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Learning to make smart choices in the context of risk: The roles of internal affective feedback and life events☆,☆☆

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ABSTRACT

Autonomic arousal may facilitate beneficial decision-making when the link between choices and outcomes is uncertain. However, it is unknown whether greater risk-specific autonomic arousal is linearly associated with faster learning to avoid risky decisions. Furthermore, although the influence of stress on decision-making is well documented, it is unknown whether recent life stress might moderate the relationship between this internal affective feedback and decision-making. We report two studies using the Iowa Gambling Task with diverse community samples. Each study demonstrated a linear relationship between the level of autonomic arousal prior to risky decision-making and the rate of learning to avoid risk. Additionally, participants' recent life events conditionally moderated this association. Specifically, the relationship between risk-specific arousal and advantageous learning was strongest for participants who experienced relatively more positive and fewer negative life events in the previous four months. These findings suggest that autonomic arousal may generally inform decision-making, but less so when life circumstances are relatively poor.

1. Introduction

Imagine that you are facing an important decision at a critical crossroads in your life. Perhaps you have two job offers in two faraway parts of the country, or you have been accepted to two different graduate programs with unclear strengths and weaknesses. You have to choose just one, and as you reach for the phone or pick up the pen to make your final decision your palms begin to sweat and your heart races slightly. When stakes are high and choices are about to be made the body reacts to help guide behavior, an experience often referred to colloquially as a "gut feeling" (Chiu et al., 2018). Internal feedback from the body has been shown to play a role in decision-making (Bechara and Naqvi, 2004), particularly when there is an element of risk (Loewenstein et al., 2001), which entails unclear links between the available choices and their outcomes as well as an opportunity for a substantial win or a loss (Bechara and Damasio, 2005). Increases in autonomic arousal before making a risky decision, compared to arousal before a safe decision, have been shown to predict the ability to learn to avoid risky decisions in favor of safe ones (Bechara et al., 2000). These findings have been replicated with both healthy and clinical populations (Bechara and Naqvi, 2004) and support the idea that physiological changes due to emotion may inform perception and may help guide behavior (Barrett, 2017; Birk and Bonanno, 2016; Damasio, 1994; Damasio et al., 1996; Wiens, 2005). Nevertheless, while autonomic arousal prior to risky choices has been associated with learning to make more safe than risky choices (Bechara and Damasio, 2005), these analyses often have compared the performance of separate groups of participants (e.g., healthy controls vs. patients with brain damage; Bechara et al., 1997). Research is needed to test *individual differences* in the arousal-choice association. Is there *a linear relationship* between a person's level of risk-specific autonomic arousal and the rate at which they learn to avoid those risky choices?

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A large body of literature addresses the complex ways in which emotion alters decision-making processes (Lerner et al., 2015; Peters et al., 2006; Slovic et al., 2004). Emotions on differing temporal scales interact to influence decision-making in complex ways that are not yet fully understood. Some very transient emotions change dynamically during the course of decision-making (e.g., a twinge of momentary negative affect while considering a particular option), whereas other emotions manifest on a much longer timescale such as days or weeks (e.g., chronic stress due to negative life events). Peters et al. (2006) summarize that short-term emotion affects decision-making by serving as a source of information and a form of "common currency" ("How does option A *feel* compared to option B?") and as a "spotlight" that focuses attention on newly encountered information that is worthy of processing. In these ways, transient emotion may generally guide the decision-making process adaptively. In contrast, more sustained emotions that are elicited outside of the decision-making task may interfere with the short-term affective contributions to decision-making processes outlined above. For instance, research in humans and rodents suggests that chronic stress may lead to a greater reliance on habitual behaviors derived from past experiences rather than present outcomes, or to decision-making processes that favor high-risk/high-reward choices over low-risk/low-reward choices (Arnsten et al., 2017; Dias-Ferreira et al., 2009; Friedman et al., 2017; Radenbach et al., 2015).

Stress can have a profound, and typically adverse, effect on the brain's ability to make wise decisions (Miu et al., 2008; Preston et al., 2007; Putman et al., 2010; Starcke and Brand, 2012). Stress has been shown to reduce cognitive resources (Eysenck et al., 2007), divide attention with internalized representations of the stressor (Klein and Boals, 2001), and increase the likelihood that a decision is made before all options are considered (Keinan, 1987). Stress has been shown to increase preference for immediate gratification at the expense of long-term benefit due to altered functioning of the brain's reward circuitry (Mather and Lighthall, 2012; Oliver et al., 2000; Putman et al., 2010). Decisions that involve risk may be particularly susceptible to impairment from stress (Miu et al., 2008; Preston et al., 2007). Increases in cortisol, a hormone released as part of the body's response to stress, have been associated with an increased likelihood of making more risky choices and overall more disadvantageous outcomes (Starcke et al., 2008). In contrast to transient negative emotion, chronic life stress may reduce the production (McEwen, 2000; McEwen, 2004) or perception (Schulz et al., 2013) of autonomic arousal. Stress from significant life events has also been shown to blunt autonomic reactivity (Clements and Turpin, 2000). Therefore, if autonomic arousal is associated with improved learning to avoid risky decisions, then groups who experience more stress, such as those in low socioeconomic status (Baum et al., 1999; Ronzani et al., 2018; Shafir, 2017), may have greater risk of impaired decision-making and poor long-term outcomes. Positive life events may buffer to some degree against the psychological impact of negative events (Cohen and Hoberman, 1983; Hobfoll, 1989), and therefore it may be fruitful to consider a broad range of recent life experiences in relationship to decision-making.

We sought to achieve three aims in the present studies. First and most importantly, we aimed to address the following question in both studies: If arousal indeed guides our decisions, then is *more* risk-specific arousal associated with learning *more quickly* to make smarter choices? The relationship between risk-specific arousal and overall performance on the IGT has been well established in the literature (for a meta-analytic review, see Simonovic et al., 2019). However, there is an important gap concerning the *speed* of learning. Although prior research has examined skin conductance level in relation to how decision-making changes over time during the IGT (e.g., Carter and Pasqualini, 2004; Hinson et al., 2006; Visagan et al., 2012), these studies evaluated patterns of autonomic activity and decision-making separately by block, often as a means of determining when advantageous decision-making starts to occur during the task. However, research is needed that tests individual differences in the *rate* of learning to test whether greater risk-specific arousal may confer an advantage in terms of enhanced *efficiency* of learning. The present studies addressed this need by evaluating whether individual differences in autonomic arousal were linearly associated with faster learning to avoid risky decisions. Second, much of the research on risky decision-making has consisted of samples that are homogeneous with respect to important demographic characteristics such as age (Miu et al., 2008) or education level (Starcke et al., 2008; Werner et al., 2009) and these samples may not be representative of the population at large. In both studies we recruited a diverse sample to address that need. Third, despite indications that significant life events may influence decision-making (Ronzani et al., 2018) or reactivity of the autonomic nervous system (Clements and Turpin, 2000) the potential influence on the relationship between autonomic feedback and decision-making has yet to be tested. One might expect that an abundance of negative, relative to positive, life events would lead to poor decision-making given that negative life events are associated with poorer behavioral performance, at least among people especially attentive to their own bodily signals (Baradell and Klein, 1993), or that life stress related to finances is associated with relative insensitivity to the probability of potential losses in a decision-making task (Ronzani et al., 2018). Nevertheless, no research study to our knowledge has measured the effect of life events on the link between physiological sensitivity to risk and decision-making. To address this gap while also replicating the first study, Study 2 tested whether individual differences in recently experienced negative and positive life events were associated with different patterns of associations between autonomic arousal before risky choices and the rate at which learning to avoid risk occurs.

2. Study 1

Building on prior work showing that autonomic arousal may generally guide decision-making, we tested whether *individual differences* in arousal are related to decision-making benefits. Specifically, we hypothesized that participants who evidenced *greater* autonomic arousal prior to risky vs. safe decisions would demonstrate *faster* rates of learning to favor the safe over risky decisions.

2.1. Method

2.1.1. Participants

A community sample of $N = 98$ participants responded to advertisements and were compensated for completing the experimental tasks in the lab. Among the 98 enrolled participants, five were removed for sleeping during the experiment, two were removed for inattention to the task (i.e., frequently not looking at the computer screen, as assessed by live video monitoring, or frequently failing to choose a deck within 10 s, as assessed by monitoring event codes), three had no skin conductance data recorded due to technical difficulties, and one did not complete one of the self-report measures, leaving 87 adults with data included in the analyses. Among this sample, the mean age was 28.6 years ($SD = 7.7$), and 55.2% were female. Almost half of the participants, 47.1%, identified as Black or African American, 25.3% identified as White, 12.6% identified as Asian, 3.4% as American Indian or Alaska Native, 2.3% identified as multi-racial, and 9.2% declined to respond. When asked about ethnicity, 25.3% identified as Hispanic or Latino, 67.8% as non-Hispanic, and 6.9% declined to answer. Regarding education, 9.2% reported completing a graduate degree, 3.4% some graduate school, 27.6% a college diploma, 46.0% some college, 12.6% high school diploma or its equivalent, and 1.1% some high school. We confirm that we have reported all conditions and data exclusions for Study 1. As noted elsewhere, the additional physiological measures of electromyography and electrocardiography were collected but not relevant to the present analyses. The sample size was determined with the goal of achieving approximately 90 participants with usable data for analysis. This sample size is considerably larger than typical studies that assess SCL during the IGT. For example, the mean sample size of similar studies

using the IGT is approximately 76 participants (see Table 3 in Simonovic et al., 2019).

2.1.2. Materials

2.1.2.1. Questionnaires. Participants completed a series of pen-and-paper self-report questionnaires. As trait anxiety has been shown to be associated with autonomic arousal (Miu et al., 2008), decision-making (Hartley and Phelps, 2012), and the ability to maintain attention (Bishop, 2009), the trait subscale of the State Trait Anxiety Inventory (STAI; Spielberger et al., 1970) was administered to assess stable trends in general anxiety levels. The Attentional Control Scale (ACS; Derryberry and Reed, 2002) has two subscales: attentional focusing and attentional shifting (Ólafsson et al., 2011). Attentional focusing is the ability to willfully maintain focus despite distraction, and attentional shifting as the ability to intentionally shift attention between competing stimuli (Ólafsson et al., 2011). Higher attentional control has been associated with resilience to stressful events (Bardeen et al., 2015; Crouch et al., 2012), and lower attentional control predicted greater vulnerability to stress when performing cognitive tasks (Grillon et al., 2016). Participants also completed the Emotion Regulation Questionnaire (ERQ; Gross and John, 2003), the Locus of Control of Behavior Scale (LCBS; Craig et al., 1984), and the Satisfaction with Life Scale (SLS; Diener et al., 1985). Internal consistency reliability was adequate or better for all self-report scales, all Cronbach αs $\geq$ 0.754.

2.1.2.2. Iowa Gambling Task. Participants chose between four decks of cards with the goal of maximizing their earnings of facsimile money, which has been shown to yield similar performance as real money in the IGT (Bowman and Turnbull, 2003). Each trial began with an anticipation screen that displayed the four decks and a dark gray background color for 3 s before the choice screen appeared with the words "Select a deck" appearing in blue font over a light gray background color. Participants were instructed that they could choose one deck at this time by clicking on it with the mouse. The duration of the anticipation screen was chosen to allow ample time to capture decision-related skin conductance responses in line with evidence that electrodermal responses typically reach their peak between 1 and 3 s after an internal or external eliciting stimulus (Dawson et al., 2007). Selecting each deck carried both rewards and penalties. Choosing repeatedly from either of the two disadvantageous or the two advantageous decks led to overall loss or gain, respectively. The disadvantageous "risky decks" (A & B) offered relatively large immediate rewards on every trial ($100), but sometimes (50% of the time for deck A and 10% for deck B) also carried penalties (ranging between $150 to $350 for deck A and $1250 for deck B), resulting in decreased earnings over the long run (net $250 loss for every 10 risky decks selected). The advantageous "safe decks" (C & D) offered relatively small immediate rewards on every trial ($50), with occasional penalties (50% of the time for deck C and 10% for deck D), which were comparatively small ($50 for deck C or $250 for deck D), resulting in increased earnings over the long run (net $250 gain for every 10 safe decks selected).

For the purpose of analysis, the 100 trials of the IGT were divided into five blocks of 20 trials each to determine changes in participant's response patterns over time. We took this approach to be consistent with prior studies of the IGT, whether they measured behavioral performance and SCL (Carter and Pasqualini, 2004; Hinson et al., 2006; Visagan et al., 2012) or behavioral performance only (e.g., Bowman and Turnbull, 2003; Turnbull et al., 2005). A measure of advantageous choosing was computed for each of these blocks as the number of times the safe decks were chosen minus number of times risky decks were chosen: $[(C + D) - (A + B)]$. The rate of learning for each participant was computed as the slope of the regression line that best fit the five points that represented the measure of advantageous choosing over the five blocks of the task. Thus, a larger slope indicated faster (i.e., more efficient) learning to choose the safe vs. risky decks.

Skin conductance level (SCL) was used as an indicator of sympathetically mediated autonomic arousal (Dawson et al., 2007) collected using the Biopac MP150 unit (Biopac, Goleta, CA) and processed using the AcqKnowledge 4.3.1 program. After cleaning the area with a disposable pre-moistened wipe, two Ag/AgCl electrodes, pre-gelled with 0.5% chloride isotonic gel, were attached to the thenar and hypothenar eminences at either side of the base of the palm on the participant's non-dominant hand. A small BioNomadix transmitter was secured to the participants' non-dominant arm with velcro straps, with wires connected to the electrodes, which transmitted the data wirelessly to the Biopac MP150 unit behind a partition several feet away. It should be noted for the sake of transparency that two additional physiological measures were collected that are not the focus of the present analysis. Specifically, sensors were attached for measuring electrocardiography and facial electromyography of the *corrugator supercilii* muscle, and two additional wireless transmitters corresponding to these measures were attached to the nondominant arm. Data were measured in microsiemens (μS) and recorded at a sampling rate of 1000 Hz. Prior to each task, calibration was performed by detaching the lead clips from the electrodermal electrodes to re-establish a baseline of 0 mS corresponding to no electrical conductance. Data were down-sampled to 10 Hz and detrended linearly for each trial to adjust for downward drift artifact.

In order to compute anticipatory autonomic responses, SCL was collected continuously during a 3-s anticipatory period before a deck could be selected for each trial of the IGT (see Fig. 1). We chose to analyze continuous SCL instead of assessing only the amplitudes of discrete skin conductance responses determined by set criteria (e.g., latency window, minimum response amplitude) as described by Dawson et al. (2007). The rationale for this approach is that there were no external sensory events that occurred at set times after which the latency period of each SCR was expected to begin. Rather, we allowed SCL to vary according to participants' internal processes, and we did not discard any time epochs as we computed mean SCL for each condition (unless there was a serious electrical artifact in which the channel did not accurately record physiological activity). For each participant SCL means were computed across trials in which risky (decks A or B) and safe (decks C and D) choices were made, and then the key measure of average risky vs. safe SCL (henceforth simply "risk-specific SCL") was computed as the following difference score: mean anticipatory SCL before risky choices minus mean anticipatory SCL before safe choices.

2.1.3. Procedure

Participants were recruited through flyers posted near the Columbia University campus and online postings on the website of Teachers College, Columbia University and on craigslist.com. After a brief phone or email screen, participants were scheduled and brought in to the lab for the experiment. First, after the written informed consent procedure, electrodes were attached to participants, and the experimenter confirmed proper recording of physiological signals. Next, participants performed a resting state task, a task measuring emotion regulatory flexibility, and then the IGT. (The tasks administered prior to the IGT were not relevant to the present hypotheses but are reported for the sake of transparency.) Throughout the procedures the research assistant administering the experiment remained in the room. A web-camera on the monitor the participants used for the tasks was on and used to monitor their performance. While the subject performed tasks on the computer the assistant waited on the other side of a divider screen and observed the subject on a computer monitor to confirm that they maintained attention on the tasks. After all computer tasks were completed sensors were removed and participants completed the pencil-and-paper questionnaires. After this they were debriefed and monetarily compensated.

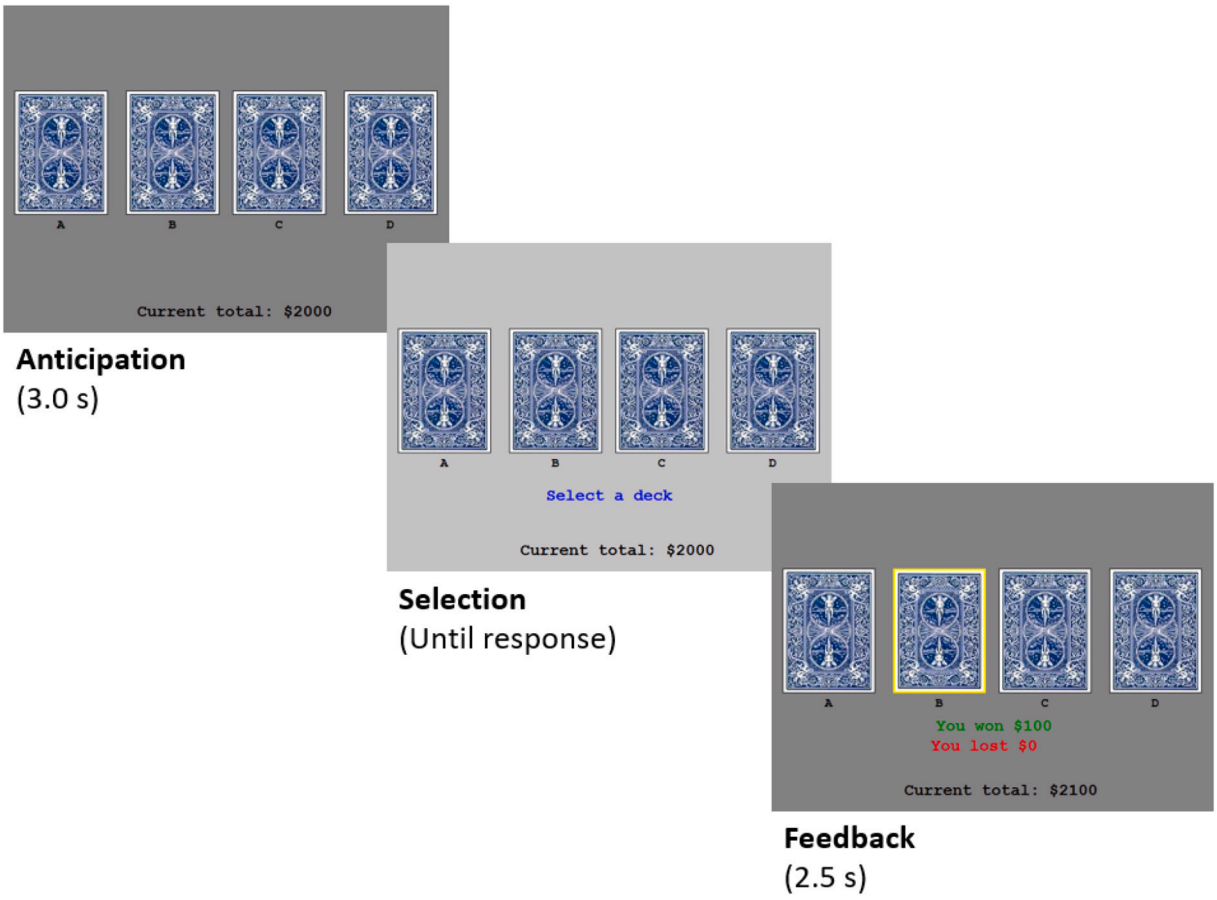

Fig. 1. Each trial of the Iowa Gambling Task began with an anticipation period lasting 3 s during which the participant could see the four virtual decks of cards prior to the subsequent selection screen during which participants indicated their chosen deck via a mouse click. A feedback screen then appeared that showed participants how much virtual money won and/or lost for that trial. Average skin conductance level during the anticipation period was assessed to capture autonomic arousal during the decision-making phase. This measure was aggregated separately for trials in which the risky decks and the safe decks were subsequently chosen by the participant. The difference in autonomic arousal was then computed for risky-minus-safe choices as a physiological marker of risk-related decision making that served as the key hypothesized predictor of learning in Studies 1 and 2.

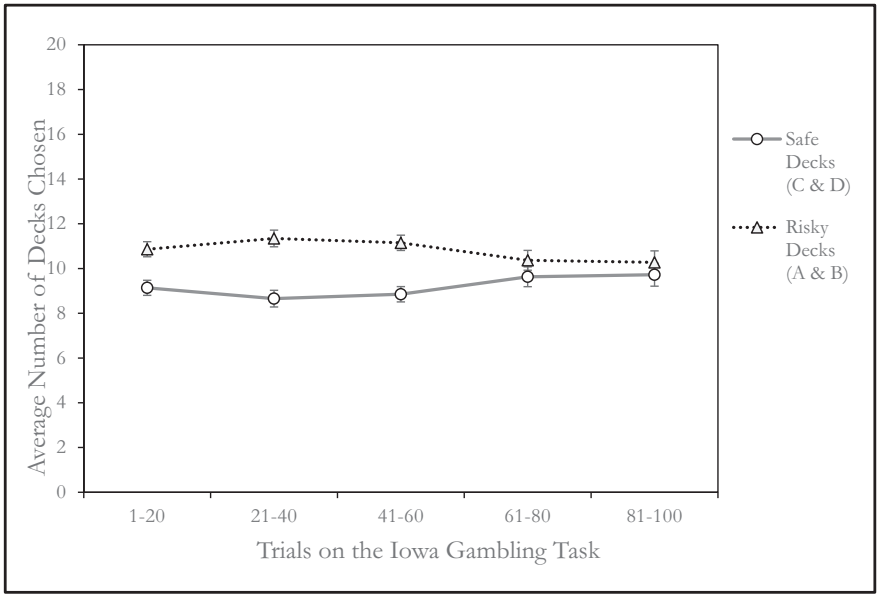

Fig. 2. Average choosing of risky and safe decks for each block of the IGT in Study 1.

2.2. Results

2.2.1. Preliminary analyses

Data were analyzed using SPSS version 25. Trends in behavioral performance over the course of the IGT were explored using a 5 × 2 repeated-measures ANOVA with within-subjects factors of block (1, 2, 3, 4, 5) and deck type (safe, risky). There was a significant main effect of deck type, $F(1, 86) = 6.65$, $p = .012$, $\eta_p^2 = 0.072$, where the risky decks ($M = 10.80$, $SD = 2.89$) were chosen more overall than the safe decks ($M = 9.20$, $SD = 2.89$). There was not a significant main effect of block. There was a significant Block × Deck Type interaction, $F(4, 344) = 2.54$, $p = .040$, $\eta_p^2 = 0.029$. These findings indicate that, although participants chose the risky decks more than the safe decks, this choice preference generally declined over time (see Fig. 2).

We identified relevant covariates to include in the final regression model using bivariate Pearson correlations to determine which psychological and demographic variables predicted rate of learning. Predictors of at least marginal significance (i.e., $p < .10$) were included in the model for hypothesis testing below. Rate of learning was positively associated with greater risk-specific SCL, $r(87) = 0.588$, $p < .001$, and negatively associated with attentional focusing scores, $r(87) = -0.237$, $p = .027$. Age, level of education, along with scores of the ERQ, LCBS, SLS, STAI-T, and ACS shifting subscale were unrelated to rate of learning, all $ps > .110$, and thus were not included in further analyses.

2.2.2. Hypothesis testing

We conducted a multiple regression model with rate of learning as the dependent variable, risk-specific SCL as the independent variable, and—based on the preliminary analyses above—attentional focusing as a covariate. The model was significant, $F(2, 84) = 27.92$, $p < .001$, $R^2 = 0.399$. Critically, as predicted, higher risk-specific SCL independently predicted a higher rate of learning to avoid risk, $B = 5.92$ ($\beta = 0.59$), 95% CI [4.22, 7.62], $p < .001$. Lower self-reported attentional focusing also predicted higher rate of learning, $B = -0.12$, b = −0.23, 95% CI [−0.21, −0.03], $p = .008$.

As requested by a reviewer, we ran a parallel model with the dependent variable being overall advantageous choosing across all blocks of the task. This dependent measure was computed by calculating the sum of trials on which Decks C and D were chosen minus the sum of trials on which Decks A and B were chosen for each block and then averaging this score across all five blocks of the task. The model was significant, $F(2, 84) = 6.17$, $p = .003$, $R^2 = 0.128$. Similar to the model above, higher risk-specific SCL independently predicted a higher overall advantageous choosing, $B = 7.02$ ($\beta = 0.30$), 95% CI [2.24, 11.79], $p = .004$. Self-reported attentional focusing did not significantly predict overall advantageous choosing, $B = -0.24$ ($\beta = -0.20$), 95% CI [−0.48, 0.01], $p = .058$.

2.3. Discussion

Individual differences in the degree of risk-specific autonomic arousal were positively associated with rate of learning to make advantageous choices. That is, the greater the arousal of the sympathetic nervous system in anticipation of risky relative to safe choices, the more quickly participants learned to make safe, instead of risky, choices. This difference was a robust predictor of the rate of learning even after adjusting for lower attentional focusing, which was associated with faster learning to avoid risky decisions on the gambling task. Participants with less ability to focus attention may have been more likely to be distracted from the task and thus more susceptible to influence from autonomic arousal. Accounting for external life events could give a clearer picture of the influence that stress from the real world has on the role of physiological feedback during decision-making.

3. Study 2

In Study 2 we sought to replicate the finding that participants who evidenced greater autonomic arousal prior to choosing risky vs. safe decks on the IGT would demonstrate faster rates of learning to avoid the risky decks (Hypothesis 1). In addition, we hypothesized that the role of autonomic arousal in decision-making would be moderated by a recent context characterized by negative or stressful life events and a relative deficit of positive events (Hypothesis 2). Whether this moderation effect might be related to differences in attentional resources or generally altered autonomic reactions was unknown, and therefore, as in Study 1, the analyses accounted for these factors.

3.1. Method

3.1.1. Participants

A community sample of 96 healthy adults responded to advertisements, passed a phone screening, and completed the experiment. Of those 96 total enrolled participants, four participants were removed for falling asleep during the task, two had unusable skin conductance data due to technical issues, and one participant was removed for having an extreme outlier score on rate of learning. Inspection showed this subject was a graduate student in psychology and it is believed he may have had some prior knowledge about the task, so his score was removed. This left a sample of $N = 89$ participants included in the analyses. Among the sample the mean age was 27.8 years ($SD = 6.8$), and 61.8% were female. Participants were racially diverse: 34.8% identified as Asian, 33.7% identified as White, 27.0% identified as Black or African American, 1.1% identified as multi-racial, and 3.4% chose not to answer. When asked about ethnicity, 14.6% identified as Hispanic or Latino, 83.1% identified as non-Hispanic or Latino, and 2.2% chose not to answer. Regarding education, 28.1% of participants reported completing a graduate degree, 23.6% some graduate school, 22.5% a college degree, 20.2% some college, 3.4% high school diploma or its equivalent, and 2.2% some high school. We confirm that we have reported all conditions and data exclusions for Study 2. As noted elsewhere, the additional physiological measures of electromyography and electrocardiography were collected but not relevant to the present analyses. The sample size was determined with the goal of achieving approximately 90 participants with usable data for analysis in order to match Study 1's size.

3.1.2. Materials

Materials were identical to those used in Study 1, except for the addition of one questionnaire: the modified Life Experiences Survey (LES; Sarason et al., 1978). The LES is a 50-item questionnaire that lists a series of impactful life events, both negative and positive. Two changes were made in this modified version. First, the reference point for amount of borrowed money in two items was updated from $10,000 to $30,000 to account for inflation. Second, the instructions were modified such that participants indicate whether these events occurred during the previous four months instead of 12 months. This more recent time frame was used to increase the likelihood that the psychological impact of these events was still potent. Research has shown that only events occurring within the past several months have reliable associations with psychological outcomes (Suh et al., 1996). Examples of events likely to be rated as negative included major personal illness or injury, death of a family member, major decrease in closeness with a family member, and trouble with in-laws. Examples of events likely to be coded as positive included engagement to a romantic partner, major increase in closeness with a family member, and a major increase in social activities. If an event was endorsed, participants were asked to report their subjective experience of that event on a 7-point Likert scale (−3 *Extremely Unpleasant*, 0 *No Impact*, +3 *Extremely Pleasant*). LES appraisal scores were computed by summing all individual item scores. Thus, lower LES appraisal scores reflected relatively more numerous and more intense negative events and fewer and less intense positive events. Internal

consistency reliability was adequate or better for all self-report scales other than the LES, all Cronbach αs ≥ 0.739. Note that a reliability test is not appropriate for the LES because the items correspond to particular life events and are not components that should be expected to load onto a larger factor.

All computer tasks were completed by participants on a Dell desktop computer with a 13-inch flat screen placed roughly 24 in. from their face. Analyses were conducted using SPSS. The moderation analysis for the second hypothesis for Study 2 was conducted using the PROCESS macro v 3.0 for SPSS (Hayes, 2017).

3.1.3. Procedure

Participant recruitment, consenting, and physiological sensor attachment procedures were the same as in Study 1. Once the experimenter confirmed proper recording of physiological signals, participants performed several tasks not directly related to the present hypotheses (a resting state task, a heartbeat perception task, a distractibility task, and a task measuring emotion regulatory flexibility) and then the IGT. After sensor removal, participants completed the questionnaires and then were debriefed and monetarily compensated.

3.2. Results

3.2.1. Preliminary analyses

As in Study 1, the average number of safe and risky choices for each of the 5 blocks of 20 trials was calculated. As in Study 1, a 5 × 2 repeated-measures ANOVA with the factors of block (1, 2, 3, 4, 5) by deck type (safe, risky). The main effect of deck type was not significant, $F(1, 88) = 3.74$, $p = .056$, $\eta_p^2 = 0.041$, such that participants did not choose risky decks ($M = 10.67$, $SD = 3.28$) significantly more or less often than safe decks ($M = 9.33$, $SD = 3.28$) across blocks. There was not a significant main effect of block. There was an interaction of Deck × Block, $F(4, 352) = 6.08$, $p < .001$, $\eta_p^2 = 0.065$, such that, although participants did not choose the safe decks more overall, similar to the previous study they nevertheless did learn to choose the safe decks more often as the blocks progressed (see Fig. 3).

3.2.2. Hypothesis testing

Regarding the first hypothesis for Study 2, to determine whether higher autonomic arousal before risk would again predict faster learning to avoid risk and whether this association would be moderated by recent life events, a regression analysis was conducted with rate of learning as the dependent variable, risk-specific SCL as the independent variable. In order to keep the same model specifications as in Study 1, attentional focusing was again included as a covariate. Additionally, LES appraisal score was included as a covariate in order to model its association with rate of learning in this simple model before testing its role as a moderating factor in the more complex regression analysis involving the same factors reported below. The simple model significantly predicted rate of learning $F(3, 85) = 4.86$, $p = .004$, $R^2 = 0.15$. Of the independent variables, only risk-specific SCL predicted rate of learning, $B = 1.84$ (β = 0.33), 95% CI [0.71, 2.98], $p = .002$. Attentional focusing and LES appraisal score did not significantly predict rate of learning, all $ps \geq .157$.

As for Study 1, in response to a reviewer, we ran a parallel model to the test directly above but with the dependent variable being overall advantageous choosing across all blocks of the task. The model was significant, $F(3, 86) = 4.85$, $p = .004$, $R^2 = 0.145$. Similar to the model above, higher risk-specific SCL independently predicted a higher overall advantageous choosing, $B = 4.92$ (β = 0.35), 95% CI [2.06, 7.78], $p = .001$. Neither self-reported attentional focusing nor LES appraisal score predicted overall advantageous choosing in this model, all $ps \geq .464$.

Regarding the second hypothesis for Study 2, we conducted a separate regression analysis using the PROCESS macro v 3.0 for SPSS to assess whether the association between risk-specific SCL (predictor) and rate of learning to avoid risk (dependent measure) was moderated by life event stress (moderator). To test the interaction effect, this moderation analysis built directly on the simpler regression analysis that was used for the first hypothesis for Study 2. Since it was not a significant predictor in the regression, ACS focusing score was not included as a covariate in the moderation model. Predictor variables were centered on the mean to aid interpretability of model estimates (Shieh, 2011). The model was run with a bootstrap estimation approach with 5000 samples (Shrout and Bolger, 2002). The overall model was significant, $F(3, 85) = 6.84$, $p < .001$, $R^2 = 0.194$. Critically, the interaction of risk-specific SCL × LES was significant, $DR^2 = 0.055$, $F(1, 85) = 5.82$, $p = .018$. To explore this interaction, the effect of risk-specific SCL on rate of learning was evaluated at high ($M + 1$ SD), medium (M), and low ($M - 1$ SD) LES scores (see Fig. 4). Higher risk-specific SCL was most robustly associated with faster rate of learning for participants with high LES scores, $B = 4.66$, 95% CI [2.18, 7.14], $p < .001$, and less so for those with medium LES scores, $B = 2.54$, 95% CI [1.36, 3.73], $p < .001$. The moderation was

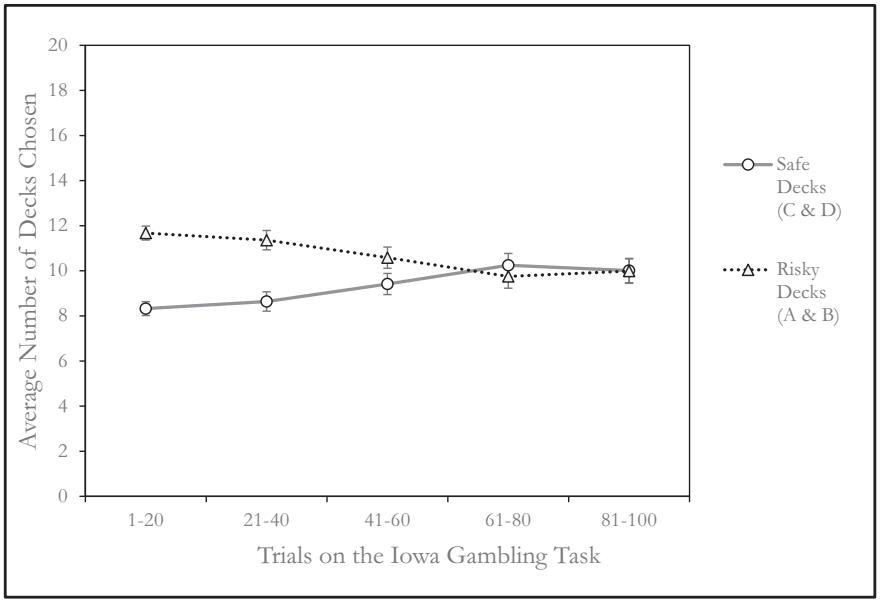

Fig. 3. Average choosing of risky and safe decks for each block of the IGT in Study 2.

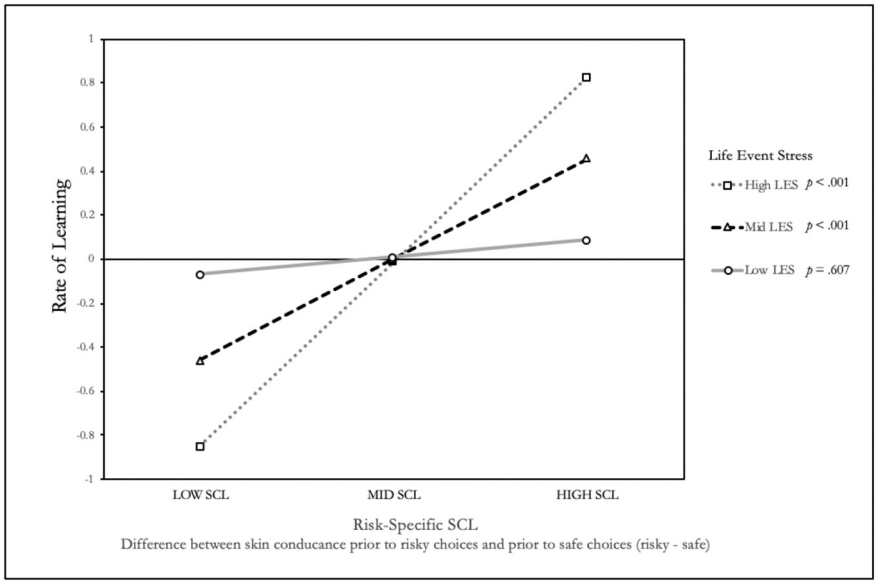

Fig. 4. Life event stress moderated the relationship between risk-specific SCL and rate of learning to avoid risk. Higher scores on the LES, the Life Experiences Survey, meant more positive and fewer negative life events in the previous 4 months, while lower LES scores meant more negative and fewer positive life events in the same period. All variables were standardized. High, mid, and low groups for risk-specific SCL and LES represent values of the relevant measure at the mean, the mean + 1 SD, and the mean − 1 SD respectively. The relationship between risk-specific SCL and rate of learning was significant for those in the medium and high LES score groups, reporting more positive and fewer negative events in the previous 4 months. However, skin conductance did not significantly predict rate of learning for those with low LES scores, indicating more negative and less positive events in the prior 4 months. LES = Life Experiences Survey score. SCL = skin conductance level.

not significant for those with low LES scores, $B = 0.43$, 95% CI [−1.22, 2.08], $p = .607$. That is, as LES scores increased, indicating more positive and fewer negative life events, the relative increase in risk-specific SCL was more strongly associated with a faster rate of learning to avoid risk. When LES scores were especially low, indicating more negative and fewer positive life events, risk-specific SCL was not associated with the rate of learning. Analysis of the Johnson-Neyman significance region showed that the model became significant with LES scores in the slightly negative region of the distribution at or above −6.47, $B = 1.23$, $p = .05$, with 27.0% of the total values below the significance region.

3.3. Discussion

Replicating the results of Study 1, the tests of the first hypothesis for Study 2 again revealed that greater autonomic arousal prior to making a risky vs. a safe decision was associated with faster learning to avoid making risky decisions. This relationship was confirmed both with correlation and linear regression analyses that adjusted for attentional focusing.

Stress from life events occurring in the previous four months, as measured by LES score, conditionally moderated the relationship between autonomic arousal and the rate at which participants learned to avoid risk. Higher scores on the LES corresponded to more positive, and fewer negative, recent life events, while lower scores implied more negative and less positive events. Notably, LES scores did not correlate with rate of learning, and did not predict rate of learning in the linear regression model. Thus, the key observed interaction between risk-specific SCL and LES score on rate of learning was particular to autonomic activity during the process of decision-making rather than reflecting a general change in the ability to learn the necessary associations to perform well on the task. Specifically, the findings suggest that, for participants with relatively lower life event stress (i.e., moderate to high LES scores), the previously observed linear relationship between risk-specific SCL and learning to avoid risky choices was evident. However, for participants with relatively higher life event stress (i.e., low LES scores), the relationship between risk-specific SCL and rate of learning to avoid risk was minimal, suggesting that elevations in SCL prior to making a risky vs. safe choice did not influence the rate at which the participant learned to avoid risky choices.

4. General discussion

Findings from both studies provide support for the hypothesis that greater autonomic arousal prior to making a risky decision, compared the same time period prior to making a safe decision, predicts a faster rate of learning to avoid risky decisions. This builds on the work of Bechara et al. (1997) who showed that participants who had elevated autonomic arousal prior to making risky decisions learned to avoid risky decisions, and those who did not show autonomic arousal prior to making a risky decision continued to make those risky decisions. However, in contrast to previous research comparing separate groups of participants, the present findings examined a continuous measure of individual differences in autonomic activity as it relates to learning speed. Each of the present studies showed a linear relationship in which participants with greater elevation in anticipatory SCL prior to making risky vs. safe decisions learned faster to avoid those risky options. Interestingly, these findings occurred even though participants did not prefer overall to make more safe than risky decisions across all trials in either study.

In addition, study 2 showed that recent life events moderated the relationship between autonomic arousal and rate of learning to avoid risk. The arousal-learning association was strongest among participants with more favorable profiles of recent life experiences (i.e., relatively fewer negative and more positive events). In contrast, for participants with more negative and fewer positive events, there was less evidence of a relationship between autonomic arousal prior to decision-making and the rate at which participants learned to avoid risky decisions.

These findings corroborate previous research showing a relationship between stress and impaired decision-making, particularly in situations involving risk (Miu et al., 2008; Preston et al., 2007; Starcke and Brand, 2012). The relationship between autonomic arousal and decision-making was linear in both studies, and in study 2 this relationship was moderated by recent life events. This suggests that real-time autonomic arousal likely informs decision-making when life circumstances are relatively good. However, when negative life events are numerous, this particular aspect of the body's influence on the mind with respect to decision-making may be lessened. Notably, the evidence for this effect occurred independently of the dispositional factor of attentional control that is known to be associated with decision-making.

The present studies had several strengths worth noting. First, the finding that greater risk-specific SCL predicted faster learning to avoid risk was replicated across both studies. Second, each study consisted of a

community sample with heterogenous representation of ethnicities and education levels, and the final analyzed sample sizes (87 and 89) were more than double that of other similar studies (Miu et al., 2008; Preston et al., 2007; Werner et al., 2013), thereby lowering the chance that the key finding that replicated across both studies may have occurred by chance. Characteristics of the study samples may explain the unusual finding that participants in both studies generally chose the risky decks more than the safe decks across all trials. In other studies of the IGT, participants tend to make more safe choices than risky ones overall across all trials (e.g., Bechara et al., 1997; Bolla et al., 2005). The higher overall preference for risky vs. safe choices in the present studies may be related to sample characteristics that differed relative to previous studies, such as socioeconomic status or education level.

The studies had several limitations. First, the cross-sectional, correlational design prevented answering causal questions. Specifically, the present design could not distinguish whether autonomic arousal contributes to the process of learning or is merely a product of learning, an issue that other researchers have attempted to tease apart (e.g., Hinson et al., 2006). While both present studies showed that higher autonomic arousal prior to making a risky decision, compared to a safe one, was a robust predictor of the rate at which participants learned to avoid unnecessary risk, it remains unclear whether the recognition and integration of afferent somatic information played a role in the learning process, or was simply produced as participants began to subconsciously associate risky decisions with their subsequent disadvantageous outcomes. Some research has used functional magnetic resonance imaging to show that activation of the insula, a region of the brain associated with the integration of afferent somatic stimuli, plays an increased role in decision-making when a person is under stress (Lighthall et al., 2012; Uy and Galvan, 2017). This pattern is consistent with the proposal that somatic feedback plays an increased role in decision-making when outcomes are unclear (Loewenstein et al., 2001).

A second notable limitation to these studies was the lack of screening for psychopathology. Several studies have shown that various psychopathologies can influence both the production and the interpretation of afferent somatic information (Ehlers and Breuer, 1996; Harshaw, 2015; Khalsa and Lapidus, 2016; Stern, 2014). Whereas depression may lower the likelihood that afferent somatic signals are perceived (Furman et al., 2013; Harshaw, 2015), there is some evidence that certain anxiety disorders may have the opposite effect (Ehlers and Breuer, 1992; Sturges and Goetsch, 1996). Future research should determine how depression and anxiety alter the relationship between autonomic arousal and decision-making to better understand the mechanisms by which mood disorders may influence decision-making.

A third limitation was the relatively low level of statistical power for detecting the interaction effect in Study 2. Although the studies were well powered to detect the robust main effect of risk-specific autonomic arousal on rate of learning, the interaction effect should be tested in future research that evaluates whether real-life stressors moderate the association of autonomic feedback and learning to avoid risk.

A fourth limitation is that the prior trial may have influenced the SCL measure during the anticipation slide for the current trial. However, this occurrence would be more likely to be a source of random error rather than systematic error. Future research should determine if the present pattern of findings occurs if longer pauses were to be inserted between trials to reduce potential contamination of SCL measurement across trials.

Finally, rate of learning in the lab-based IGT task is an imperfect measure of the capacity to learn to avoid risk when making real-world decisions. For this experimental measure to be maximized, a participant would have to make many more risky choices in earlier relative to later trials of the task. However, the computation is based on an assumption that participants will rarely learn to avoid risky decisions *very* early during the task (i.e., in the first 20 trials of block 1). Future research that models not only the slope but also the intercept of task performance may help to address this issue.

There are several pertinent future directions. First, researchers should test whether learning to avoid risk is similarly predicted by risk-specific arousal in decision-making tasks that have other contingencies of rewards and penalties in order to determine whether the effects persist outside of the particular design features of the IGT (Dunn et al., 2006). Second, research should test whether risk-specific arousal is *causally* related to rapid learning, and if so, whether the arousal drives the efficiency of learning or whether faster learning results in higher arousal. Third, research should test the extent to which emotion is related to the rate of learning independent of conscious cognitive processes. Fourth, while the present studies investigated stressful life events over the previous four months for reasons grounded in previous science (Suh et al., 1996), earlier stressors may have also been relevant. By assessing the full scope of life events (e.g., Stress and Adversity Inventory; Slavich and Epel, 2010; the Life Events Checklist; Weathers et al., 2013), future research may test whether an accumulation of stressful events over the lifespan lessens the importance of autonomic arousal's role in the speed of learning.

5. Conclusion

The present studies replicated and extended prior research connecting autonomic arousal to the likelihood of learning to avoid risk when making decisions. During a gambling task, the level of autonomic activation prior to making a risky decision, compared to activation prior to making a safe decision, was a robust predictor of the rate at which participants learned to avoid making risky decisions. This relationship was apparent across both studies, even after adjusting for a cognitive factor associated with decision-making (attentional control). The effect was more pronounced among people who recently experienced more positive and fewer negative life events. The mechanisms for this moderation effect should be tested in future research (e.g., decreased mental resources, increased reward salience). These findings build upon previous research showing that the relationship between afferent somatic information is tied to decision making. The results suggest that a context of substantial life stress may lessen the influence of somatic information on choices during risky decision-making processes.

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