2.36$, $p = .018$, indicating that participants who experienced a greater cortisol spike after the cold pressor task demonstrated greater learning in the subsequent sociocultural norm learning task across successive trials (see Figure 5). We did not find evidence for a curvilinear relationship between cortisol reactivity and trial order on learning (please see the Supplemental Materials, pp. 8, 13, for scatter plots and detailed analysis).

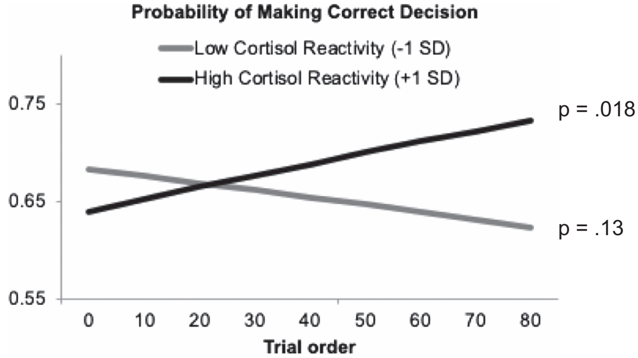
In an additional analysis, we also controlled for individual differences in how long participants kept their hand in the water during the cold pressor task. It is possible that participants who left their hand in longer might have higher cortisol reactivity because they experienced the cold pressor longer and that people who left their hand in longer are also the kind of people who might take study-related tasks more seriously and, therefore, perform better on the learning task. However, controlling for the duration of time participants kept their hand in water did not affect the results reported above. Please see the Supplemental Materials (p. 8) for the complete analysis.

Discussion

This study found that participants who experienced a bigger increase in cortisol following exposure to a physical stressor were subsequently faster at learning the greeting norms of a new culture from experiential feedback in a laboratory task. Importantly, we replicated the findings from the pilot study using a direct measure of HPA axis activation. Participants whose HPA axis was not particularly reactive to the stressor (i.e., whose cortisol levels did not increase much from baseline after they put their hands in ice water) did not learn the local norm about which greetings fit which social situations. However, participants whose HPA axis was relatively more reactive (i.e., those who experienced a greater increase in cortisol from baseline after putting their hands in ice water) managed to learn the proper norm for greeting despite multiple irrelevant cues and noise in the feedback. However, the key limitations of this study are that our sample was restricted to men, and the sample size was small. We address these limitations in the subsequent studies.

Figure 5

Participants' Average Accuracy (Y-Axis) for Every 10 Trials (X-Axis), by Their Cortisol Reactivity (Study 1)



Study 2

Study 2 was designed to accomplish multiple objectives. First, we sought to conceptually replicate the results from the previous studies in a larger, more inclusive sample drawn from the student pool at the same university as in Study 1. Second, we sought to increase the generalizability of our findings by using a self-report scale to assess participants' dispositional stress reactivity. Instead of measuring stress reactivity using a self-report questionnaire administered before the norm learning task, we could have measured stress reactivity through self-reports of experienced stress during the sociocultural learning task. However, such an approach has at least two shortcomings. First, the measurement of acute stress experienced during the sociocultural learning task does not provide a clear test of the hypothesis that dispositional stress reactivity is an *antecedent* of sociocultural learning because learning and subjectively experienced stress reactivity are measured concurrently. Second, prior work indicates that measuring subjective experiences in the middle of a psychological task can interfere with the naturally occurring mechanisms at play (Kassam & Mendes, 2013). Thus, rather than interrupt participants during the sociocultural learning task by asking them about their subjectively experienced stress, we measured dispositional stress reactivity prior to the learning task. To provide complementary evidence, we measure acute stress experienced in the sociocultural learning task in Study 4.

Method

Participants

We decided on a sample size of 150, which would be over three times the sample size employed in recent research using similar methods and designs (Savani et al., 2022, Studies 1–3). As we intended to exclude participants who faced technical problems with Inquisit and expected some no-shows, we posted a lab study seeking 200 undergraduate students at a large university in Singapore. In response, 183 students participated in the study. We excluded eight participants who mentioned they faced technical problems during the study, leaving 175 participants (109 women and 66 men; M_{age} = 21.89 years, 174 Singapore citizens, one noncitizen; 164 ethnic Chinese, nine Indians, and two Malays).

Procedure

We used the perceived stress reactivity scale (Schlotz, Yim, et al., 2011) to assess participants' dispositional responses to stressors in everyday life. Specifically, we used the reactivity to social conflict subscale (five items), the reactivity to failure subscale (four items), and the reactivity to social evaluation subscale (five items) from the original scale as these subscales demonstrated the strongest correlation with participants' cortisol spike in a Trier Social Stress Test (see Schlotz, Hammerfald, et al., 2011) and had the highest reliability among English-speaking participants (see Schlotz, Yim, et al., 2011). Each item assessed the participant's typical response to stressful situations on a 3-point scale. For example, "When I have conflicts with others that may not be immediately resolved … (1) *I generally shrug it off*, (2) *It usually affects me a little*, and (3) *It usually affects me a lot*." We presented the response options such that higher numbers indicated a stronger stress response. Next, participants completed the 80-trial sociocultural norm learning task used in Study 1, in which they had to learn the norms of greeting in Kyrgyzstan with spurious feedback on 20% of the trials.

Results

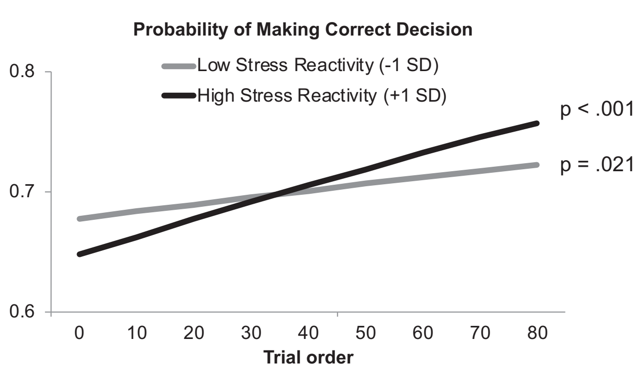
We averaged the items assessing dispositional stress reactivity ($\alpha = .78$) such that higher scores indicated greater stress reactivity. We analyzed the data using hierarchical logistic regression, as in the previous studies (see Table 1). The correct cue was the same as in Study 1. We found a main effect of trial order but no main effect of dispositional stress reactivity. More importantly, the interaction was significant. Next, we conducted simple slopes analyses. For participants with higher dispositional stress reactivity (1 *SD* above the mean), the effect of trial order was positive and significant, $B = .53$, 95% CI [.35, .71], $SE = .093$, $OR = 1.70$, $z = 5.66$, $p < .001$. However, for participants with lower dispositional stress reactivity (1 *SD* below the mean), the effect of trial order was attenuated, $B = .21$, 95% CI [.03, .40], $SE = .092$, $OR = 1.24$, $z = 2.32$, $p = .021$. This finding indicated that people with higher dispositional stress reactivity were faster at learning the greeting norms of a foreign culture (see Figure 6). We did not find any evidence for a curvilinear relationship between dispositional stress reactivity and trial order on learning (please see the Supplemental Materials, pp. 10, 13).

Discussion

Study 2 found that participants who scored higher on a self-report measure of dispositional stress reactivity were subsequently faster at learning the norms of an unfamiliar sociocultural context. The results of the present study are important for two key reasons. First, we found converging evidence for the role of dispositional stress reactivity in facilitating sociocultural norm learning using a scale measure, complementing the prior studies using a genetic propensity score (pilot study) and cortisol reactivity (Study 1). Importantly, this study addressed the limitations of the previous studies by using a larger and more inclusive sample.

Figure 6

Participants' Average Accuracy (Y-Axis) for Every 10 Trials (X-Axis), by Their Dispositional Stress Reactivity (Study 2)



Study 3

This study had two primary objectives. First, we aimed to replicate the association between stress reactivity and sociocultural learning using a preregistered design. Specifically, prior to data collection, we preregistered the hypothesis that individuals higher in dispositional stress reactivity would be faster at learning unfamiliar sociocultural norms from experiential feedback. Second, to better understand the mechanisms linking stress reactivity to sociocultural learning, we explored whether the association between dispositional stress reactivity and sociocultural learning would extend to a nonsocial learning task. Previous research on exogenously induced stress and learning has been conducted primarily with tasks that do not involve social stimuli, and the findings to date are mixed—researchers have observed positive, negative, and null associations between markers of stress and nonsocial learning (Ell et al., 2011; Lighthall et al., 2013; Mather & Lighthall, 2012; Otto et al., 2013). Given the mixed results in this literature, we did not formulate specific predictions for the association between stress reactivity and nonsocial learning. One hypothesis is that if stress reactivity is associated with greater attention to feedback, then it would predict learning in both social and nonsocial tasks. However, if stress reactivity is associated with greater attention to social cues (Roelofs et al., 2007; Shirtcliff et al., 2014), then the findings observed in Study 2 may not generalize to a nonsocial task. This study was conducted with participants from the student pool at a large public university in Singapore.[4]

Method

The hypotheses, sample size, participant inclusion criteria, methods, and analysis plan for this study were preregistered at https://osf.io/erh3k/.

Participants

As this was the first study manipulating sociocultural versus nonsocial learning, we did not have a basis for calculating the sample size for this study. We decided on a sample size of 200. Over a 2-week period, 175 participants signed up and completed the study in the lab. As per the preregistered criteria, we excluded three participants who indicated that they faced technical problems while completing the study on Inquisit. The final sample consisted of 172 participants (134 women and 38 men; $M_{\text{age}} = 21.85$ years; 155 Singapore citizens, 16 others, and one unreported; 147 ethnic Chinese, 12 Indians, three Malays, two Europeans, five others, and three biracial).

[4] We conducted another study with a similar design with U.S. participants, but after completing data collection, we noticed a coding error in the sociocultural learning condition; however, there were no errors in the nonsocial learning condition. For transparency, we report the association between dispositional stress reactivity and nonsocial learning from this additional study in Supplemental Study 1.

Procedure

We first measured participants' perceived stress reactivity using the three subscales used in Study 2. Participants were then randomly assigned to either the sociocultural norm learning task or an equivalent nonsocial learning task. For the nonsocial learning task, we adapted the 80-trial sociocultural norm learning task used in the previous studies (Studies 1–2) by replacing the individuals' pictures with Greebles (Gauthier & Tarr, 1997). Greebles are a class of invented objects used as stimuli in research on object recognition. Instead of deciding how to greet individuals in Kyrgyzstan ("wave" vs. "nod"), participants were told that they needed to learn to classify Greebles as either "W" or "N" by pressing the corresponding keys. To mimic the cues in the sociocultural norm learning task, each Greeble image was accompanied by three words (i.e., *day* or *night*, *indoor* or *outdoor*, and *sitting* or *standing*). Similar to the original sociocultural norm learning task, only one of these cues was relevant in deciding how to classify the image. Thus, the task was identical across conditions except for whether participants were presented with faces (or Greebles). Participants received feedback about whether they classified the image correctly. Across both conditions, participants received noisy feedback in 20% of the trials. The 80 trials were randomized for each participant.

Results

We averaged the dispositional stress reactivity items such that higher scores reflected a stronger response to stressors ($\alpha = .73$). As per the preregistered analysis plan, we estimated a hierarchical logistic model by condition. The dependent variable was the participant's accuracy on each trial (0 = incorrect, 1 = correct), and the predictor variables were trial order (range 0–1), participants' dispositional stress reactivity score (mean-centered), and their interaction. The correct cue was the same as in Study 1 in the sociocultural learning condition ("wave" if outside and "nod" if inside) and its equivalent in the nonsocial learning condition ("W" if outside and "N" if inside). The slope of trial order was allowed to vary across participants, and the covariance between this slope and the intercept was estimated. Given that participants' starting accuracy was greater than chance, we estimated a model with an intercept.[5] Please see Table 2 for the results.

The main effects of trial order and dispositional stress reactivity were nonsignificant. Importantly, as preregistered, we replicated the interaction between trial order and stress reactivity in the sociocultural learning condition (see Table 2). As per the preregistered analysis plan, we also tested for the three-way interaction between trial order, stress reactivity, and condition (−.5 = nonsocial learning task, .5 = sociocultural learning task). The main effects of trial order ($B = .15$, 95% CI [.031, .27], $SE = .06$, $OR = 1.16$, $z = 2.47$, $p = .014$), dispositional stress reactivity ($B = -.43$, 95% CI [−.70, −.15], $SE = .14$, $OR = .65$, $z = 3.06$, $p = .002$), and condition ($B = .23$, 95% CI [.06, .39], $SE = .08$, $OR = 1.25$, $z = 2.71$, $p = .007$) were significant. The two-way interaction between trial order and stress reactivity was significant ($B = .74$, 95% CI [.34, 1.14], $SE = .20$, $OR = 2.11$, $z = 3.67$, $p < .001$). The interactions between trial order and condition ($p = .91$) or stress reactivity and condition ($p = .41$) were not significant. The three-way interaction was also not significant ($p = .29$), indicating that more stress-reactive participants were faster at learning both sociocultural and nonsocial rules.

Finally, we conducted simple slopes analyses in the *sociocultural norm learning* condition to assess the pattern of the two-way interaction. At one standard deviation below the mean, the effect of trial order was close to zero and nonsignificant, $B = -.02$, 95% CI [−.28, .24], $SE = .13$, $OR = .98$, $z = .16$, $p = .88$, indicating that participants low in dispositional stress reactivity failed to learn the relevant cultural norms across successive trials. However, at one standard deviation above the mean on dispositional stress reactivity, the effect of trial order was positive and significant, $B = .31$, 95% CI [.08, .54], $SE = .12$, $OR = 1.36$, $z = 2.65$, $p = .008$, indicating that participants high in dispositional stress reactivity were faster at learning the norms of a new culture (see Figure 7). We did not find any evidence for a curvilinear relationship between dispositional stress reactivity and trial order on learning (please see the Supplemental Materials, pp.11, 13, for details).

In the *nonsocial learning* condition, at one standard deviation below the mean on dispositional stress reactivity, the effect of trial order was nonsignificant, $B = -.14$, 95% CI [−.36, .09], $SE = .11$, $OR = .87$, $z = 1.20$, $p = .23$. However, at one standard deviation above the mean, the effect of trial order was significant, $B = .44$, 95% CI [.20, .69], $SE = .13$, $OR = 1.56$, $z = 3.57$, $p < .001$ (see Figure 8).

Discussion

This study accomplished two key objectives. First, it conceptually replicated the results of the previous studies in a preregistered experiment and provided converging evidence for our hypothesis that stress reactivity is beneficial for sociocultural norm learning. Second, this study showed that participants with higher stress reactivity were also faster at learning how to classify Greebles. One interpretation of these results is that the relationship between stress reactivity and learning operates through a mechanism that is not specific to sociocultural learning, such as increased sensitivity to feedback or greater motivation to avoid negative feedback (Cavanagh et al., 2011; Henckens et al., 2016; Raio et al., 2017; Wolf, 2019). Complementary mechanisms that contribute to feedback sensitivity may also support faster learning among individuals higher in stress reactivity (e.g., greater energy mobilization; Zänkert & Kudielka, 2019).

However, a separate study with a similar design and a different sample (U.S. residents recruited from Amazon Mechanical Turk) showed the opposite effect in the nonsocial learning condition (see Supplemental Study S1). That is, in a similar task in which they were asked to classify Greebles, the interaction between stress reactivity and participants' accuracy across successive trials was statistically significant and negative. In other words, more stress-reactive individuals became less accurate over time in the nonsociocultural learning task. We discuss these divergent findings in the General Discussion section.

Study 4

Using a multimethod approach (HPA axis GPS, direct measurement of cortisol responses to a stressor, and a psychological measure

[5] We preregistered a model without a constant term, expecting that participants would start out with near-chance accuracy. However, the constant term in both regressions was significant (see Table 2), so we used a model with a constant term instead.

Table 2
Detailed Hierarchical Logistic Regression Results for Study 3 (Simple Slopes Within Condition)

Independent variable	Sociocultural norm learning condition	Nonsocial learning condition
Main effect: Trial order	N.S.: $B = .14$, 95% CI [−.024, .31], $SE = .09$, $OR = 1.15$, $z = 1.68$, $p = .093$	N.S.: $B = .16$, 95% CI [−.012, .32], $SE = .086$, $OR = 1.16$, $z = 1.82$, $p = .069$
Main effect: Dispositional stress reactivity	N.S.: $B = -.32$, 95% CI [−.74, .10], $SE = .22$, $OR = .72$, $z = 1.48$, $p = .14$	SIG.: $B = -.54$, 95% CI [−.89, −.19], $SE = .18$, $OR = .58$, $z = 3.05$, $p = .002$
Dispositional Stress Reactivity × Trial	SIG.: $B = .54$, 90% CI[a] [.051, 1.03], $SE = .30$, $OR = 1.72$, $z = 1.82$, $p = .035$ (Higher stress reactivity was associated with faster learning across trials)	SIG.: $B = .96$, 95% CI [.42, 1.50], $SE = .27$, $OR = 2.61$, $z = 3.51$, $p < .001$ (Higher stress reactivity was associated with faster learning across trials)
Constant	SIG.: $B = .38$, 95% CI [.26, .50], $SE = .06$, $OR = 1.46$, $z = 6.10$, $p < .001$	SIG.: $B = .15$, 95% CI [.04, .26], $SE = .06$, $OR = 1.16$, $z = 2.67$, $p = .008$

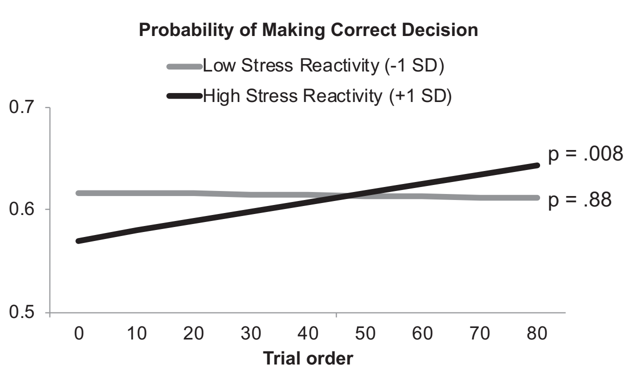
Note. N.S. = nonsignificant; CI = confidence interval; *SE* = standard error; *OR* = odds ratio; SIG. = significant.
[a] 90% CI and one-tailed test as we preregistered a directional hypothesis. The 95% CI [−.043, 1.13] included zero. The two-tailed *p* value was .069.

of dispositional stress reactivity), the previous studies consistently demonstrated that individuals higher in stress reactivity are faster at learning diverse sociocultural norms through experiential feedback. In these studies, stress reactivity was measured prior to the sociocultural learning task, enabling us to conclude that stress reactivity is an antecedent of sociocultural learning. As per our theorization, the acute stress generated by repeated negative feedback in novel sociocultural interactions motivated more stress-reactive individuals to learn the sociocultural norms faster to avoid more negative feedback. Study 4 was designed to examine this mechanism, specifically, whether individuals higher in dispositional stress reactivity are more likely to perceive greater situation-specific stress when faced with the sociocultural learning task, which in turn spurs faster learning.

In our previous studies, we purposely chose not to measure stress experienced during the sociocultural learning task because asking participants to report their psychological states can disrupt naturally occurring psychological processes as they unfold (Kassam & Mendes, 2013). Measurement effects exist in domains where the act of measuring a construct changes the properties of the observed. In other words, "Reporting how we are feeling requires awareness and conscious assessment of our emotional states, and these processes may alter the emotional experiences" (Kassam & Mendes, 2013, p. 1). For example, participants who experienced anger after an evaluative math task experienced lower cardiac output if they were asked to report their emotions compared to when they were not asked to do so (Kassam & Mendes, 2013). Thus, in the present study, as we measure subjective stress at multiple points in the learning task, the relationship between dispositional stress reactivity and the learning slope is likely to be disrupted. Therefore, the key relationship of interest in this study was not whether there is a direct association between dispositional stress reactivity and the learning slope but whether there is an indirect association between dispositional stress reactivity and the learning slope through stress experienced during the learning task.

Moreover, we theorize that stress reactivity is adaptive in that an initial stress response should motivate behavioral change (i.e., faster learning), and this behavioral change should facilitate recovery of stress levels. We thus tested a path model whereby individuals higher in dispositional stress reactivity experience more task-specific acute stress early in the sociocultural learning task, which spurs faster learning that lowers stress levels at the end of the task.

Figure 7
Accuracy Across Trials by Dispositional Stress Reactivity in the Sociocultural Norm Learning Condition (Study 3)



Note. Participants' accuracy across trials by dispositional stress reactivity in the sociocultural norm learning condition (Study 3).

Method

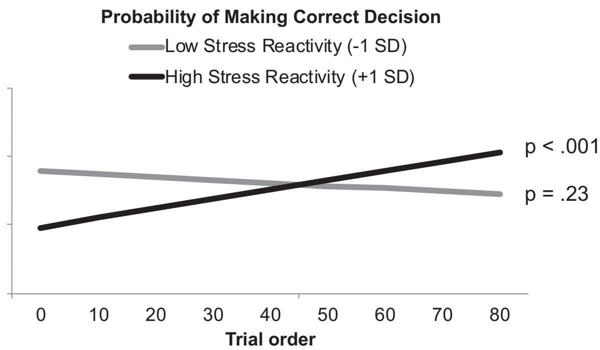
The sample size, methods, participant inclusion criteria, and analysis plan for this study were preregistered at https://aspredicted.org/z872-t8c5.pdf.[6]

Participants

As per the preregistration, we posted this study for 100 participants at the behavioral lab at a large university in Singapore. In response, 99 participants completed the study (62 women, 35 men, and two nonbinary; $M_{age} = 21.76$ years; 99 Singapore citizens; 95 ethnic Chinese, two Indians, one Malay, and one Japanese).

[6] In the preregistration, we proposed to exclude participants who faced technical problems during the study. However, the research assistant who programmed the study failed to include this question. The log files of Inquisit, the program used to run the study, showed that no participant faced a technical issue (see Study 4_errorslog.csv uploaded on the OSF at https://osf.io/yb4ga/).

Figure 8
Accuracy Across Trials by Dispositional Stress Reactivity in the Nonsocial Learning Condition (Study 3)



Note. Participants' accuracy across trials by dispositional stress reactivity in the nonsocial learning condition (Study 3).

Procedure

All participants first responded to the dispositional stress reactivity scale used in Studies 2–3 (Schlotz, Yim, et al., 2011). Next, similar to Studies 1–3, participants were asked to imagine that they had moved to Kyrgyzstan and would need to learn how to greet people in Kyrgyzstan. We measured participants' anticipatory stress in the task (following Gaab et al., 2005). Specifically, we told participants that before they began working on this task, we would like to know how they felt about it. Participants then indicated how stressful they expected the task to be on four items measured on a 7-point scale. Specifically, participants were asked, "I think this task will be. …" followed by the response options "not at all annoying/frustrating/unpleasant/stressful" to "extremely annoying/frustrating/unpleasant/stressful." Participants then began the 80-trial sociocultural norm learning task used in Studies 1–3, in which they had to learn the norms of greeting in Kyrgyzstan with spurious feedback on 20% of the trials. However, unlike in the previous studies, participants were asked to appraise their cumulative experience of stress after every 20 trials (i.e., a total of four times during the 80-trial task). Specifically, participants were asked to indicate: "Thus far, this task feels. …" followed by the response options "not at all annoying/frustrating/unpleasant/stressful" to "extremely annoying/frustrating/unpleasant/stressful" (measured on 7-point scales).

Results

Table 3 presents the descriptive statistics and correlations. As hypothesized, participants with greater dispositional stress reactivity reported experiencing greater acute stress in anticipation of and during the sociocultural learning task.

Relationship Between Dispositional Stress Reactivity and Learning

Per the preregistered analysis plan, we ran a hierarchical logistic model (HLM) with trials nested within participants. The trial-level outcome variable was whether participants selected the greeting consistent with the underlying rule (i.e., "wave if outside, and nod if inside"; same as previous studies). The predictor variables were trial order (recoded to range from the first trial = 0 to the last trial = 1), dispositional stress reactivity (mean-centered), and their interaction. There were no significant effects of trial order (B = .04, 95% CI [−.12, .20], SE = .08, OR = 1.04, z = .54, p = .59), dispositional stress reactivity (B = −.09, 95% CI [−.57, .38], SE = .24, OR = .91, z = .38, p = .70), and the interaction term (B = −.25, 95% CI [−.77, .27], SE = .27, OR = .78, z = .94, p = .35). The constant term was significant (B = .48, 95% CI [.34, .63], SE = .07, OR = 1.62, z = 6.43, $p < .001$). Although we consistently replicated the effect of dispositional stress reactivity on participants' rate of sociocultural learning in the previous studies (Studies 2 and 3 used the same measure of dispositional stress reactivity as the present study), this effect did not emerge in the present study. As anticipated in the preregistration, this may have been due to the repeated measurements of situation-specific experienced stress, which likely disrupted the direct link between dispositional stress reactivity and learning. We did not find any evidence for a curvilinear relationship between dispositional stress reactivity and trial order on learning (please see the Supplemental Materials, p. 13, for details).

Nonpreregistered Indirect Effect Analysis

We next tested whether dispositional stress reactivity would have an indirect effect on learning through acute stress. Although we did

Table 3
Descriptive Statistics and Correlations for Measures in Study 4

Variable	*M*	*SD*	Alpha	1	2	3	4	5	6	7	8
1. Dispositional stress reactivity	2.07	0.31	0.77	—							
2. Anticipatory stress	1.83	0.94	0.86	.20*	—						
3. First stress appraisal (at the end of 20 trials)	2.22	1.21	0.91	.29**	.67***	—					
4. Second stress appraisal (at the end of 40 trials)	2.33	1.33	0.93	.26**	.64***	.83***	—				
5. Third stress appraisal (at the end of 60 trials)	2.32	1.43	0.94	.26**	.58***	.86***	.90***	—			
6. Fourth stress appraisal (at the end of 80 trials)	2.74	1.65	0.96	.33***	.42***	.69***	.67***	.72***	—		
7. Slope of learning (Trials 1–80)	0.009	0.71		.036	.072	.29**	.32**	.27**	.0001	—	
8. Slope of learning (Trials 21–80)	0.035	1.66		.048	.10	.24*	.35**	.28**	−.07	.90***	—

* $p < .05$. ** $p < .01$. *** $p < .001$.

not observe a direct effect of stress reactivity and learning, we can observe an indirect effect even in the absence of a direct effect (e.g., Hayes, 2009; MacKinnon et al., 2000; Shrout & Bolger, 2002). As the PROCESS macro (Hayes, 2017) does not allow multilevel analyses, we first ran a similar HLM as above but with trial order as the sole predictor. We then extracted each participant's learning slope from the model. Then, we conducted a bootstrapped analysis with 20,000 samples using Model 4 of the SPSS PROCESS macro (Hayes, 2017) with participants' dispositional stress reactivity as the independent measure (X), their learning slope as the dependent measure (Y), and five competing mediators: anticipatory stress before the learning task began (M1), stress experienced during the first 20 trials (M2), cumulative stress experienced during the first 40 trials (M3), cumulative stress experienced during the first 60 trials in the task (M4), and cumulative stress experienced during all 80 trials at the end of the task (M5). This analysis revealed a significant positive indirect effect of dispositional stress reactivity on sociocultural learning through greater stress experienced during the first 20 trials (M2), $ab = .33$, $SE = .16$, 95% CI [.07, .71]. These significant results can be predicted if the assumption of a mediation model is correct. Specifically, participants high in dispositional stress reactivity who experienced greater stress early in the task were faster at learning novel sociocultural norms.

The indirect effects through anticipatory stress (M1: $ab = -.16$, $SE = .12$, 95% CI [−.45, .001]) and stress experienced later in the task (M3: $ab = .33$, $SE = .23$, 95% CI [−.0014, .89]; M4: $ab = -.06$, $SE = .18$, 95% CI [−.40, .33]) were not significant. Interestingly, there was a negative indirect effect through stress experienced at the end of the task (M5), $ab = -.38$, $SE = .19$, 95% CI [−.86, −.11]. However, these results are difficult to interpret given the endogeneity between the experienced stress and the learning task. Specifically, the better participants learned the underlying rules, the lower the stress they should experience over time, so experienced stress and learning are not independent of each other.

To eliminate this endogeneity, we tested whether stress experienced during the first 20 trials predicted participants' learning slope in the subsequent 60 trials. Specifically, similar to the above analysis, we first ran an HLM with trial order as the sole predictor to extract each participant's learning slope for trial numbers 21–80. Then, we conducted a bootstrapped analysis with 20,000 samples using Model 4 of the SPSS PROCESS macro (Hayes, 2017) with participants' dispositional stress reactivity as the independent measure (X), their learning slope for trials 21–80 as the dependent measure (Y), and stress experienced during the first 20 trials (M) as the mediator. This analysis revealed an even larger, significant positive indirect effect of dispositional stress reactivity on sociocultural learning in trials 21–80 through greater stress experienced during the first 20 trials, $B = .39$, $SE = .19$, 95% CI [.07, .82]. Thus, the stress experienced in the first 20 trials underlies the relationship between dispositional stress reactivity and faster learning in the subsequent 60 trials.

Sequential Mediation Analysis

Our theorization rests on the premise that more stress-reactive individuals experience greater stress early on during sociocultural interactions, and this motivates them to learn the relevant norms faster to avoid more subsequent negative feedback and, consequently, reduce their experienced stress. We tested this complete path using PROCESS Model 6 (20,000 bootstrapped samples) with participants' dispositional stress reactivity as the independent measure (X), stress experienced during the first 20 trials as the first mediator (M1), slope of learning from 21 to 80 trials as the second mediator (M2), and stress experienced at the end of 80 trials as the dependent measure (Y). This analysis revealed a significant negative sequential indirect effect ($ab = -.093$, $SE = .056$, 95% CI [−.23, −.0104]) such that participants higher in dispositional stress reactivity experienced greater stress in the first 20 trials of the task and learned faster in the next 60 trials, which predicted lower stress at the end of the task.[7]

Recovery of Stress Level

To test whether greater learning led to a recovery in the experienced stress level of more stress-reactive individuals, we computed the stress experienced in the last 20 trials of the task by subtracting cumulative stress experienced until 60 trials from the cumulative stress experienced in all 80 trials. The results showed that individuals high in stress reactivity experienced significantly lower stress at the end of the task, $M = .13$, 95% CI [.10, .16], $SD = .88$, than individuals low in stress reactivity, $M = .73$, 95% CI [.69, .77], $SD = 1.34$, $t(97) = 2.64$, $p = .0096$, Cohen's $d = .53$. This finding is consistent with our assumption that high-stress reactivity facilitates learning which, in turn, facilitates reduction in stress.

Discussion

This study found that people with higher dispositional stress reactivity experienced greater stress when faced with novel sociocultural situations and, consequently, were faster at learning the relevant situational norms. Importantly, we found that participants' stress appraisal for the first 20 trials was most predictive of their increase in learning, in comparison to stress experienced at other points, such as their anticipatory stress or stress experienced later on in the task. These relationships were contaminated by the fact that the extent to which participants learned the underlying rule and the amount of stress they experienced during the task are likely bidirectionally related. Importantly, an analysis eliminating this endogeneity found that the amount of stress participants experienced during the first 20 trials predicted their speed of learning in the subsequent 60 trials.[8] Finally, providing support for our theorizing, we found a sequential indirect path from dispositional stress reactivity to greater stress early on in the task, which predicted greater learning in the subsequent trials, which in turn predicted lower stress toward the end of the task. In other words, more stress-reactive participants experienced greater stress early on in the sociocultural norm learning task, learned the relevant rule faster in the subsequent trials, and thus

[7] We also conducted additional analysis to address the endogeneity issue mentioned earlier. Specifically, we calculated the stress experienced in the last 20 trials by subtracting stress after 60 trials from stress after 80 trials. A similar sequential mediation analysis (PROCESS Model 6) with this stress measure as the dependent variable revealed an even larger significant sequential indirect effect ($ab = -.12$, $SE = .068$, 95% CI [−.28, −.019]) from dispositional stress reactivity to greater stress experienced in the first 20 trials and faster learning in the next 60 trials, leading to lower stress after the final 20 trials.

[8] Note that the subjective measure of stress after the first 20 trials was specific to the norm learning task because we asked participants to rate how stressful the task was until that point.

experienced lower stress later on in the task. This finding is consistent with our theorizing that the initial stress response was adaptive because it predicted behavioral change (i.e., faster learning), and this behavior change facilitated recovery of stress levels.

Although we did not replicate our direct effect of dispositional stress reactivity on the rate of learning in this study, this study's procedure differed significantly from that of the previous studies that found this relationship. In particular, we measured a potential mechanism—stress experienced in the sociocultural learning task. The measurement of explicit stress appraisals during the sociocultural learning task may have weakened the direct effect of dispositional stress reactivity on learning (Kassam & Mendes, 2013). Despite the lack of a direct effect, we still found evidence for an indirect effect in line with our theorizing: Higher dispositional stress reactivity predicted greater experienced stress in the initial phase of the sociocultural learning task, which in turn predicted faster learning later on in the task. Importantly, an indirect effect does not require a direct effect to be meaningful (e.g., Hayes, 2009; MacKinnon et al., 2000).

General Discussion

Four studies (and a pilot study) identified a novel antecedent of sociocultural learning—individual differences in stress reactivity. A pilot study found that people with a greater genetic susceptibility toward greater stress reactivity, as computed by a GPS across 59 SNPs on 10 different genes (e.g., genes related to the functioning of CRH, glucocorticoid, and mineralocorticoid receptors), were faster at learning the actual norms of another culture in a lab-based learning task. Study 1 showed that people who experienced a greater increase in cortisol following exposure to an external stressor were subsequently faster at learning the norms of an unfamiliar culture in a simulated interaction. Study 2 replicated these findings in a larger sample while assessing dispositional stress reactivity using a self-report scale; this scale has previously been shown to predict HPA axis stress reactivity and the subjective experience of stress following stressor exposure (Schlotz, Hammerfald, et al., 2011; Schlotz, Yim, et al., 2011). Study 3 found that dispositional stress reactivity was associated with faster learning in both a sociocultural norm learning task and a nonsocial learning task. Finally, Study 4 provided evidence for the underlying mechanism. Individuals higher in dispositional stress reactivity experienced greater acute stress when faced with new sociocultural norms they needed to learn, and this aided their learning.

Theoretical Contributions

The current research contributes to an emerging literature on how people learn the norms to interact with others from different ethnicities, countries, regions, faiths, and sexual orientations. Although extensive research has looked at the consequences of norm violations for individuals, much less attention has been paid to how people learn new sociocultural norms to avoid future transgressions. A large body of work shows that interacting with people from communities other than one's own can be stressful and, therefore, leads to lower executive control and worse performance on tasks that require cognitive resources (Richeson & Shelton, 2003, 2007; Richeson & Trawalter, 2005). Although the effect of induced stress on nonsocial learning has been studied (e.g., Lighthall et al., 2013; Otto et al., 2013; Raio et al., 2017), the effect of stress on learning diverse sociocultural norms is less well-understood. We contribute to the literature on sociocultural learning by demonstrating that stress reactivity can be beneficial for people seeking to learn diverse, unfamiliar social norms through trial and error, even in the presence of noisy feedback. We found converging evidence that people with higher stress reactivity were faster at learning diverse, unfamiliar social norms.

The present research contributes to the literature on the stress that people encounter when they seek to learn the diverse norms governing social interactions in unfamiliar settings. The century-long research tradition on acculturative stress has struggled to operationalize its key construct distinctly from its antecedents and consequents, leading a recent review to recommend the abandonment of the construct (Rudmin, 2009). One challenge has been to measure its theorized consequences—adaptive information processing, on the one hand, and psychopathology, on the other—in isolation from the stress itself. Past self-report instruments measuring stress and sociocultural adjustment have conflated the construct with its purported consequence (Rudmin, 2009). To capture sociocultural learning distinctly from stress and its causes, we used a laboratory task in which we assessed learning as the change in accuracy across trials. Thus, our research helps distinguish the stress and coping perspective on acculturation from the learning new norms and social skills perspective (Masgoret & Ward, 2006; Ward, 1997) and provides empirical evidence documenting this relationship.

A challenge faced by past research in this literature is measuring the stress response distinctly from its antecedents, that is, objective stressors such as uncomfortable social interactions in new settings. Even studies that have used biomarkers, such as baseline blood pressure or cortisol, fail to meet this challenge because individual differences in these physiological measures may reflect both differences in exposure to objective stressors and differences in acute stress reactivity. We addressed this issue across all studies by measuring stress reactivity before the norm learning task. For example, in Study 1, we measured participants' stress reactivity as indexed by changes in their cortisol level upon exposure to a physical stressor and then assessed the extent to which they learned the norms of an unfamiliar culture using a different task. Consistently, five studies found that individual differences in stress reactivity measured before the norm learning task predicted faster learning in the norms task.

The current research contributes to the literature on cultural learning by measuring learning as improved accuracy in behavioral choice across trials. Past research on cultural learning typically just asks people to report how well they have learned local sociocultural norms (e.g., Searle & Ward, 1990; Ward & Kennedy, 1999) or how comfortable people feel interacting with people from other backgrounds (Black & Stephens, 1989). This method suffers from many problems associated with self-report measures (e.g., social desirability, reference point effects, lack of objectivity). Our paradigm instead looks at the process of learning over time from trial-and-error feedback (Morris et al., 2019; Savani et al., 2022). This method provides a richer picture of the learning process than one-time self-report or performance measures.

Limitations and Future Directions

One limitation of the current research is that the sample sizes of our first two studies are small, given current norms. However, we sought to counteract the relatively smaller number of participants by using precise measures of both the independent and the dependent variables. Instead of measuring people's genetic variations on a binary scale, the pilot study used a continuous GPS that assessed people's stress reactivity using the weighted average of a large number of genetic variations derived from a GWAS (e.g., genes related to HPA axis function, including CRH, glucocorticoid receptors, and mineralocorticoid receptors). Furthermore, we obtained a relatively precise measure of sociocultural learning by asking people to learn the norms of a new culture using either a 50-trial or an 80-trial task. Study 1 obtained a relatively precise measure of stress reactivity (cortisol change) by using a cold pressor. We measured cortisol in duplicate to ensure reliability and used well-established procedures for setting up the cortisol study. Finally, we sought to address the sample size limitations by using larger samples in the subsequent studies.

An important limitation of the pilot study is that we used an existing GWAS on psychiatric disorders to derive the GPS associated with people's stress system (Cross-Disorder Group of the Psychiatric Genomics Consortium, 2013). The ideal study would first conduct a large sample GWAS of sociocultural learning and then conduct a replication sample to verify the findings of the GWAS. Such a study would require sample sizes in the thousands but would be the ideal next step in this research area. Ideally, this study would identify polymorphisms on genes related to the HPA axis among the polymorphisms associated with sociocultural learning.

In terms of diversity and inclusiveness of the sample, one limitation of Study 1 is that we only sampled men. Although prior research has not found gender differences in participants' cortisol reactivity following the cold pressor task (Lighthall et al., 2013; Schwabe & Wolf, 2009), future research can examine whether the current finding replicates with women. Given that the pilot study and Studies 2–4 all included both men and women and conceptually replicated Study 1's findings, we do not have any reason to believe that the findings from Study 1 would not generalize to women.

Careful readers may note that participants with higher stress reactivity seem to perform worse in the initial trials of the learning task (Figures 3–6). However, this pattern is likely an artifact of the analytic model. Although logistic regressions fit an S-shaped curve, the average accuracy in our studies is closer to 50% than to 0% or 100%, and the middle section of the S-shaped logistic curve is approximately linear. Thus, the model seeks to fit an approximately linear curve to the change in each participant's accuracy across subsequent trials. In reality, though, participants experience no gains in accuracy for the first 10 or 20 trials as they try out different rules (see the Supplemental Materials, p. 14), and once they have narrowed down on the correct rule, their accuracy tends to increase. However, existing regression-based analytic tools do not provide a way to test for this "initial plateau followed by an increase" pattern in terms of change in accuracy across trials. When a logistic regression is fit to this pattern, it can give the impression of low initial accuracy even though this is not actually the case.

Study 3's results suggest that the relationship between stress reactivity and learning generalizes across social and nonsocial tasks; however, we found the opposite relationship between dispositional stress reactivity and learning in a nonsocial task in a separate study (see Supplemental Study S1, p. 15, for details). In this study, U.S. residents recruited from Amazon Mechanical Turk were asked to classify Greebles according to a hidden rule, similar to the nonsocial learning condition in Study 3. In the supplemental study, the interaction between stress reactivity and participants' accuracy across successive trials was statistically significant and *negative*. In other words, more stress-reactive individuals became less accurate over successive trials in the nonsocial learning task, in contrast to Study 3, in which they became more accurate over successive trials in the nonsocial learning condition. Although there may be multiple explanations for these divergent findings, one explanation is culture—Study 3 was conducted with predominantly ethnically Chinese participants who tend to anthropomorphize nonliving objects (Tan et al., 2018), compared to Supplemental Study S1, which was conducted with American participants. As our focus is on sociocultural learning in the present research, additional research is needed to resolve this inconsistency between dispositional stress reactivity and nonsocial learning.

We found that higher perceived stress early in the sociocultural learning task is a mechanism through which stress reactivity spurs faster sociocultural learning, in line with our theorizing. However, other complementary biological mechanisms may also be involved. For example, it is plausible that individuals higher in stress reactivity marshal increased metabolic resources (i.e., glucose) as part of the acute stress response (Zänkert & Kudielka, 2019), which, in turn, enhances sensitivity to feedback in the sociocultural task that speeds up learning. This energy-mobilization mechanism can be tested in future studies through measurement or manipulation of glucose levels.

Study 4 found that the sociocultural learning task induces subjective stress. However, it is not clear whether the stress generated by this task is acute enough to generate a physiological stress reaction that is evident in a cortisol spike. Prior work has found that social stressors, such as the Trier Social Stress Test, do induce a cortisol spike (Schlotz, Hammerfald, et al., 2011). This finding suggests that the stress generated by the sociocultural learning task may be accompanied by a spike in cortisol, particularly for those higher in stress reactivity. However, other evidence indicates that some stressors that increase subjective stress (e.g., mental arithmetic tasks) do not consistently increase cortisol levels (Giles et al., 2014), suggesting that the sociocultural learning task may not lead to a cortisol spike. To address this question, future studies can randomly assign participants to a sociocultural learning task or a control condition and then measure cortisol levels at multiple time points. It would also be beneficial to measure SNS changes in such studies, which occur over relatively faster timescales compared to the HPA axis and might also contribute to sociocultural learning (Zänkert & Kudielka, 2019).

The current research measured HPA axis activity and psychological factors that have been previously shown to predict HPA axis activity. We can conclude that stress reactivity is an antecedent of sociocultural learning, but we cannot draw strong causal conclusions because we used correlational designs. Thus, it would be valuable to conduct follow-up experimental studies to determine causality, such as pharmacological manipulations of the HPA axis (Wolf, 2019). Future studies can also measure or manipulate the SNS to examine its role in sociocultural learning, independently or in interaction with the HPA axis, as an extension of the current research (Ali et al., 2017).

In line with past research on cultural learning (Morris et al., 2019; Savani et al., 2022), the change in accuracy across successive trials was our focal dependent measure. A potential advantage is that accuracy is a face-valid and parsimonious outcome measure. However, we only modeled a single parameter (i.e., the change in accuracy over trials), but reinforcement-learning models often model multiple parameters (Rescorla & Wagner, 1972). Additionally, unlike other studies on learning (Colas et al., 2022), we did not include any practice trials. Moreover, given our focus on learning, we did not include a test or performance block after the learning phase in which participants do not receive any feedback. Although there is evidence that faster learning on the sociocultural norm learning task used in Studies 1 to 4 is associated with greater acculturation in a foreign culture (S. M. Madan et al., 2018, as cited in Savani et al., 2022), such a design would have allowed us to separately assess the relationship between stress reactivity and learning versus performance. To address these limitations, future research needs to design studies that include an initial practice block in which participants do not receive any feedback, a learning block in which they receive feedback, and a final performance block in which they again do not receive any feedback. In addition, future research may model people's learning slopes using computational reinforcement-learning models (e.g., temporal difference prediction) rather than our logistic regressions (Colas et al., 2022; Foerde & Shohamy, 2011).

Across five studies, we find that stress reactivity is beneficial for learning and, hence, adaptive when people have the opportunity to learn and correct their errors. However, this finding points to an important boundary condition. Specifically, stress reactivity may not be beneficial if people do not have the opportunity to learn and improve their performance in the future; in such cases, a heightened stress response may exacerbate feelings of helplessness. Future research can directly test this idea by administering tasks in which the feedback that participants receive is random rather than based on an underlying rule; in such settings, a stronger stress response is likely to be maladaptive.

Another limitation of the current studies is that they focused on people's ability to learn diverse norms associated with unfamiliar cultures. However, there are numerous other norms that people need to learn in their everyday lives, including norms associated with different regions, social classes, institutions, and standards (S. M. Madan et al., 2022). We found parallel results both with the speed with which Singaporeans learned the norms of interaction in everyday situations that have occurred in the United States and the speed with which they learned the fictional social norms of another culture. Thus, we reason that the findings from the present study are likely to generalize to different sociocultural settings. Nevertheless, future research can explicitly test this idea by sampling other situations where people must learn diverse norms.

Finally, the current studies were conducted in a high-income Asian country, Singapore. Singapore is characterized as collectivistic, high power distance, and tight (Gelfand et al., 2011; Hofstede, 1980; S. Madan et al., 2023). The data do not allow us to assess whether current findings would generalize to low-income countries or countries with a very different cultural profile (e.g., individualistic, low power distance, loose), although there is no reason to expect this to be the case. As in other domains (e.g., Savani et al., 2016), it is possible that there are cultural similarities in this phenomenon. The current studies also focused on how quickly people can learn the norms of a new sociocultural context that was framed as being similar in status to their own. Thus, the data do not allow us to assess whether current findings would generalize to interactions in which the two groups vary significantly in power or status.

Future research can examine whether our findings generalize from the individual level to the society level. That is, do societies that are exposed to many historical stressors have high societal-level stress reactivity? For example, countries that are frequently subject to earthquakes, tsunamis, and hurricanes may over time become highly responsive to stressors, whereas those with less historical evidence may become paralyzed. To deal quickly with stressors, society needs to engage as much of the population as possible toward damage mitigation and restoration of normality, which is fostered by tight norms (Gelfand et al., 2011; Morris, 2024). Moreover, past research has found that when people perceive a high degree of threat in the environment, they prefer tighter cultural norms (Gelfand & Lun, 2013; Jackson et al., 2019; Ma et al., 2023). If people higher in stress reactivity are more sensitive to environmental threats (Boyce & Ellis, 2005), these findings raise the possibility that groups high on stress reactivity can end up developing tighter norms due to higher threat perception.

Nobody wants to get stressed, particularly the stress of navigating unfamiliar social interactions. However, stress can be both beneficial and detrimental. The current research indicates that those who experience greater stress reactivity can learn diverse norms faster and, thus, likely be better able to effectively navigate a rapidly evolving sociocultural landscape.

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Received May 13, 2023
Revision received October 21, 2024
Accepted October 26, 2024 ■