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# Social Stress Facilitates Risk in Youths

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This research examined the influence of social stress on risk processes in youths. Study 1 ( $N = 89$ ) randomly assigned male youths to perform either a stressful social-evaluative or nonstressful control task followed by a risk-perception measure. Compared to controls, social stress participants perceived *less* risk in their environment. Study 2 ( $N = 188$ ) extended findings by testing effects of social stress on risk perception in males and females, and across 3 age groups: teenagers (15–19), young adults (25–40), and older adults (60–75). Replicating Study 1, teenagers experiencing social stress perceived less risk than age-matched controls. However, adults assigned to experience social stress reported *greater* risk perception compared to their age-matched controls. Effects of social stress also extended to risk-taking behavior. Stressed teenagers engaged in more risk-taking behavior relative to controls, and showed increased reward and lowered cost sensitivity during decision-making. These findings offer basic and translational value regarding factors that influence how youths evaluate risk.

**Keywords:** risk-taking, risk-perception, youth, psychophysiology, social stress

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Spending oneself into debt, gambling compulsively, or abusing substances all represent risky behaviors with hefty consequences: Americans lose \$100 billion each year gambling and societal costs of substance abuse exceed \$700 billion annually (Centers for Disease Control and Prevention, 2014; U.S. Department of Health and Human Services, 2014). Traditionally, risky behavior is attributed to impulsivity or self-control failure (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Metcalfe & Mischel, 1999): People succumb to risks when they fail to inhibit prepotent tendencies to engage in potentially costly, but rewarding, behavior.

Risk processes, however, are influenced by multiple factors including developmental period, social factors like evaluative pressure, and affective responses (Jamieson, Koslov, Nock, & Mendes, 2013; Lerner & Keltner, 2001). For example, research reliably shows that adolescents are riskier than both younger children and adults and these risky years can accumulate to large long-term societal and individual costs (e.g., Steinberg, 2007). Thus, curbing risk during this sensitive period may have multiple benefits. Efforts to reduce risk in youth populations, however, have been largely unsuccessful. For instance, meta-analytic data demonstrates the widely implemented Drug Abuse Resistance Education

program might do more harm than good because it does not address the causes of risk taking (see Lilienfeld, 2007, for a review). The research presented here is predicated on the belief that it is important to understand situational, affective, and biological underpinnings of risk processes to inform effective efforts to improve outcomes. To this end, we examined the effect of social stress and concomitant physiological responses on risk in youths.

## Physiological Responses to Social Stress

Acutely stressful social situations produce potent neurobiological responses (Dickerson & Kemeny, 2004; Mendes & Park, 2014). The biopsychosocial model of challenge and threat provides a theoretical framework to interpret responses to social evaluative pressures (see Blascovich & Mendes, 2010, for a review). Uncertain or negatively valenced social stress elicits a cascade of responses associated with threat (Dickerson & Kemeny, 2004). Threat responses manifest when appraisals of situational demands exceed perceptions of coping resources (cf. Folkman, Lazarus, Dunkel-Schetter, DeLongis, & Gruen, 1986; Folkman & Lazarus, 1985).

Physiologically, the experience of threat stimulates the hypothalamic–pituitary–adrenal (HPA) axis, which is commonly measured with its end product, cortisol. Cortisol increases have been linked to loss in social standing (Mehta, Jones, & Josephs, 2008), negative social feedback (Koslov, Mendes, Pajtas, & Pizzagalli, 2011), and feelings of shame (Dickerson & Kemeny, 2004). Indeed, meta-analytic data demonstrate that cortisol increases are most consistently linked to situations in which “an important aspect of the self-identity is or could be negatively judged by others” (Dickerson & Kemeny, 2004, p. 358).

Downstream, the experience of threat elicits avoidant behaviors and somatic freezing, is associated with poorer performance on some cognitive tasks, and impairs interpersonal processes in adults

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(e.g., Akinola & Mendes, 2012; Mendes, Gray, Mendoza-Denton, Major, & Epel, 2007; Lang, 2014; Peters, Overall, & Jamieson, 2014). Importantly for this research, acute physiological stress responses can have direct consequences for decision-making. Avoidance-motivated threat responses, compared to approach-motivated challenge responses, produce more cautious risk decisions in adults (e.g., Greenwood, Elliot, & Jamieson, in press; Jamieson, Koslov, et al., 2013; Kassam, Koslov, & Mendes, 2009).

### Social Evaluative Stress in Youths

Social stress is ubiquitous in adolescents and teenagers (e.g., Costello, Mustillo, Erkanli, Keeler, & Angold, 2003; Haugland, Wold, Stevenson, Aaroe, & Woynarowska, 2001; Kessler et al., 2005) and situations when social status is ambiguous or uncertain can be particularly threatening (e.g., Josephs, Sellers, Newman, & Mehta, 2006; Mendes, Major, McCoy, & Blascovich, 2008; Sapolsky, 2005). Unfortunately, ambiguity and concerns about social status are highly prevalent during transitions to high school and college. For instance, during transitional periods social networks and hierarchies are disrupted as old friendships dissolve and new ones are not yet created. This can create status ambiguities and promote acts of social aggression, including peer exclusion, social rejection, or rumor-mongering, to consolidate social status (G. Cohen & Prinstein, 2006; Faris & Felmlee, 2011; Pellegrini & Long, 2002).

Acute social stressors are not only prevalent in youth populations, but dysregulated neuroendocrine responses to social stressors in teenagers are at the root of many mental and physical health problems (Lopez-Duran, Kovacs, & George, 2009; Marceau, Ruttle, Shirlcliff, Essex, & Susman, 2014; Wolkowitz, Epel, & Reus, 2001). Moreover, a multitude of negative health outcomes are rooted in risky decision making, including (but not limited to) harm to self or others, unplanned pregnancies, sexually transmitted diseases, and alcohol or substance abuse.

### Social Stress and Risk-Taking

Social factors can be important determinants of risk. For instance, attributions of social feedback can modulate physiological responses and guide risk decisions (e.g., Jamieson, Koslov et al., 2013; Mendes et al., 2008). Whereas internal attributions of negative social feedback elicit threat responses and can lead to cautious decisions, external attributions provoke approach-oriented responses and potentiate risk (Jamieson, Koslov et al., 2013). Similarly, cortisol production resulting from the experience of acute social stress has been linked with cautious decisions among police officers (Akinola & Mendes, 2012) and cautious driving behavior in older adults (Mather, Gorlick, & Lighthall, 2009).

Offering a useful parallel to acute stress changes and risky behavior, distinct emotional responses have been linked to perception of risk. In adults, participants who were dispositionally fearful or were induced to experience fear perceived *more risk* than adults who were either dispositionally angry or induced to feel anger (Lerner & Keltner, 2001). Similar to threat states, fear states reduced control and certainty appraisals relative to anger states, and certainty appraisals mediated the link between different emotions and risk perception.

In youths, however, we argue that acute social stress will *decrease* risk-perceptions and *increase* risk-taking. Although risky

behaviors undertaken in youth can result in short- and long-term negative consequences, successful risks also have the potential to increase social standing. For instance, a risky but “peer-valued” act, such as alcohol consumption, has the potential to increase social standing if the behavior is undertaken in an evaluative context. That is, the instability of social hierarchies in youth creates the potential additional rewards for taking risks: Youths can gain social capital and reap traditional rewards (money, pleasure, etc.).

Social processes are particularly important when considering health and decision-making outcomes in youth populations because of the prevalence of social stress stemming from increasingly frequent peer interactions during this developmental period (see Somerville, 2013 for a review). Notably, adolescents are more vigilant for social feedback compared to adults (Harter, 1999; Harter, Waters, & Whitesell, 1998; Westenberg, Drewes, Goedhart, Siebelink, & Treffers, 2004) and experience stronger physiological responses to acute social stress relative to younger children (van den Bos, de Rooij, Miers, Bokhorst, & Westenberg, 2014). Thus, psychological, biological, and behavioral responses to acute social stressors are likely critical for understanding risk-taking in adolescents and teenagers.

To date, research has yet to manipulate acute social evaluative stress—and measure accompanying physiological responses—to examine how social stress might causally influence risk processes in youths. Two of the biggest hurdles to accumulating research on social determinants of risk have been (a) reliance on self-reports of stress experiences and correlational methods with known limitations (Kessler, Wittchen, Abelson, & Zhao, 2000) and (b) undervaluing contextual factors by treating recall, simulation, and experience as the same construct (see Reyna & Farley, 2006, for similar arguments). We sought to address these limitations by inducing and experimentally manipulating social stress with a standardized laboratory paradigm, assessing acute neuroendocrine and cardiovascular responses to social stress, and measuring effects of stress on risk-perception and risk-taking.

Contrary to the typical association between acute social stress and increased caution in adults (e.g., Akinola & Mendes, 2012; Jamieson et al., 2013; Mather et al., 2009), evaluative threat may operate to facilitate risk in youths. Neurodevelopmental data supports this prediction as research indicates adolescents are more reward sensitive than adults (Steinberg, 2008), prefer quantitative reasoning strategies (Reyna & Farley, 2006), and are sensitive to social-emotional information conveyed by others (Centifanti, Mo-decki, MacLellan, & Gowling, 2014).

### Study 1

Study 1 tested the prediction that social stress compared to no-stress would *decrease* risk-perception in youths. Initially, we focused on males given the documented likelihood that males are riskier than females (e.g., Coates & Herbert, 2008; Sapienza, Zingales, & Maestripieri, 2009). Animal models suggest that adolescent males may be prone to take risks because of dopaminergic remodeling in reward systems and prefrontal cortex (Romer, 2010; Steinberg, 2008). Recent human research indicates that threat cues elicit more impulsive responses in male adolescents than in children or adults, and behavioral impulsivity was accompanied by heightened activation in brain areas implicated in detection of social-emotional cues (Dreyfuss et al., 2014).

We implemented a well-validated, standardized laboratory paradigm to manipulate social stress: the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993). The TSST requires participants to deliver a self-relevant speech to evaluators who provide neutral/negative feedback followed by verbal math. Male youths were randomly assigned to complete the speech and math components under evaluative scrutiny with two interviewers in the room (social stress) or alone (no stress).

Immediately following the TSST, participants completed a measure of general decision processes focused on risk perception. (Fischhoff, Bruine de Bruin, Parker, Millstein, & Halpern-Felsher, 2010; Fischhoff et al., 2000; Parker & Fischhoff, 2005; Persoskie, 2013; Slovic, Fischhoff, & Lichtenstein, 1979). We focused on risk perception and subjective risk decision processes in our initial examination for several reasons. Paramount among these, perceptions of risk predict “real-world” risk behavior. For instance, research has demonstrated that youths’ global perception of risk is negatively correlated with risk behavior (Bruine de Bruin, Parker, & Fischhoff, 2007; Parker & Fischhoff, 2005). That is, the less risk youths perceive in their environment, the riskier they behave. Additionally, risk perception and subjective decision measures can capture multiple risk domains. Instead of focusing on one particular type of risk (e.g., reckless driving or gambling), global risk perception measures cut across myriad domains including health, financial, and social-relational risks. However, we note that, unlike the global measure used here, more specific risk perception measures that rely on verbatim memory representations of behavior are positively correlated with risk behavior (e.g., Mills, Reyna, & Estrada, 2008).

Finally, the risk perception scale administered in Study 1 incorporated decision competence items taken from the Youth Decision Making Competence Questionnaire (Y-DMC; Parker & Fischhoff, 2005). Although adolescents and adults exhibit similar logical reasoning and information processing competencies, self-regulatory processes that recruit multiple systems continue developing into young adulthood (see Albert & Steinberg, 2011, for a review). However, decision competence is a potentially interesting risk process to assess because higher levels of decision competence have been associated with less self-reported health risk behaviors (Parker & Weller, 2015).

The hypothesis tested in Study 1 was whether the experience of social stress would decrease risk perception in male youths. We also expected that social stress, relative to the nonstress control condition, would increase cortisol, engender threat appraisals, and increase self-reports of negative affect. These predictable changes allowed us to test biological and subjective responses to stress as possible mediators to changes in risk perception.

## Method

**Participants.** European American males ( $N = 89$ ) aged 16–20 ( $M_{\text{age}} = 18.5$ ) were recruited using posted flyers, online advertisements (craigslist.org), direct recruitment from local high schools, and summer school study pools when high school students attended summer classes at the university. Parental permission was obtained for participants under 18. We prescreened and excluded participants for hypertension, cardiac abnormalities, and medications with hemodynamic side effects. Only European American participants were recruited to maintain same-race evaluations (all

the interviewers were European American) to avoid attributional ambiguity in the social stress context (see Jamieson et al., 2013; Mendes et al., 2008). Participants were compensated \$25 or 2 credit hours if they were recruited from the study pool.

**Social stress manipulation.** Participants were randomly assigned to either a social-evaluative stress condition or a nonevaluated control condition. Stress condition participants ( $n = 46$ ) completed an age-modified TSST that included a 5-min speech about their dream job followed by a 5-min mental arithmetic task: Counting backward from 996 in steps of seven. Participants were seated and delivered their speeches to/performed the math task in front of two same-race evaluators (one male; one female). Throughout the tasks, evaluators provided neutral to negative nonverbal feedback (stoic expressions, crossing arms, frowning brow, etc.). Evaluators were selected who appeared slightly older than participants (i.e., ~20 years old) to optimize intimidation, but still have evaluators fall within the participants’ general peer range. Control participants ( $n = 43$ ) performed the same speech and math tasks, but did so alone and thus were not evaluated (see Akinola & Mendes, 2008, for similar procedures). This procedure controlled for time, priming of speech/math content, and metabolic demands associated with speaking, but differed in the critical factor of social evaluation.

**Stress appraisals.** An appraisal questionnaire developed to differentiate between *challenge* and *threat* states was completed immediately after the TSST (Mendes et al., 2007). As is recommended, composites of situational demands (e.g., “this situation is demanding,” Cronbach’s  $\alpha = .78$ ) and personal resources (e.g., “I have the abilities to perform well,”  $\alpha = .70$ ) were constructed (e.g., Beltzer, Nock, Peters, & Jamieson, 2014). One control participant did not answer all stress appraisal items.

**Affective states.** Affective states were assessed after the TSST using the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). Scores were averaged to form positive ( $\alpha = .71$ ) and negative ( $\alpha = .84$ ) affect composites. Two participants (both control) did not complete all PANAS items.

**Risk perception.** To assess risk perception, participants completed a questionnaire constructed of items adapted from the Y-DMC (Parker & Fischhoff, 2005). Items were selected based on pilot data, and the full scale was not used in the current research because of time constraints. Please refer to the Appendix for the full scale used in this research.

Specifically, the risk perception measure incorporated the Consistency of Risk Perception subscale, which has been used previously to assess risk perception (Bruine de Bruin et al., 2007). These items present various negative and positive events and ask respondents to estimate percent chance that the event will occur (Fischhoff et al., 2000, 2010; Slovic et al., 1979). For example,

*Positive event:* What is the percent chance that you will win a prize of some kind at least once in the next year?

*Negative event:* What is the percent chance that something will happen later this week that will really stress you out?

Six binary risk problems were also adapted from the Sunk Cost and Resistance to Framing subscales of the Y-DMC. Sunk cost items assess loss aversion processes. Loss-averse individuals tend to make more cautious, less risky choices (Tversky & Kahneman, 1991). The resistance to framing items tapped intertemporal choice



(e.g., Kable & Glimcher, 2007) and uncertainty (e.g., Loewenstein, Weber, Hsee, & Welch, 2001) processes. For example,

*Sunk cost:* You and your friend have driven half way to a resort. To get a lower price, you have put down a \$100 deposit for the weekend there. Even if you cancel, you cannot get the \$100 back. Both you and your friend feel sick. You both feel that you both would have a much better weekend at home. Your friend says it is “too bad” you have paid the deposit because you both would much rather spend the time at home, but you cannot afford to waste \$100. You agree. Do you drive on or turn back?

*Intertemporal choice:* Imagine that you have just won a lottery. You can now choose between the next options: (a) you get \$100, 26 weeks from today, or (b) you get \$120, 30 weeks from today. Which would you like better?

An overall risk perception composite was constructed by averaging negative event items, reverse-scored positive event items, and reverse-scored binary risk problems, which were assigned values of 100 (risky option) and 0 (less risky option). Thus, higher scores on the composite corresponded to increased perception of risk ( $\alpha = .71$ ). Consistent with conceptualizations of risk perception in previous research (Bruine de Bruin et al., 2007), we also analyzed only the Consistency of Risk Perception subscale. This produced the same pattern of findings as the overall composite that included the binary risk problems.<sup>1</sup>

**Neuroendocrine responses.** To measure HPA activation, we assessed cortisol levels using three 1-ml saliva samples collected over the course of the experiment. Baseline samples (T1) were collected when participants arrived for the study after a minimum of 20 min of acclimation to the lab. A posttask sample (T2) was taken following the TSST timed to occur between 15 and 18 min after the initial description of the speech/math task (and prior to the risk perception measure), and a recovery sample (T3) was taken 30 min after T2. All studies were conducted during the afternoon between the hours of 1:00 p.m. and 5:00 p.m., when cortisol levels are at their waking nadir.

Samples were collected with IBL SaliCap sampling devices which require participants to expectorate 1 ml of saliva into a cryovial via a plastic straw. Saliva samples were stored immediately at  $-80^{\circ}\text{C}$  until they were shipped overnight on dry ice to a laboratory in Dresden, Germany, where they were assayed for salivary-free cortisol using commercial immunoassays kits (IBL-Hamburg, Germany). Intra- and interassay coefficients of variance were less than 10%. Due to an insufficient sample, the recovery sample for one participant (stress condition) could not be assayed.

## Results

### Self-reports.

**Stress appraisals.** Resources and demands were significantly correlated ( $r = -.314$ ,  $p = .003$ ; 95% confidence interval [CI]  $[-.409, -.087]$ ), and thus analyzed in a multivariate analysis of variance (MANOVA) model. This produced a multivariate effect, Wilks'  $\lambda = .926$ ,  $F(2, 85) = 3.41$ ,  $p = .038$ ,  $\eta_p^2 = .074$ . Univariate tests indicate that male youths subject to social stress appraised the task as more demanding ( $M = 4.75$ ,  $SD = 1.39$ ) than no-stress controls ( $M = 4.09$ ,  $SD = 1.21$ ),  $F(1, 86) = 9.41$ ,  $p = .003$ ,  $d = .66$  ( $\beta = -.655$ ; 95% CI  $[-1.21, -.101]$ ). Social stress participants also reported marginally lower resource appraisals ( $M =$

$4.59$ ,  $SD = 1.21$ ) than controls ( $M = 4.99$ ,  $SD = .82$ ),  $F(1, 86) = 3.47$ ,  $p = .066$ ,  $d = .40$  ( $\beta = .398$ ; 95% CI  $[-.046, .842]$ ).

**Affective state.** Positive and negative affect reports were not significantly correlated,  $r = .094$ ,  $p = .389$ . Independent-samples  $t$  tests tested for social stress effects. Stress condition youths reported more negative affect ( $M = 2.18$ ,  $SD = .90$ ) than controls ( $M = 1.80$ ,  $SD = .60$ ),  $t(85) = 2.32$ ,  $p = .023$ ,  $d = .50$  (95% CI for mean difference  $[-.718, -.055]$ ). No effects emerged for positive affect (overall  $M = 3.01$ ,  $SD = .66$ ),  $t < 1$ .

**Neuroendocrine responses.** The effect of social stress on cortisol was tested in a 3 (Time: baseline vs. posttask vs. recovery)  $\times$  2 (Stress Condition) mixed ANCOVA with time since waking as a covariate. Main effects for time,  $F(1, 85) = 12.21$ ,  $p = .001$ ,  $d = .75$ , and condition,  $F(1, 85) = 19.52$ ,  $p < .001$ ,  $d = .95$ , were interpreted in the context of the Time  $\times$  Condition interaction,  $F(1, 85) = 11.66$ ,  $p = .001$ ,  $d = .74$ .

Baseline cortisol did not differ as a function of condition,  $F < 1$ . However, consistent with meta-analyses, social evaluative stress increased posttask cortisol levels ( $M = 18.67$  nmol/L,  $SD = 10.28$ ) relative to controls ( $M = 8.62$ ,  $SD = 5.08$ ),  $F(1, 85) = 27.41$ ,  $p < .001$ ,  $d = 1.13$  ( $\beta = -10.03$ ; 95% CI  $[-13.50, -6.56]$ ). Cortisol levels also remained elevated 30 min after stress offset compared to controls ( $M_{\text{stress}} = 11.22$ ,  $SD_{\text{stress}} = 5.79$ ;  $M_{\text{control}} = 6.37$ ,  $SD_{\text{control}} = 3.41$ ),  $F(1, 85) = 6.36$ ,  $p = .013$ ,  $d = .54$  ( $\beta = -4.81$ ; 95% CI  $[-6.79, -2.83]$ ).

**Risk perception.** Our primary prediction was that, contrary to adult data showing threat states *increase* risk perception, male youths would report *decreased* risk perception following social stress compared to a nonstress control. Supporting this prediction, male youths assigned to social stress, indeed, perceived less risk ( $M = 37.37$ ,  $SD = 9.26$ ) than controls ( $M = 42.67$ ,  $SD = 37.38$ ),  $t(87) = 2.93$ ,  $p = .004$ ,  $d = .63$ .

We then tested for associations between risk perception and the stress response measures. Consistent with the idea that the experience of social threat decreases risk perception in youths, as shown in Figure 1 posttask cortisol reactivity (T2 – T1) negatively predicted risk perception,  $\beta = -.235$ ,  $p = .027$ , (95% CI  $[-.412, -.026]$ ). That is, larger cortisol increases following stress task led to *lower* risk perceptions. The self-reported variables (stress appraisals and affective reports) were not associated with risk perception,  $ps > .24$ .

## Discussion

Consistent with meta-analysis of cortisol reactivity (Dickerson & Kemeny, 2004), the experience of social evaluative stress activated the HPA axis evidenced by elevated cortisol following the task and extending through recovery, increased reports of negative affect, and increased appraisals of situational demands. More importantly, social threat *decreased* male youths' perception of their future risk, and greater increases in cortisol were associated with *lower* risk perceptions. This finding runs counter to research with adults using similar constructs of threat, stress, and fear and similar

<sup>1</sup> Analyses of only the Consistency Risk Perception subscale produced the predicted main effect for social stress condition in Study 1,  $t(87) = -3.10$ ,  $p = .003$ ,  $d = .66$ , and the hypothesized Stress  $\times$  Age Group interaction in Study 2,  $F(2, 182) = 3.97$ ,  $p = .021$ ,  $d = .30$ .

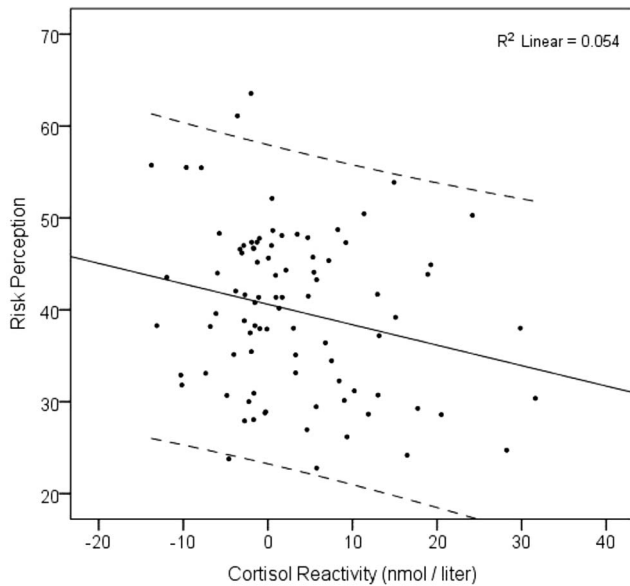


Figure 1. Association between post-Trier Social Stress Test cortisol reactivity and risk perception in Study 1. Solid line = interpolation line, dashed line = 95% confidence interval.

measures (e.g., Akinola & Mendes, 2012; Jamieson et al., 2013; Lerner & Keltner, 2001; Mather et al., 2009).

Although the effects of social stress on youths' risk perception run counter to the pattern observed among adults, the findings are in-line with maturational imbalance (Casey, Jones, & Hare, 2008; Galvan, 2010; Steinberg, 2007, 2008) and "fuzzy trace" models (Reyna & Farley, 2006). For instance, maturational imbalance models argue for increased heightened reward sensitivity in adolescence relative to childhood and adulthood, which may be exacerbated by social stress. Similarly, fuzzy trace theory suggests teenagers are more likely than adults to quantitatively reason when making risk decisions. If social stress sensitizes adolescents for rewards, this information will be weighted more heavily in decision processes.

Although results were consistent with hypotheses, Study 1 included limitations. First, the sample was all male, which was deliberate as we sought to recruit a particularly risky sample for this initial examination. However, female youths may exhibit the same pattern of risky behavior in social contexts as their male counterparts (e.g., Gardner & Steinberg, 2005; Johnson, Dariotis, & Wang, 2012). Second, Study 1 did not include adult comparison groups, even though many of the arguments are that adults respond to stress and threat differently than youths. Finally, conclusions regarding effects of social stress on youths' risk processes were limited to risk perception, not risk behavior.

## Study 2

Study 2 sought to address limitations of Study 1 and extend findings. First, female youths and adult comparison groups were recruited to more clearly demonstrate divergent effects of social stress on risk perception: decreased risk perception in youths, increased risk perception in adults. We also sought to extend

effects of social stress to risk behavior in the youth sample and explore possible mechanisms.

Similar to Study 1, Study 2 included a standardized TSST social stress manipulation, which was followed by a risk perception measure among three age groups: youths (15–19), young adults (25–40), and older adults (60–75). Immediately following the risk perception measure, the youth sample completed an assessment of risk behavior (Columbia card task [CCT], Figner, Mackinlay, Wilkening, & Weber, 2009). The CCT also allowed us to examine sensitivity for rewards/costs as potential mechanisms (cf. Somerville, Hare, & Casey, 2011) because it provides independent assessments of loss/reward sensitivity unlike global risk behavior measures such as the balloon analogue risk task, driving games (e.g., Mather et al., 2009), or the Iowa gambling task and associated variants. Previous adolescent research suggests even global risk behavior measures may be sensitive to social stress (Johnson et al., 2012).

Observed associations between neuroendocrine responses and risk perception in Study 1 also warranted replication and further examination in Study 2. First, all three age groups—teenagers, young adults, and older adults—provided three saliva samples that were assayed for cortisol to index threat. Then, an a priori mediation analysis was planned to assess whether increases in cortisol might explain youths' reductions in risk perception. Finally, the teenagers recruited for Study 2 were affixed with cardiovascular sensors to measure acute stress responses online, which provided a more nuanced examination of how physiological responses to social stress might feed forward to affect risk behavior.

## Predictions

Although we did not expect to observe differences in affective experiences or physiological responses to the stressful evaluative task as a function of age group, we anticipated effects of social stress on risk perception would vary across age groups. Specifically, we predicted youths would perceive *less* risk following social stress compared to no-stress control condition youths (i.e., replicating Study 1), but the adult samples would perceive *more* risk under stress compared to their age-matched nonstress controls. Extending findings of Study 1, we also predicted posttask cortisol reactivity would emerge as a mediator of the social stress-risk perception relationship within the youth sample.

We tracked cardiovascular responses to social stress in this youth group, and this group also completed a risk behavior measure. Consistent with a large corpus of research using the TSST (e.g., Jamieson, Nock, & Mendes, 2012) teenagers exposed to social stress were expected to exhibit threat-related cardiovascular responses—sympathetic arousal coupled with increased vascular resistance—relative to age-matched controls. Extending risk perception findings, teenagers assigned to the social stress condition were predicted to take more risks compared to age-matched controls (cf. Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Cavalca et al., 2013) via increased attention for reward information. Finally, we tested the mediating role of cardiovascular indexes of threat in explaining risk behavior, similar to the risk perception mediation analysis planned above.

## Method

**Participants.** One hundred eighty-eight ( $N = 188$ ) participants (54% female; 91% European American; 4% Black/African American, 5% Asian) were recruited using online advertisements, posted flyers, and department study pools (Sona) tapping student and nonstudent samples.<sup>2</sup> We advertised and recruited adult participants in two age ranges: younger adults ( $n = 40$ ; 25–40 years,  $M = 30.73$ ,  $SD = 4.31$ ; 52.50% female) and older adults ( $n = 45$ ; 60–75 years,  $M = 66.31$ ,  $SD = 5.41$ ; 55.56% female)<sup>3</sup> to compare with the youth group recruited for this study ( $n = 103$ ; 15–19 years,  $M = 17.75$ ,  $SD = 1.18$ , 54.37% female).

Parental permission was obtained for participants under 18. We prescreened and excluded participants for physician diagnosed hypertension, cardiac abnormalities, and medications with hemodynamic side effects. Participants were compensated \$30 or 2 credit hours if they were students.

**Procedure.** Study procedures were identical to Study 1, but with three modifications. First, all participants received the same TSST instructions (self-relevant speech followed by mental math under conditions of evaluation). However, whereas youths spoke about their “dream job,” adults spoke about other self-relevant topics such as opinions on “social security reform,” “rising cost of gasoline,” and “social and government reform.” Again, controls performed the same tasks, but did so alone devoid of social evaluation.

Second, at the outset of the study the youth sample (but not the two adult samples) were affixed with noninvasive cardiovascular sensors and relaxed for a 5-min baseline recording in a seated position before receiving TSST instructions. Youths’ cardiovascular responses were then monitored throughout the TSST/control tasks. Finally, the youth group completed the risk behavior game (the CCT) after risk perception.

**Self-report measures.** The stress appraisal and affect questionnaires were identical to those used in Study 1 (resource appraisals  $\alpha = .73$ ; demand appraisals  $\alpha = .74$ ; negative affect  $\alpha = .80$ ; positive affect  $\alpha = .70$ ). Five participants (three stress, two control; four youths, one young adult) did not complete all appraisal items and were excluded from analyses. One young adult participant assigned to the stress condition did not complete the PANAS and was excluded from analyses.

**Neuroendocrine responses.** As in Study 1, cortisol was measured with three 1-ml saliva samples collected at baseline (T1), following the TSST (T2), and at recovery 30 min after T2 (T3). Again, samples were collected with IBL SaliCap sampling devices and stored in a  $-80^{\circ}\text{C}$  freezer until shipped on dry ice for offsite assay where inter- and intraassay coefficients were less than 10%. One participant (stress condition, older adult) did not provide usable saliva samples.

**Cardiovascular responses.** Sensors to record electrocardiography, impedance cardiography (ICG), and blood pressure were affixed to youths at the outset of the study. Electrocardiography and ICG signals were collected at 1,000 Hz, and integrated with Biopac MP150 hardware (Biopac, Inc., Goleta, CA). Waveforms were visually examined offline, edited, and ensembled averaged using Mindware software (IMP v2.6, Mindware Technologies, Gahanna, OH). Reactivity was computed by subtracting scores taken during the final minute of baseline from those collected during the first minute of the speech when reactivity is at its peak

as is standard in social stress research using such measures (see Jamieson et al., 2012; Jamieson, Nock et al., 2013; Mendes, Blascovich, Lickel, & Hunter, 2002; Mendes et al., 2008 for other examples using this approach).

Analyses focused on preejection period (PEP)—a measure of SNS activation—and two measures that differentiate threat from challenge states: cardiac output (CO) and total peripheral resistance (TPR). PEP indexes the heart’s contractile force by measuring time from left ventricle contraction to aortic valve opening. Greater sympathetic nervous system (SNS) arousal is indicated by shorter PEP intervals. CO is the average amount of blood ejected per minute. Increases indicate improved cardiac efficiency, which is typically observed in challenge states. TPR is a measure of vascular resistance calculated by dividing mean arterial pressure by CO. When threatened, cardiac activity increases but arterioles constrict resulting in more overall vascular resistance. TPR was calculated using the following validated formula: mean arterial pressure/CO  $\times 80$  (Sherwood, Dolan, & Light, 1990). Due to excessive artifacts in the ICG signal, physiological responses could not be assessed for four youths (three stress, one control).

**Risk perception.** The risk perception measure was identical to that reported in Study 1 ( $\alpha = .68$ ).

**Risk behavior.** Youths performed the “hot” or affective version of the CCT (see Figner et al., 2009, for additional details). CCT trials begin with the presentation of 32 cards “face down” on a screen. The objective was to select as many “gain” cards as possible without selecting a “loss” card. Participants could voluntarily terminate trials at any time and “keep” points accrued. However, if a loss card was selected, points were subtracted and the trial ended. The number of loss cards in the array (one or three), amount each gain card was worth (10 or 30 points), and amount each loss card was worth ( $-250$  or  $-750$ ) was displayed throughout trials. These three sources of information: probability of loss, gain magnitude, and loss magnitude were independently randomized across the 24 trials.

The critical outcome was the number of cards participants selected: The more cards participant chose, the greater their risk behavior. However, because loss cards create an artificial ceiling, the number of cards selected on nonloss trials was the primary dependent measure. To increase engagement, participants could receive a \$5 bonus if scores exceeded a (unspecified) threshold (all participants received the bonus). As is standard with this task, participants were informed that final scores would be computed

<sup>2</sup> The studies reported here were conducted over a 5-year period, with the first study completed before we began recruitment for the adult sample. The youth sample in Study 2 began after the adult samples began recruitment. The experimental protocols for the three age groups were identical except for the following: (a) Older participants had a different speech topic than youths, (b) after the risk perception measure youths completed the risk taking measure (adults did not), and (c) we obtained cardiovascular reactivity from the youths in addition to the neuroendocrine responses. Finally, we recruited twice as many youths as older participants because of our primary interest was examining youth risk taking processes.

<sup>3</sup> We advertised an age range of 60 to 75 years old and checked IDs of participants who came in. A few participants ended up being older than they had represented in the initial recruitment call. We allowed these participants ( $n = 3$ ) to complete the study, and their data are included in analyses. Data were reanalyzed with these three participants over 75 excluded. This had no effect on results or conclusions.



using three random trials to discourage “chasing”—increasing risk behavior following losses.

## Results

**Self-reports.** See the online supplemental materials for all raw means and standard deviations for self-reported measures as a function of condition and age group.

**Stress appraisals.** As in Study 1, Demand and Resource subscales were correlated,  $r = -.394$ ,  $p < .001$  (95% CI  $[-.674, -.327]$ ). So, data were analyzed in a 2 (Stress Condition)  $\times$  3 (Age Group) MANOVA model. This produced a multivariate main effect for social stress, Wilks'  $\lambda = .911$ ,  $F(2, 172) = 8.40$ ,  $p < .001$ ,  $\eta_p^2 = .089$ , and a marginal multivariate effect for age group, Wilks'  $\lambda = .953$ ,  $F(4, 344) = 2.10$ ,  $p = .080$ ,  $\eta_p^2 = .024$ .

Univariate tests demonstrate stress condition participants perceived the task as more demanding ( $M = 4.13$ ,  $SD = 1.50$ ) than controls ( $M = 3.33$ ,  $SD = 0.98$ ),  $F(1, 173) = 16.86$ ,  $p < .001$ ,  $d = .62$  ( $\beta = -1.08$ ; 95% CI  $[-1.82, -.340]$ ). Stress participants also reported marginally lower resource appraisals ( $M = 4.62$ ,  $SD = 1.08$ ) than controls ( $M = 4.87$ ,  $SD = 0.97$ ),  $F(1, 173) = 3.07$ ,  $p = .082$ ,  $d = .27$  ( $\beta = .258$ ; 95% CI  $[-.339, .856]$ ).

Additionally, a main effect for age group on resource appraisals,  $F(2, 173) = 3.66$ ,  $p = .028$ ,  $d = .29$ , suggested younger adults reported fewer resources ( $M = 4.42$ ,  $SD = 0.98$ ) compared to youths ( $M = 4.93$ ,  $SD = 1.02$ ),  $F(1, 173) = 7.03$ ,  $p = .009$ ,  $d = .40$  (95% CI for the mean difference  $[.127, .888]$ ). No age group effects were observed for demand appraisals,  $F < 1$ .

**Affective state.** Positive and negative affect were not significantly correlated,  $r = -.083$ ,  $p = .256$ , and were thus analyzed in 2 (Stress Condition)  $\times$  3 (Age Group) between-subjects ANOVAs. Participants subject to social stress reported more negative affect ( $M = 1.92$ ,  $SD = 0.66$ ) than controls ( $M = 1.52$ ,  $SD = 0.47$ ),  $F(1, 181) = 19.05$ ,  $p < .001$ ,  $d = .66$  ( $\beta = -.459$ ; 95% CI  $[-.798, -.120]$ ). No other effects were observed,  $F_s < 1.5$ ,  $p_s > .25$ .

Given the lack of Age Group  $\times$  Condition interactions in the self-report data, age groups did not significantly differ in their experience of the social stress manipulation despite the small difference in speech topic across age groups.

### Physiological responses.

**Neuroendocrine.** Effects of stress and age on cortisol levels were tested in a 3 (Time: baseline vs. posttask vs. recovery)  $\times$  2 (Stress Condition)  $\times$  3 (Age Group) mixed ANCOVA with time since waking as the covariate. This yielded a main effect for age group,  $F(2, 173) = 3.39$ ,  $p = .036$ ,  $d = .28$ . Consistent with previous research on adrenal hormones across the life span (e.g., Lamberts, van den Beld, & van der Lely, 1997), youths' cortisol levels were higher across all sampling periods ( $M_{overall} = 10.80$  nmol/L,  $SD = 6.86$ ) compared to younger adults ( $M = 8.21$ ,  $SD = 3.78$ ),  $F(1, 179) = 9.19$ ,  $p = .003$ ,  $d = .46$  (95% CI for mean difference  $[.599, 5.13]$ ), and older adults ( $M = 8.51$ ,  $SD = 4.26$ ),  $F(1, 179) = 7.18$ ,  $p = .008$ ,  $d = .41$  (95% CI for mean difference  $[.354, 4.77]$ ). Age did not interact with time or condition.

Unsurprisingly, we observed a main effect for condition,  $F(1, 173) = 6.64$ ,  $p = .011$ ,  $d = .39$ , and a Condition  $\times$  Time interaction,  $F(1, 173) = 10.95$ ,  $p = .001$ ,  $d = .50$ . Baseline cortisol levels did not significantly differ as a function of condition,  $F <$

1. Compared to controls, the stress condition exhibited elevated cortisol levels immediately following the TSST ( $M_{stress} = 12.99$ ,  $SD_{stress} = 7.71$ ;  $M_{control} = 8.75$ ,  $SD_{control} = 6.46$ ),  $F(1, 173) = 47.31$ ,  $p < .001$ ,  $d = 1.05$  ( $\beta = -4.18$ ; 95% CI  $[-6.25, -2.12]$ ), and at recovery 30 min later ( $M_{stress} = 10.66$ ,  $SD_{stress} = 7.59$ ;  $M_{control} = 6.73$ ,  $SD_{control} = 3.98$ ),  $F(1, 173) = 40.64$ ,  $p < .001$ ,  $d = .97$  ( $\beta = -3.99$ ; 95% CI  $[-5.74, -2.24]$ ).

**Cardiovascular.** First, we tested for differences in youths' raw baseline PEP, CO, and TPR levels as a function of condition that could obscure reactivity effects. No baseline effects were observed,  $t_s < 1$ . As expected, youths assigned to the social stress condition exhibited increased SNS arousal (lower PEP intervals) from baseline to task performance ( $M = -16.98$  ms,  $SD = 11.11$ ) compared to controls ( $M = -2.86$ ,  $SD = 8.90$ ),  $t(97) = -7.01$ ,  $p < .001$ ,  $d = 1.42$  ( $\beta = 14.11$ ; 95% CI  $[10.11, 18.11]$ ).

We then tested for changes in CO. Consistent with PEP findings, social stress elevated CO from baseline (.46 L/min,  $SD = 1.38$ ) compared to no stress ( $M = -.03$ ,  $SD = .95$ ),  $t(97) = 2.10$ ,  $p = .039$ ,  $d = .43$  ( $\beta = -.496$ ; 95% CI  $[-.965, -.026]$ ); however, this effect likely stemmed from sympathetic arousal differences rather than per beat cardiovascular efficiency as stroke volume (blood ejected per beat) reactivity did not differ between conditions,  $t < 1$ .

Finally, we observed a significant effect of social stress on TPR reactivity,  $t(97) = 3.78$ ,  $p < .001$ ,  $d = .77$  ( $\beta = -153.44$ ; 95% CI  $[-233.94, -72.93]$ ). Participants subject to social evaluation during the TSST experienced increased vascular resistance ( $M = 247.39$  dyn·s·cm<sup>-5</sup>,  $SD = 220.61$ ) relative to controls ( $M = 93.94$ ,  $SD = 182.63$ ), providing support for the interpretation that social stress elicited a threat pattern of physiological reactivity.

**Risk perception.** One primary goal of this study was to replicate and extend results from Study 1 by examining effects of social stress on risk perception across three age groups. Because, in general, risk perception changes over the life span (e.g., Heckhausen, & Schulz, 1995; Leventhal & Crouch, 1997) we created  $z$  scores within age group. Standardized scores were analyzed in a 2 (Stress Condition)  $\times$  3 (Age Group) between-subjects ANOVA. Raw risk perception scores were also analyzed and produced the same findings as the standardized score analysis reported below (please refer to the online supplemental materials for analysis of raw risk perception).

Risk perception analysis produced the predicted Stress Condition  $\times$  Age Group interaction,  $F(2, 182) = 6.49$ ,  $p = .002$ ,  $d = .38$  (see Figure 2). To test specific hypotheses, social stress and no-stress conditions were compared within age group using contrasts based on a priori predictions (Kirk, 1995). Replicating the pattern observed in Study 1, youths subject to social stress reported lower risk perceptions than age-matched no-stress controls,  $F(1, 182) = 7.73$ ,  $p = .006$ ,  $d = .41$  ( $\beta = .497$ ; 95% CI  $[.40, .552]$ ). However, both groups of adults perceived *greater* risk following the social stress task than adults in the no-stress control condition: young adults:  $F(1, 182) = 4.04$ ,  $p = .046$ ,  $d = .30$  ( $\beta = -.304$ ; 95% CI  $[-.377, -.231]$ ); older adults:  $F(1, 182) = 15.75$ ,  $p < .001$ ,  $d = .58$  ( $\beta = -.702$ ; 95% CI  $[-.775, -.629]$ ; see Figure 2).

Unlike Study 1, the youth sample recruited for Study 2 included males and females. To explore whether social stress might have affected male and female youths differently, a follow-up analysis analyzed youths' risk perception in a 2 (Sex: male vs. female)  $\times$



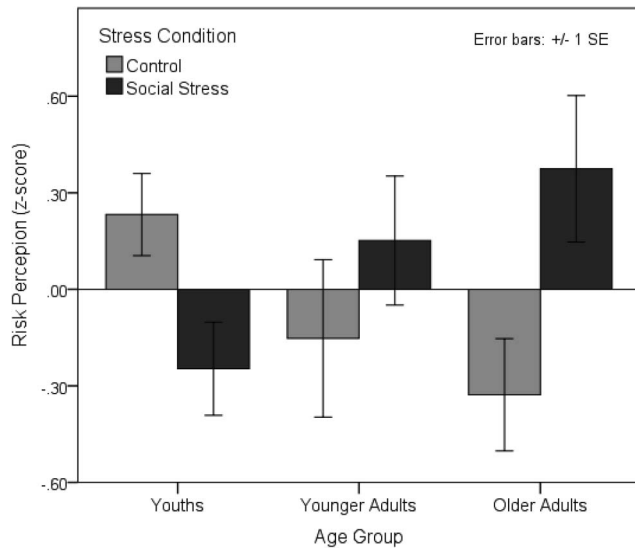


Figure 2. Standardized risk perception scores as a function of stress condition and age group.

2 (Stress Condition) ANOVA model.<sup>4</sup> This yielded a main effect for sex,  $F(1, 99) = 5.11, p = .026, d = .45$  ( $\beta = -4.34$ ; 95% CI =  $-8.49$  to  $-.183$ ), but no interaction with condition,  $F < 1$ . Overall, male youths perceived less risk ( $M_{\text{standardized}} = -.21, SD = .93; M_{\text{raw}} = 39.99, SD = 7.08$ ) than female youths ( $M_{\text{standardized}} = .18, SD = 1.03; M_{\text{raw}} = 42.96, SD = 7.85$ ), but the effect of condition on risk perception did not vary as a function of sex.

We observed no main effects for sex or Sex  $\times$  Condition interactions among the adults groups, even though the main effect for risk perception persisted in these groups,  $F_s < 1$ .

**Risk perception mediation.** In Study 1 we observed an association between poststress cortisol responses and risk perception in youths. To examine this effect in Study 2, a bootstrapping mediation analysis (Preacher & Hayes, 2004; 20,000 resamples) indicated that, within the youth sample, social stress decreased risk perception through increased posttask cortisol levels,  $\beta = -.335, p = .009, 95\% \text{ CI } [-.616, -.102]$  (see Figure 3a for path coefficients).

In an exploratory mediation analysis we tested the same model in adult participants (adult groups were collapsed to maximize power). Posttask cortisol levels partially mediated the effect of stress condition on risk perception,  $\beta = .245, p = .041, 95\% \text{ CI } [-.02, .450]$  (Figure 3b). However, similar to the main effects, and contrary to the youth data, higher cortisol was associated with greater risk perception among adults. We note, however, that this model should be interpreted with caution as the confidence interval for the indirect effect included zero.

**Risk behavior.** We then tested whether effects of social stress on risk processes in youth extended to risk behavior. Consistent with hypotheses (and the risk perception findings), teenagers exposed to social stress showed more risk-taking behavior (selected more cards during the CCT;  $M = 10.65, SD = 3.00$ ) than controls ( $M = 9.00, SD = 3.59$ ),  $t(101) = 2.52, p = .013, d = .50$  ( $\beta = -1.65$ ; 95% CI  $[-2.95, -.353]$ ).

Next, we examined how youths used gain/loss information during decision-making. To do so, we first regressed cards chosen on loss probability, loss magnitude, and gain magnitude for each participant. Then, to test for differences as a function of stress condition standardized beta-weights were analyzed in a series of independent samples  $t$  tests: win/loss probability, loss magnitude, and gain magnitude were not significantly correlated (absolute value of  $r_s < .16, p_s > .13$ ).<sup>5</sup> Due to a lack of variability (e.g., all successful trials for a participant had the same loss magnitude value, for instance), win/loss probability betas could not be computed for three participants (two stress, one control), loss magnitude betas could not be computed for four participants (three stress, one control), and gain magnitude betas could not be computed for four participants (two stress, two control).

During the CCT stressed youths were less sensitive to win/loss probability (i.e., number of loss cards in the array;  $M = -.300, SD = .370$ ) than no-stress controls ( $M = -.513, SD = .275$ ),  $t(98) = -3.28, p = .001, d = .66$  (95% CI for mean difference  $[-.341, -.084]$ ). Similarly, teenagers subject to social stress were less sensitive to loss magnitude ( $M = -.084, SD = .329$ ) compared to age-matched controls ( $M = -.293, SD = .335$ ),  $t(97) = -3.13, p = .002, d = .64$  (95% CI for mean difference  $[-.342, -.077]$ ). Finally, consistent with recent neurodevelopmental research (e.g., Galvan, 2010), teenagers assigned to experience social stress were *more* sensitive for gain magnitude (i.e., reward sensitivity;  $M = .288, SD = .316$ ) compared to controls ( $M = .064, SD = .378$ ),  $t(97) = -3.18, p = .002, d = .64$  (95% CI for mean difference  $[-.363, -.084]$ ).

To summarize, teenagers assigned to the no-stress condition were less risky when the probability of loss was higher and when loss cards carried greater loss magnitude, which suggests thoughtful use of loss information affecting risk behavior. No significant relationship emerged between gain information and risk behavior in the control condition, one-sample  $t < 1$  (compared to 0). However, when considering youths assigned to experience social stress, gain magnitude predicted more cards selected. When reward value was higher, stressed youths were riskier. Also, unlike control participants, stressed youths were insensitive to loss magnitude—as loss values increased, stressed youths did not use the loss amount information to modify their behavior, one-sample  $t < 1$ . Finally, similar to controls, loss probability did predict risk behavior, one-sample  $t(47) = -5.63, p < .001$ , choosing fewer cards when the probability of losing was higher. However, as shown above, sensitivity for loss probability information was weaker in the social stress versus control condition.

**Risk behavior mediation.** We tested whether physiological reactivity, specifically vascular resistance (TPR: higher levels suggest greater threat), would mediate the link between stress condition and risk behavior (Preacher & Hayes, 2004; 20,000 resamples). This analysis complements the mediation model for risk

<sup>4</sup> Sex was included in the overall model with condition and age group. This produced a marginal main effect for sex,  $F(1, 176) = 3.12, p = .080, d = .26$ .

<sup>5</sup> Standardized beta weights were also analyzed in a MANOVA model, which corrects for family wise error. This analysis had no impact on findings or interpretation of the data as this analysis produced the predicted multivariate effect for condition, Wilks'  $\lambda = .751, F(3, 93) = 10.28, p < .001, \eta_p^2 = .249$ .

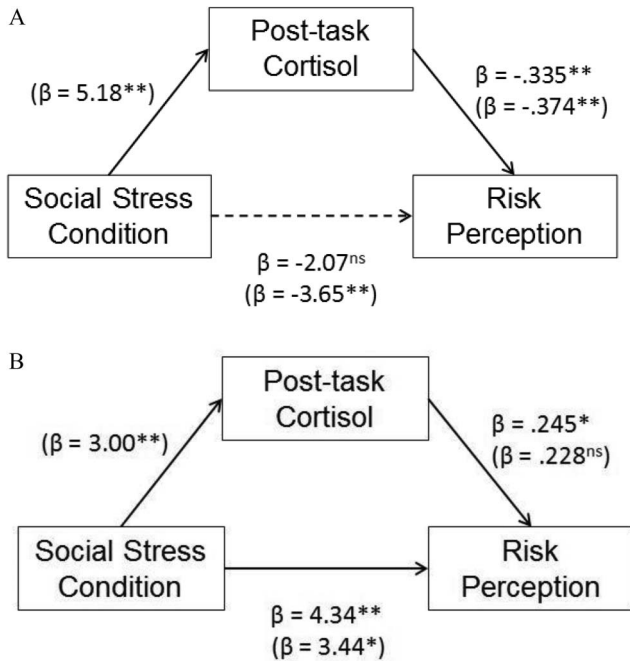


Figure 3. Panel A: Mediating effect of cortisol on the relationships between stress condition and risk perception in the youth sample. Panel B: Mediating effect of cortisol on the relationships between stress condition and risk perception in the collapsed adult sample. Stress condition is dummy coded (social stress = 1, no-stress = 0). Zero-order correlations are presented in parentheses. Betas are unstandardized. \*  $p < .05$ . \*\*  $p < .01$ .

perception presented above. TPR emerged as a partial mediator of the relationship between condition and risk behavior,  $\beta = .004$ ,  $p = .014$  (95% CI [.001, .007]; see Figure 4 for path coefficients). The more vascular resistance teens experienced, the riskier they were.

Exploratory analyses examined stress appraisals, PEP, and CO as potential mediators of the condition-risk link, but none emerged as significant predictors,  $ps > .30$ .

#### Comparisons of youths' risk perception and risk behavior.

Exploratory analysis indicated that risk perception and risk behavior were negatively correlated,  $r = -.237$ ,  $p = .016$  (unstandardized  $\beta = -.070$ , 95% CI [-.126, -.013]). As might be expected, the more risk teenagers perceived, the less risky they were. A follow-up MANOVA that accounts for the correlation between perception and behavior demonstrates that accounting for effects of risk perception does not alter the interpretation of risk behavior, and vice versa, Wilks'  $\lambda = .905$ ,  $F(2, 100) = 5.24$ ,  $p = .007$ ,  $\eta_p^2 = .095$ . Compared to no-stress controls, stressed teenagers perceived less risk,  $F(1, 101) = 6.21$ ,  $p = .014$ ,  $\eta_p^2 = .058$  ( $\beta = -.479$ , 95% CI [-.860, -.098]), and took more risks,  $F(1, 101) = 6.37$ ,  $p = .013$ ,  $\eta_p^2 = .059$  ( $\beta = 1.65$ , 95% CI [.353, 2.95]).

## Discussion

Study 2 replicated and extended findings from Study 1. Social evaluative stress *decreased* risk perception in youths, but *increased* risk perception in two adult samples. Interestingly, the

effect of social stress on risk perception was greater in the older versus younger adults (see Mather et al., 2009 for a similar finding). A second goal of this study was to examine if participant sex moderated the general finding about social stress decreasing risk perception in youths. Although male youths perceived less risk overall, we did not observe any significant differences between male and female youths in how social stress affected risk perception. This pattern is consistent with research that suggests, in general, males may be more risky than females during adolescence (e.g., Byrnes, Miller, & Schafer, 1999) and research suggesting testosterone predicts sex differences in risk behavior (Coates & Herbert, 2008; Sapienza, Zingales, & Maestripieri, 2009). However, these data emphasize the importance of accounting for effects of social-situational influences on risk and suggest social processes may operate similarly across sexes (Chein et al., 2011).

Interesting associations emerged between cortisol and risk perception emerged in Study 2. Consistent with findings from Study 1, increases in posttask cortisol levels explained the effect of social stress on risk perception in the youth group. However, exploratory analyses suggested cortisol increases predicted increased risk perception in adults.

Study 2 also extended effects of social stress on youth risk processes to risk behavior. Specifically, data demonstrated social stress increased youths' risk behavior relative to a nonstressful control condition. These risk behavior findings complement the effects of social stress on risk perception. Thus, not only does the experience of social stress lead youths to perceive less risk in their environment, but it also potentiates risky behavior and decision making.

The cardiovascular reactivity and risk behavior data obtained from the youth group in Study 2 also provided insights into potential mechanisms. Youths subject to social stress showed greater reward sensitivity and were insensitive to loss magnitude (Somerville et al., 2011). Also, cardiovascular responses (at least partly) explained the association between social stress and risk behavior. Taken together, across two risk measures (perception and behavior), the greater the physiological changes linked to threat, the riskier youths were.

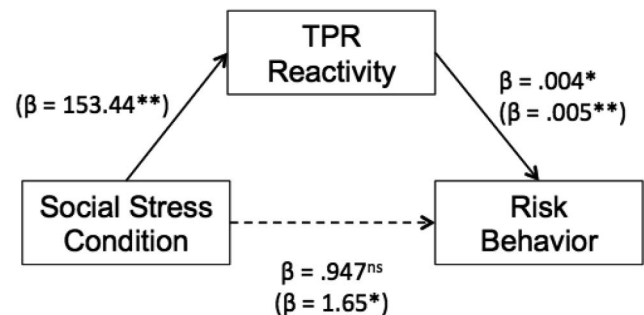


Figure 4. Total peripheral resistance (TPR) reactivity as a mediator of risk behavior. Higher Columbia card task scores index increased risk behavior and higher TPR reactivity scores index more vascular resistance. Social stress condition is dummy coded (social stress = 1, no-stress control = 0). Zero-order correlations are presented in parentheses. Betas are unstandardized. \*  $p < .05$ . \*\*  $p < .01$ .

## General Discussion

In the research reported here acute social evaluative stress *decreased* youths' risk perception and *increased* youths' risk behavior relative to a nonstressful control condition. This pattern stands in stark contrast to the effect of social stress observed in adults: In Study 2, evaluative threat increased adults' perception of risk (see Mather et al., 2009, for a similar finding). Moreover, the data suggest physiological responses may help explain the association between social stress and risk outcomes. The greater the physiological changes linked to threat (increased cortisol or vasoconstriction), the less risk youths perceived and the more risks they took.

These findings have several implications for theory development. First, life history strategy (LHS)—which seeks to explain why and how organisms allocate resources throughout the life span (Stearns, 1992)—provides a framework to understand how social threat might facilitate risk in youth (Ellis, Boyce, Belsky, Bakermans-Kranenburg, & van IJzendoorn, 2011). There are two general types of LHS, fast and slow, which have implications for risk. Individuals with a fast LHS make riskier choices compared to slow LHS individuals, who prefer caution. As a group, youths have a faster LHS compared to adults (see Ellis et al., 2012, for a review). Heightened reward sensitivity under conditions of stress observed here corresponds nicely to effects of uncertainty on risk preference in previous LHS research (e.g., Griskevicius, Tybur, Delton, & Robertson, 2011). From an evolutionary perspective, youths can reap more benefits from successful risks in social situations than can adults because of unstable social hierarchies in adolescence. Thus, it may not be surprising that a pattern of physiological reactivity (threat) associated with caution in adults led to increased risk behavior in youths. To extend knowledge along these lines, future studies may seek to consider the moderating impact of demographic factors that can create uncertainty (e.g., socioeconomic status or prejudice/discrimination). Youths facing hurdles to success (e.g., low socioeconomic status) may be particularly risky under social stress conditions, which have the potential to further impede achievement and lead to negative health outcomes (e.g., J. Cohen et al., 2010).

These findings are also consistent with neurodevelopmental models. Recent advances in neuroscience indicate maturational imbalances between reward and control systems increase adolescents' reliance on reward information (Casey et al., 2008; Galvan, 2010; Steinberg, 2007, 2008). The result is that adolescence is a unique period when reward seeking is elevated and cognitive control is limited, which increases adolescents' estimations of the predicted value of potential gains from risks (J. Cohen, et al., 2010). Thus, adolescents experiencing social stress would be vigilant for the potential rewards that can be reaped and perceive less risk in their environment, stimulating risky behavior. Similarly, these data are consistent with the "fuzzy trace" model that suggests adolescents and adults mentally represent information differently (Reyna & Farley, 2006). Adults' decisions stem from gist-based representations (i.e., "fuzzy" memory traces) that carry affective information (Rivers, Reyna, & Mills, 2008), but adolescents prefer quantitative reasoning when processing risk. Given their increased reliance on reward information under conditions of social stress, it may not be surprising youths in the stress condition perceived less risk and took more risks than controls.

More broadly, these data suggest social-situational processes may be more fully integrated into cognitive-based risk models. Our experimental data add to the growing body of research that demonstrates social factors (particularly social stress) can modulate cognitive processing of information pertinent to risk behavior (e.g., Jamieson et al., 2013). Finally, these data implicate physiological mechanisms underlying the impact of social stress on risk decisions in youth, which is relevant for the development of process-focused interventions. Learning effective emotion regulation strategies to alter physiological responses may help attenuate risk and improve downstream outcomes. That is, efforts to reduce or alter acute stress reactivity (e.g., Jamieson et al., 2012) have the potential to help improve youth decision outcomes.

Important limitations, however, must be noted. First, the risk measures were completed alone rather than under additional evaluation. This was deliberate so we could examine how risk was affected by stress residue left from social evaluation rather than test compound effects of social stress plus additional evaluation. However, risk decisions are often made in peer group contexts, and group context may interact with stress and/or sex in ways not examined here. Second, while the risk behavior task used in Study 2 allowed us to assess reward/cost sensitivity and has some face validity (gambling), it is not clear how it maps onto health behaviors like drug use or reckless driving. Although the risk perception measure (Studies 1 and 2) has been shown to predict "real-world" risk, future research may seek to examine nuanced differences between different risk domains, such as financial and physical (e.g., drug use). Whereas the costs of financial risks can indirectly impact health, physical risks have much more proximal health consequences.

The specific social processes that were driving effects observed here could be further scrutinized in future research. The extant literature suggests that *social evaluative* stress, specifically, should operate to facilitate risk in youths (e.g., G. Cohen & Prinstein, 2006; Ellis et al., 2011, 2012; Faris & Felmlee, 2011; Pellegrini & Long, 2002), but the data reported here cannot explicitly rule out possible similar effects (stress = increased risk in youth) as a function of physical stress or nonevaluative social stress. Thus, future studies may seek to explore how a Cold Pressor task, for instance, might influence risk processes in youth. Moreover, although research suggests mere presence of peers facilitates youth risk (e.g., Gardner & Steinberg, 2005), previous mere- and peer-presence studies of youth risk have not explicitly eliminated all potential for evaluation. Thus, a systematic manipulation of the "magnitude" of evaluative pressure (and source of evaluation) could help refine effects reported here.

Along similar lines, the specific developmental processes that undergird risk outcomes remain unclear. We can implicate neurodevelopment and evolutionary factors that point to adolescence as the rare time when general approach orientation to threats might increase fitness (see Ellis et al., 2012), but we can only speculate on possible processes. Even though we show evidence of physiological stress responses mediating risk perception, we fall short of providing specific developmental neurobiological mechanisms. However, others have persuasively argued for neurodevelopmental imbalances as likely causal mechanisms, though with younger adolescent samples (Reyna, 2004; Somerville, Hare, & Casey, 2011; Steinberg, 2008).



Related to the above point, the studies presented here examined effects of social stress in samples of 15–20-year-old youths (“late adolescents”). Our sample could have included some heterogeneity in pubertal development (typically occurring between 13 and 15), which has potential consequences for the sensitivity of reward systems (e.g., Casey et al., 2008). Moreover, the younger participants in our sample may have been particularly intimidated by the “substantially older” (~20-year-old) evaluators, though exploratory analyses found no moderating effect for age in the youth samples. In all, we sought to examine the effects of social stress on youths’ risk perception. The observed effects speak to the consistency of the observed social stress effects across a wide age range of youths. However, future research may seek to more closely examine the moderating impact of pubertal onset and other important neurodevelopmental factors.

The ultimate goal of studying risk processes is to limit excessively risky behavior. The findings reported here add to the growing body of evidence that suggests social influences on risk outcomes vary substantially across the life span. Notably, we also highlight important contribution of physiological responses to social evaluative stress on youths’ cognitive processing of risk. This research suggests updates to theoretical models of adolescent risk. Specifically, more fully integrating social stress and physiological responding may help better define risk processes in youth populations. Moreover, this research suggests it may be possible to attenuate risk in adolescents by targeting proximal affective mechanisms rather than by focusing on treating symptoms (Lilienfeld, 2007).

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(Appendix follows)

## Appendix

### Risk perception questionnaire used in Studies 1 and 2a

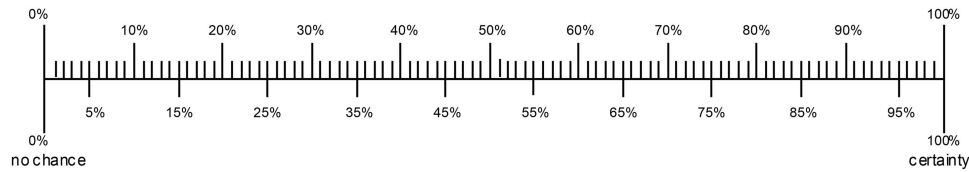
#### Percent Chance Questions

**Instructions.** Each of these questions asks for your best guess at the chance that something will happen in the future. They use the “percent chance” or “probability” scale that you see below. Please put a mark on the scale to answer the questions.

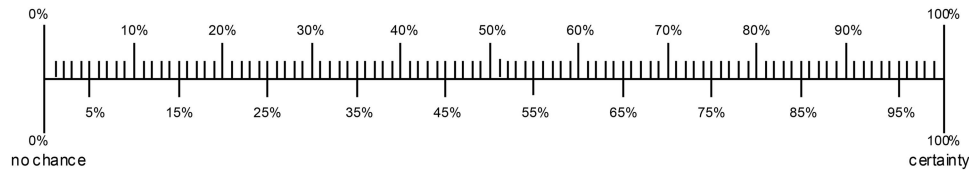
If you think that something has no chance of happening, mark it as having a 0% chance. If you think that something is certain to happen, mark it as having a 100% chance.

Just to make sure that you are comfortable with the scale, please answer the following practice questions.

What do you think is the percent chance that you will eat pizza sometime in the next year?

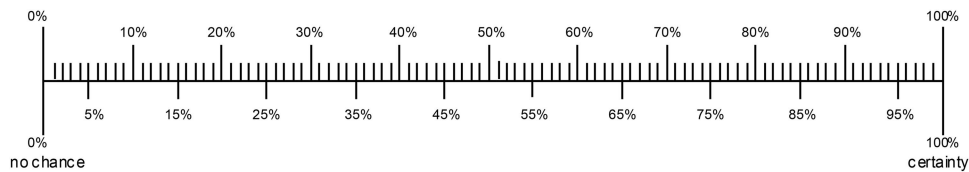


What do you think is the percent chance that you will get the flu sometime in the next year?

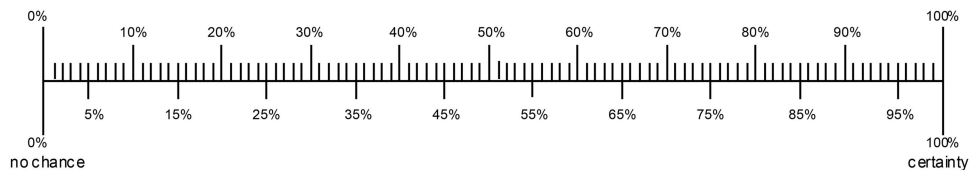


That is the end of the practice. Now please continue with the rest of the questions. You will not have to explain any of your answers.

A1. What is the percent chance that a friend or family member will get angry with you today?

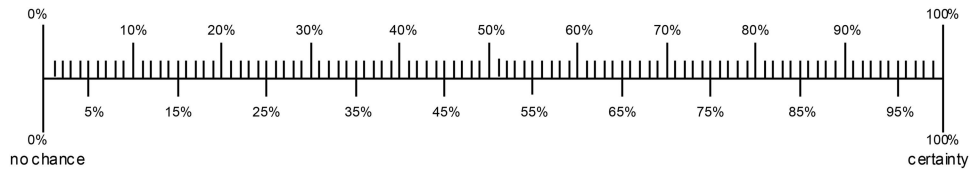


A2. What is the percent chance that you will accomplish something you feel good about this week?

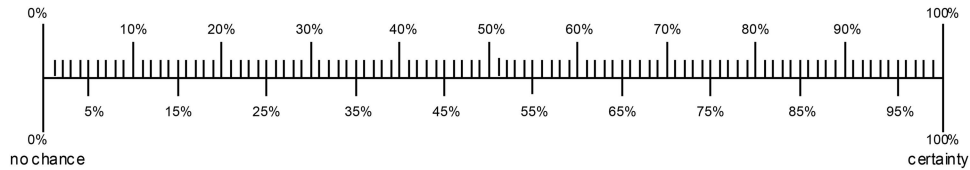


(Appendix continues)

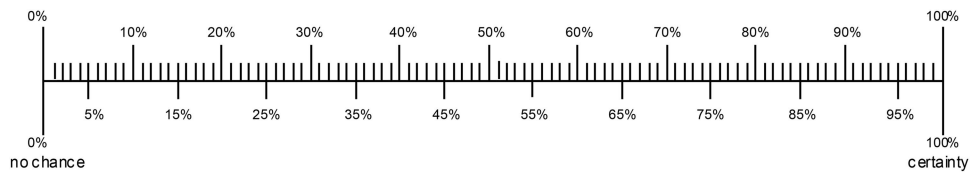
- A3. What is the percent chance you will get into a traffic accident on the way home today that is not your fault?



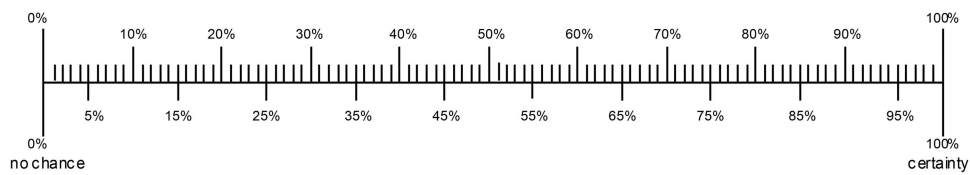
- A4. What is the percent chance you will make a good impression on someone tonight?



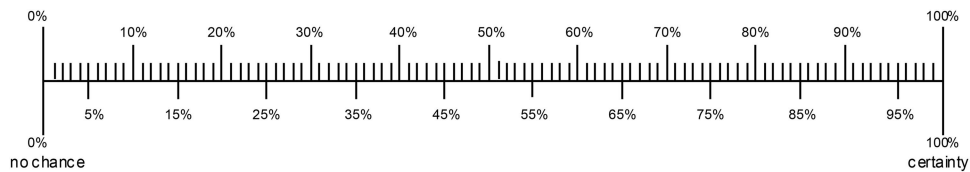
- A5. What is the percent chance you will oversleep sometime this week?



- A6. What is the percent chance that something will happen later this week that will really stress you out?



- A7. What is the percent chance you will find a \$20 bill on the floor when you leave William James Hall today?



(Appendix continues)



### Decision Problems

**Problem 1.** You go to your favorite ice cream shop and choose two flavors. Flavor A tastes good. Flavor B tastes great but is really bad for you. You then realize that you can only afford one, so you must give up one flavor. Which do you choose to give up? A B

**Problem 2.** Imagine that a type of condom has a 95% success rate. That is, if you have sex with someone who has the AIDS virus, there is a 95% chance that this type of condom will prevent you from being exposed to the AIDS virus. Should the government allow this type of condom to be advertised as “an effective method for lowering the risk of AIDS?” Yes No

**Problem 3.** You and your friend have driven half way to a resort. To get a lower price, you have put down a \$100 deposit for the weekend there. Even if you cancel, you cannot get the \$100 back. Both you and your friend feel sick. You both feel that you both would have a much better weekend at home. Your friend says it is “too bad” you have paid the deposit because you both would much rather spend the time at home, but you can’t afford to waste \$100. You agree. Do you drive on or turn back? (Drive/Turn back)

**Problem 4.** Imagine that you have just won a lottery. You can now choose between the next options:

A: You get \$100, 26 weeks from today.

B: You get \$120, 30 weeks from today.

Which would you like better? (A/B)

**Problem 5.** Imagine that you are told by your doctor that you have a cancer that must be treated. Your choices are as follows:

**Surgery.** Of 100 people having surgery, 10 die because of the operation and 66 die by the end of 5 years.

**Radiation therapy.** Of 100 people having radiation therapy, none die during treatment and 78 die by the end of 5 years.

Which treatment would you choose? (Surgery/Radiation)

**Problem 6.** Imagine that you must play a gamble in which you can lose but cannot win.

25% chance of losing \$200

(and 75% chance of losing nothing)

You can either take a chance with the gamble or buy an insurance for \$50 that protects you against losing. If you buy this insurance, you cannot lose \$200, but you must pay the \$50 for the insurance.

What would you do? (Gamble/Insurance)

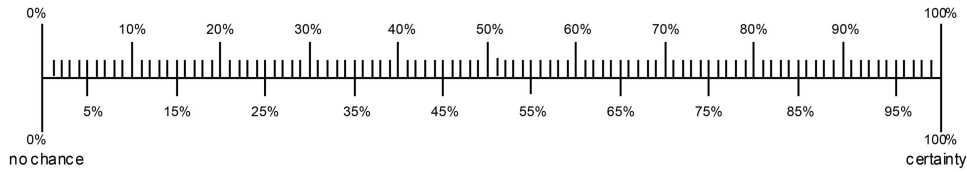
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### Percent Chance Questions

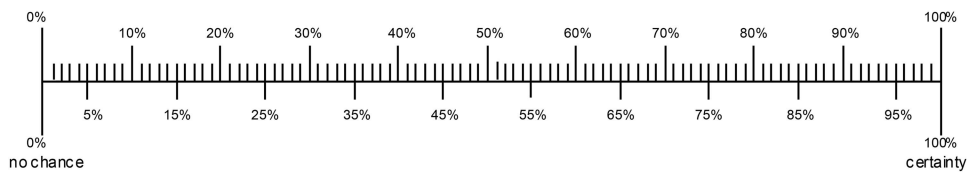
**Part 2.** Here are some more questions that ask for your best guess at the chance that something will happen in the future. If you think that something has no chance of happening, mark it as having a 0% chance. If you think that something is certain to happen, mark it as having a 100% chance. You will not have to explain any of your answers.

These questions concern some issues that you might face in the next year.

1. What is the percent chance that you will die (from any cause—crime, illness, accident, and so on) in the next year?

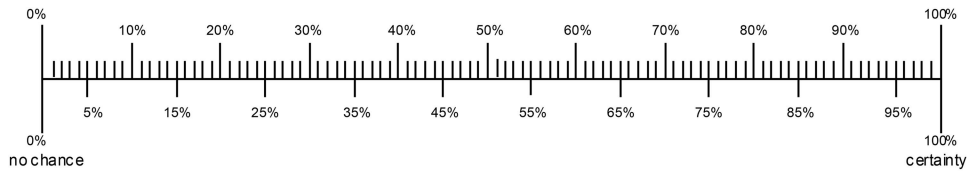


2. What is the percent chance that you will be in a traffic accident some time this year?

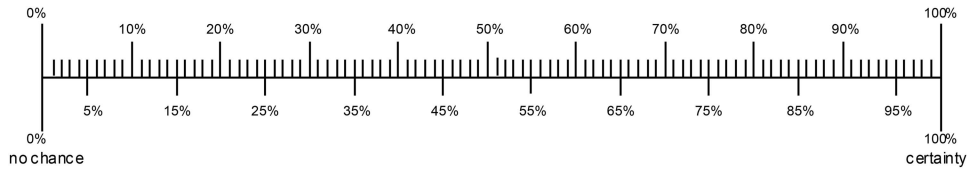


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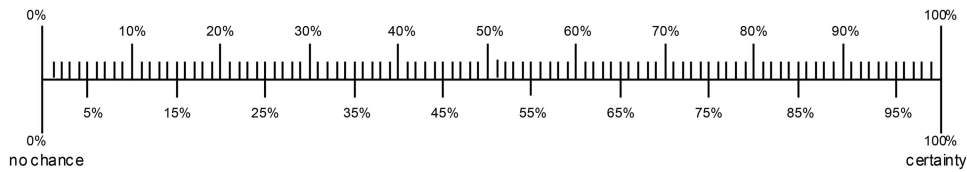
3. What is the percent chance that you will be a victim of a violent crime at least once in the next year?



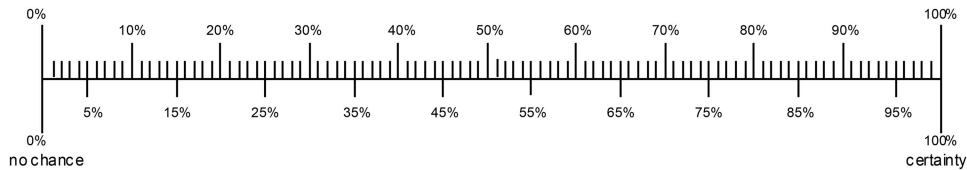
4. What is the percent chance that you will win a prize of some kind at least once in the next year?



5. What is the percent chance that you will be arrested, rightly or wrongly, at least once in the next year?

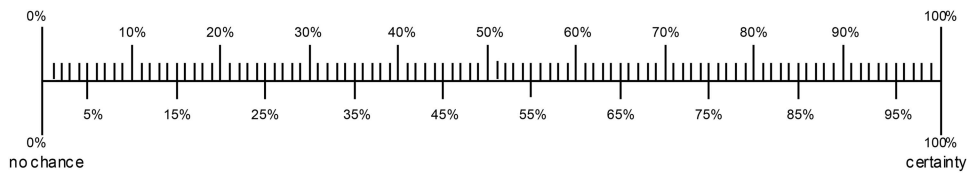


6. What is the percent chance that you get an unexpected large amount of money in the next year?

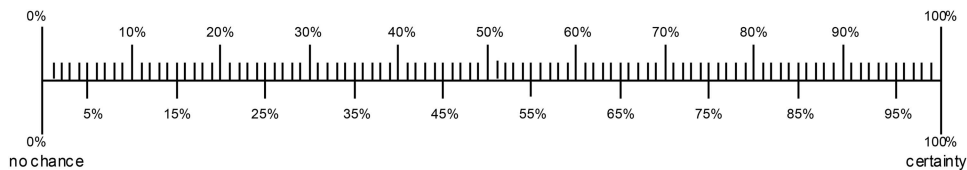


The next questions ask about you 10 years from now.

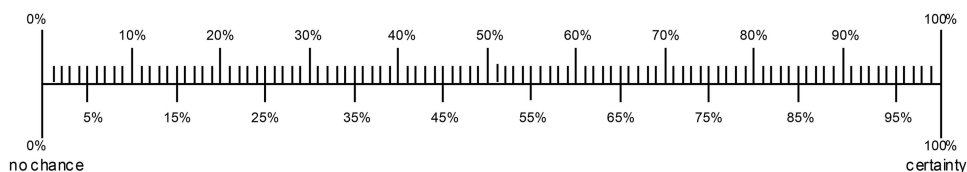
7. What is the percent chance that you will make a lot of money between now and ten years from now?



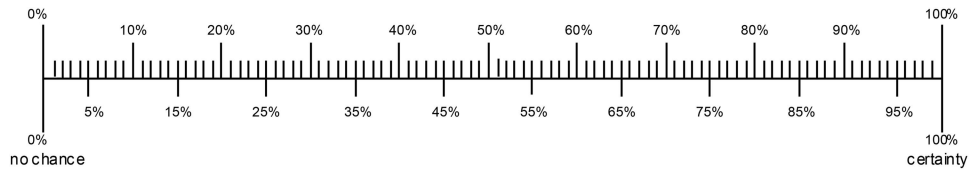
8. What is the percent chance that you will be arrested, rightly or wrongly, at least once between now and ten years from now?



9. What is the percent chance that you will die (from any cause—crime, illness, accident, and so on) between now and ten years from now?



10. What is the percent chance that you will become famous some time between now and ten years from now?



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