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Dissecting "Peer Presence" and "Decisions" to Deepen Understanding of Peer Influence on Adolescent Risky Choice

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This study evaluated the aspects of complex decisions influenced by peers, and components of peer involvement influential to adolescents' risky decisions. Participants (N = 140) aged 13–25 completed the Columbia Card Task (CCT), a risky choice task, isolating deliberation-reliant and affect-reliant decisions while alone, while a friend monitors choices, and while a friend is merely present. There is no condition in which a non-friend peer is present. Results demonstrated the risk-increasing peer effect occurred in the youngest participants in the cold CCT and middle-late adolescents in the hot CCT, whereas other ages and contexts showed a risk-decreasing peer effect. Mere presence was not sufficient to influence risky behavior. These boundaries in age, decision, and peer involvement constrain prevailing models of adolescent peer influence.

Adolescence is a developmental phase characterized by widespread changes in physical, neurobiological, and psychological maturation, and achievement of numerous emergent cognitive and social competencies. Despite these achievements, adolescents face a unique set of health vulnerabilities with a 200% increase in mortality relative to childhood largely due to preventable factors involving risk: automobile accidents, other accidents, self-harm, and drug and alcohol abuse (Eaton et al., 2008). Enhanced preference for risk during adolescence has additionally been observed in laboratory studies which mimic risky decisions using gambling or odds-weighing tasks: a recent meta-analysis (Defoe, Dubas, Figner, & van Aken, 2015) demonstrated that relative to adults, adolescents made riskier decisions, that this was especially evident in younger adolescents, and when the decisions provided instant feedback about whether they won or lost. Across these classes of adolescent behavior, a key moderating factor exists: adolescents are more likely to engage in risky behavior in the presence of peers (Blakemore & Robbins, 2012; Steinberg, 2004), which was historically coined the "risky shift" (Vinokur, 1971). For example, when driving, adolescents are more likely to make dangerous moves in the presence of peers (Doherty, Andrey, & MacGregor, 1998; Simons-Morton et al., 2011), and crime statistics indicate that adolescents are more prone to deviant behavior when with others than when alone (Erickson & Jensen, 1977; Zimring, 2000).

Adolescent peer influence has also been documented in controlled laboratory environments. For example, an influential study using a simulated driving task showed that adolescents took more risks in the presence of peers than when alone, effects that were larger in adolescence than in older ages (Gardner & Steinberg, 2005). This and other laboratory-based studies (e.g., Reynolds, MacPherson, Schwartz, Fox, & Lejuez, 2014; Simons-Morton et al., 2011; Smith, Chein, & Steinberg, 2014) imply peer effects on risk taking cannot merely be

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explained by increased access to risk-enabling scenarios with peers, as the experimental contexts hold risk access constant.

While much has been learned about the phenomenon of peer influence on adolescent risk taking, it is less understood *how* and *why* peers exert a strong influence on adolescent decisions. The concepts of "peers" and "decisions" are complex and multifactorial, which necessarily complicates simple descriptions of peer influence. Indeed, additional studies have failed to observe peer effects on adolescents' risky decisions (Kessler, Hewig, Weichold, Silbereisen, & Miltner, 2016; Powers et al., 2018; Rosen et al., 2016) suggesting that important yet poorly understood boundary conditions may exist that amplify or reduce the likelihood of peers influencing adolescents' decisions. In this study, we used experimental methods to decompose the concepts of "peers" and "decisions" to observe which subprocesses shape risk taking during adolescence. Our goals were to identify potential boundary conditions and moderators that could influence the strength of peer effects in adolescents and adults.

Peer Contexts

Theories from developmental psychology have proposed adolescent motives that could amplify peer influence on risk taking. One line of work has emphasized the explicit social motivations of adolescents to create or maintain social bonds and enhance social status in the eyes of peers. Adolescents tend to appraise risky behaviors as "high status" (Cohen & Prinstein, 2006) and are sometimes motivated to engage in risky behavior due to its association with heightened popularity in adolescence (e.g., Mayeux, Sandstrom, & Cillessen, 2008; Prinstein, Meade, & Cohen, 2003). In addition, adolescents are also particularly motivated by homophily, the desire to behave similar to friends (Kandel, 1978). Thus, individuals could engage in risk taking if the individual perceives that friends hold risk-permissive attitudes or engage in risk taking themselves (Prentice & Miller, 1993). Work has shown that risk-permissive attitudes are more common in adolescents (Benthin, Slovic, & Severson, 1993; Gerrard, Gibbons, Benthin, & Hessling, 1996), providing a possible route by which adolescents are more subject to overt norm- and reputation-based motivations.

These mechanisms suggest adolescents may commit risky acts in the presence of peers because they believe it would elevate, protect, or otherwise reinforce their social relationships. But for these goals to be effective, it would be critical that peers have awareness of the actor's risky choices (else, the acting adolescent has no opportunity to gain "credit"). In work to date, it is standard for risk-taking tasks to allow for such direct observation. Other work, however, has demonstrated that decision making can be influenced in the absence of an active audience and where "credit" for one's decision is impossible. For instance, the mere presence of a depiction of inanimate "cartoon" eyes increases prosocial decision making presumably by activating internal social schemas related to others (Bateson, Nettle, & Roberts, 2006). Our prior work has demonstrated that being looked at in a one-shot encounter with an unknown peer is sufficient to generate robust induction of self-conscious emotion and physiological reactivity in adolescents (relative to children and adults; Somerville et al., 2013). Finally, in rodents, the mere presence of a conspecific (a species unlikely to engage in explicit, status-based motivations) increases alcohol consumption behaviors during the pubertal window (Logue, Chein, Gould, Holliday, & Steinberg, 2014), consistent with an alternative theoretical account that peer presence enhances risky choice by amplifying the reward value of risks (e.g., Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Smith, Steinberg, Strang, & Chein, 2015). Taken together, these findings raise the possibility that even the most minimal peer contexts could shape adolescent risky decision making (Somerville, 2013).

This study evaluated whether direct observation of the participant's choice was necessary to evoke peer effects on adolescent risk taking. Participants made decisions, whereas peers were configured in three different ways during a risky decision task: peers absent, present and actively monitoring the participant's choices on a computer screen (allowing for explicit reputational mechanisms), and present in the same room but unable to view the participant's computer screen. Moreover, this study permits an examination of reward sensitivity mechanisms within the peer contexts by quantifying the degree to which participants' choices differently scale with gain magnitude in the three peer conditions.

Decision Contexts

Much of the evidence documenting peer effects has used tasks that emulate real-world contexts in which peers influence adolescents' risky decisions, such as driving. However, it is less clear whether peer effects extend to other decision contexts that rely more on explicit deliberation and reasoning. This open question is especially important given that prior work has shown that adolescents' propensity for risky decisions is not uniform across decision contexts, but appears to be moderated by a variety of factors besides peer presence, including the presence of immediate outcome feedback and heightened emotional arousal, and the availability of a safe choice option (Defoe et al., 2015; see Hartley & Somerville, 2015 for a review).

Work using the Columbia Card Task (CCT; Figner, Mackinlay, Wilkening, & Weber, 2009) demonstrates the importance of decision contexts. The CCT is a gambling-style card game in which participants gain or lose points based on the number of cards turned and the odds of winning or losing. Greater card turning results in greater potential rewards but also greater probability of losing (i.e., risk), and thus the number of cards turned over is an indicator of risk taking. In one CCT version (the *cold CCT*), participants tend to rely on deliberation and mathematical reasoning to make decisions, and adolescents showed no evidence of riskier decision tendencies compared to adults (Figner et al., 2009). Conversely, in the *hot* CCT, participants tend to choose based on emotion and excitement, and adolescents' risky choice escalated more than adults' (Figner et al., 2009).

As such, one should consider whether adolescent susceptibility to peer effects is more prominent in "hot" decision contexts. "Hot" decisions confer an increase in risky choice in adolescents and thus might represent a context susceptible to further elevation by peers. Previous work has demonstrated that peer evaluation negatively impacts performance on a difficult "cold" relational reasoning task but equally for adolescents and adults (Dumontheil, Wolf, & Blakemore, 2016). Taken together, this prior work raises the possibility that age differences in peer effects differ in "hot" and "cold" contexts. This study used the CCT to quantify peer effects on risk taking in these distinct contexts.

Peer Relations

Prior work in developmental psychology has examined which *types* of peer relationships are particularly influential on adolescents' risky decisions. This work has primarily used survey methods to collect data on the perceived levels of closeness between peers and asked whether that predicts an uptick in health risk behaviors. Broadly, the findings of this work have been mixed. Urberg, Değirmencioğlu, and Pilgrim (1997) found that adolescents are more likely to conform to high levels of peer alcohol use if the adolescent perceived high levels of closeness and acceptance in their friendship. That is, adolescents were more likely to conform to risky behavior of especially close peers, perhaps a result of mutual socialization processes (Cohen & Prinstein, 2006). Other work emphasizes risky behavior as a potential means to build cohesion with peers who are not already close friends. Research on health risk behaviors has shown adolescents more likely to conform with the risk preferences of a *less* close peer (Heilbron & Prinstein, 2008). Yet other work has shown that close peers have a stronger momentary effect on risky decisions, whereas less cohesive friends have a stronger effect on predicting growth trajectories on adolescent alcohol use (Bot, Engels, Knibbe, & Meeus, 2005). Given these mixed findings, we included an exploratory analysis of friendship closeness as a moderator of peer effects.

This Study

Here we manipulated peer context and decision type, and measured dyadic conditions relevant to peer relations to identify possible boundary conditions and moderators of peer influence on adolescent decision making. To test peer involvement, we applied two peer manipulation conditions: (a) the commonly used method of having a friend actively observe the participant's decisions (i.e., *peer monitoring*); and (b) having a friend in the room while the participant engages in the task, though the friend cannot see the decisions the participant makes (i.e., *mere presence*). While the first condition allows assessment of whether active peer monitoring is key to induce peer effects, the second allows assessment of whether merely having a peer in the room with the decision maker is sufficient to evoke peer effects on adolescent risky decision making. To measure decision type effects, participants completed both cold and hot CCT and we measured peer closeness and risk attitudes in each dyad member.

Finally, we used a large sample across a broad age range to compare the degree to which adolescents and adults are susceptible to peer effects. While some studies have included a sufficiently wide age range to compare adolescent versus adult peer influence effects (Chein et al., 2011; Gardner & Steinberg, 2005), many studies only test adolescents (e.g., de Boer, Peeters, & Koning, 2016; Kretsch & Harden, 2014; Smith et al., 2014) or emerging adults (Reynolds et al., 2014; Silva, Shulman, Chein, &

Steinberg, 2015). While useful, these latter studies do not permit the evaluation of whether adolescents are *especially* influenced by peers, a widespread assumption in the field. To ensure that all age groups would equally understand the task, we set the lower age boundary at 13 years (as in Figner et al., 2009). The age of 25 was selected as an upper limit, although it is important to note that individuals in that age range do not necessarily constitute fully stabilized "adults" from neurobiological (Somerville, 2016) or risk-preference (Duell et al., 2017) perspectives. This study used age as a continuous variable in analyses, which permitted identification of linear (rising or falling progressively with age) and nonlinear effects (peaking during mid-to-late adolescence).

Method

Sample

Healthy participants aged 13.07–25.47 (N = 236; n = 118 same sex pairs; 61 female and 57 male pairs) took part in this study (data were collected March 2014–April 2015). N = 140 participants (M_{age} = 17.99, SD = 2.98) generated usable CCT data sets, whereas for n = 96, participation was fully constrained to a role of "friend." As shown in Table S1, the quantity of participants across the age range was approximately uniform, and sex (51.4% female participants) was evenly distributed across age. The sample ethnicity was 89% non-Hispanic and 11% Hispanic, and the racial makeup was 57% White, 25% Asian, 6% Black, 10% more than one race, and 2% Native American. Ethnicity was well-balanced over age (see Table S1). Race was less uniformly balanced across the sample, evident in a trend-level chi-squared test of independence between race and age (p = .053, see Table S1). This partial imbalance was likely the result of random chance, as recruitment procedures were carried out consistently for all ages.

Participants were recruited from the greater Boston area which includes both urban and suburban environments, and the sample is approximately representative of the overall demographic makeup of the area. Prospective participants were identified through advertisements across the local area, outreach activities at schools and at community events, and an online research participation portal that serves both university students and nonstudent community members in the area.

The sample size for this study was prespecified based on a two power analyses computed in G*Power (Faul, Erdfelder, Lang, & Buchner, 2007). For the first power analysis, we estimated the number of participants needed to observe "the adolescent peer effect" based on results of a prior experiment (Gardner & Steinberg, 2005) demonstrating heightened risk taking in peer monitoring versus alone conditions (d = .472). Using analysis of variance (ANOVA), 95% power to detect a similarly sized effect at $\alpha < .05$ would be achieved with a sample size of n = 70 data sets per social condition. A second power analysis targeted age differences in peer influence on risky decisions. The anticipated effect size for the Age × Peer interaction effect was $\eta_p^2 = .17$, based on the results of the same experiment. We used this effect size in a separate power analysis computed in G*Power (Faul et al., 2007) to estimate the required sample size for this study's design with age as a between-subjects factor and the peer manipulation as a mixed factor with three levels and two measurements per person. Based on this effect size, 80% power would be achieved through testing a total of n = 140. Given these power considerations, we chose not to examine additional between-subjects variables such as participant sex or race.

This study's design differed from those available for power analysis in the following ways: (a) Instead of discrete age groupings, we evaluated age using continuous linear and quadratic predictors to more precisely capture and describe age differences; and (b) to take into account the complex features of our study's partially within and partially between design and to analyze data at the unaggregated trial level, we took advantage of modern analytical approaches (Bayesian mixed-effects models), instead of using ANOVA. Given that the actual study parameters thus differ from the constraints of initial power analysis (which we based on existing study designs and data analysis practices), the quantity of data acquired was increased to > 90 usable data sets for each social condition. We believe these modifications would increase, rather than decrease statistical power: First, the continuous use of age allows for more specific tests of age effects. Furthermore, not using age categories means that we avoid loss of information (which is usually associated with loss of statistical power; see MacCallum, Zhang, Preacher, & Rucker, 2002). Second, the use of a Bayesian mixed-models approach sidesteps the need to exclude participants with partially missing data. Third, by modeling more of the data-generating processes via the trial-level analyses, we not only analyze far more data points (more than 12,000 at the trial level vs. several hundred if we would analyze at an aggregated level), but we expect that modeling more of the relevant processes will reduce unexplained variance in the model, which, in turn, leads to more precise estimates of the effects of interest.

The study is a partially within and partially between subjects design in which $n = 140$ participants each generate data for two of three social conditions. As a result, the following number of data sets were acquired for each social condition: alone condition: $n = 92$; mere presence condition: $n = 94$; peer monitoring condition: $n = 94$ (a total of 280 hot and 280 cold CCT data sets from $n = 140$ participants). Within the $n = 140$ usable participants, three data sets contained partially missing data, but were included in analyses when possible (see Supporting Information for a full description of missing data and Table S1 for counts of usable data by age and condition). Adults provided informed written consent. Participants younger than 18 provided written assent and received written permission for their participation from a parent or legal guardian. All research procedures were approved by the Committee for Use of Human Subjects at Harvard University.

Dyad Characteristics

Individuals who expressed interest in the study were asked to identify a potential friend with whom to coparticipate. The friend was stipulated to be approximately the same age, of the same sex, and not romantically involved. The mean age difference within dyads was 0.57 years $\pm$ *SD* = 0.90 years. Perceptions of dyadic closeness were measured for each participant within the dyad using two self-report questionnaires, the Inclusion of Other In the Self Scale (IOS; Aron, Aron, & Smollan, 1992) and the Unidimensional Relationship Closeness Scale (URCS; Dibble, Levine, & Park, 2012).

We evaluated the risk attitudes of both participants in the pair using the Domain-Specific Risk-Taking Scale (DOSPERT). The DOSPERT assesses the likelihood of engaging in a series of risky scenarios. Participants completed age-appropriate versions of the DOSPERT (participants 13–17 years old completed the Adolescent version; Figner, van Duijvenvoorde, Blankenstein, & Weber, 2015, and participants 18 and older completed the Adult version; Blais & Weber, 2006; Weber, Blais, & Betz, 2002). The adult and adolescent scales contained different numbers of items, and for a subset of the adolescent participants we omitted three questions referencing explicitly illegal activity (stealing, pirating music, underage drinking) as requested by one source of participant recruitment. To adjust for these differences, we computed the total score as the mean item score (range = 1.0–7.0) with greater scores indicating greater endorsement of risk taking. Omitting these items did not have a systematic effect on total scores (see Supporting Information).

Columbia Card Task

The CCT (e.g., Figner et al., 2009; van Duijvenvoorde et al., 2015) is designed to disentangle the contributions of gain, loss, and odds to risky choice. On a given trial, 32 cards (a combination of gain and loss cards) are displayed face down on the computer screen. If participants turn over gain cards, they accrue a specified number of points and if the participant selects a loss card they lose a specified number of points and the trial ends. A running total of points is displayed showing the number of points earned within that trial.

At the top of the screen, information is provided about the quantity and value of the gain and loss cards for that trial: *gain amount*, the number of points earned per gain card turned (10 or 30), *loss amount*, the number of points lost if a loss card is turned (−250 or −750), and the *odds of losing*, the number of loss cards (1 or 3). These values were selected from prior work indicating that with these parameters, participants' choice behavior hovers between ceiling and floor levels (Figner & Weber, 2011; Figner et al., 2009). Gain amounts, loss amounts, and odds vary trial-to-trial and were factorially crossed to generate eight different trials, each of which is repeated three times to yield a total of 24 trials per CCT. Participants completed two versions of the CCT per social condition: *cold* (Figure 1a) and *hot* (Figure 1b).

The *cold* CCT encourages decision making based on mathematical calculation and deliberate reasoning (Figner et al., 2009). Participants selected the number of cards they wished to take by clicking a number between 0 and 32 at the top of the screen. Participants indicated the *total* number of cards they wish to take, and no feedback was provided about the number of points earned until the end of the experiment. The *hot CCT* encourages decisions based on "gut feelings" and triggers excitement and physiological arousal (Figner et al., 2009). Participants selected one card at a time by clicking on a specific card, which turns over to reveal whether it is a gain or loss card. If a gain card was selected, accumulated points were immediately updated and

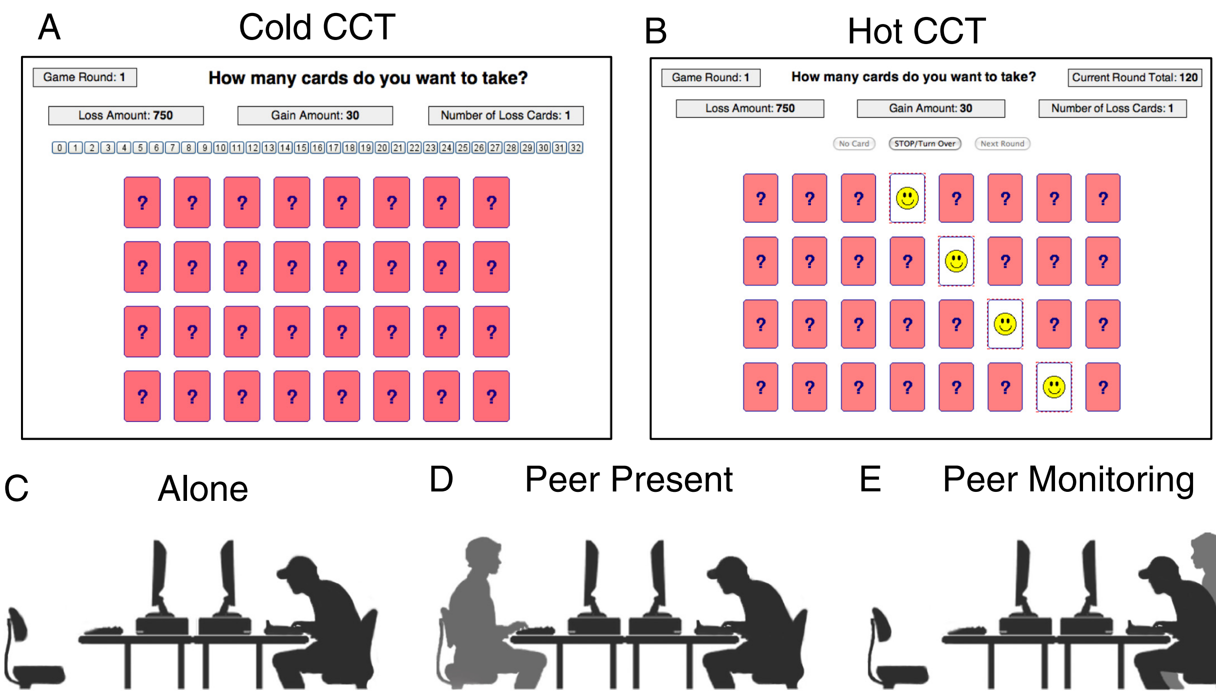

Figure 1. (A and B) The Columbia Card task (CCT) is a risky card-turning game in which participants earn points by turning over win cards and lose points if they turn over loss cards. The odds, gain, and loss amounts vary trial-by-trial and are displayed at the top of the screen. (A) In the cold CCT task, participants make a single selection per trial of how many cards to turn over. (B) In the hot CCT task, participants select cards one-at-a-time and receive immediate feedback. Participants completed the hot and cold CCT tasks in three peer configurations: (C) alone in a room, (D) when their friend was in the same room but could not observe the participant's choices, and (E) when their friend was in the same room actively monitoring the participant's choices.

participants could then choose to turn over another card of their choosing or press STOP at the top of the screen. This continued iteratively until the participant chose to stop taking cards or until the participant selected a loss card, whichever came sooner. Participants saw their current point total for the trial, which changed with every card they turned over. If a participant decided to stop the current trial, or selected a loss card, the trial ended and the remaining cards were turned over to show which were gain cards and which were loss cards.

Social Manipulation

Participants completed the risky choice task in three different peer configurations. In the *alone* condition (Figure 1c), one participant completed CCTs alone in a testing room, whereas the coparticipant sat in a separate room. In the *mere presence* condition (Figure 1d), participants were seated on opposite sides of a table at computers that faced back-to-back so that the coparticipants were present in the same room but could not see the other's computer screen. This condition was designed to isolate peer effects evoked by the mere presence of the peer but while the peer could not monitor their specific choices. In the *peer monitoring* condition (Figure 1e), one participant completed CCTs, whereas the coparticipant sat in a chair next to the participant and viewed the participant's computer screen. The coparticipant was instructed to monitor the participant's responses to the task. For all conditions, participants were instructed not to speak with one another during the CCTs, and the door to the testing room remained ajar so that compliance could be monitored. However, it was not possible to verify whether participants engaged in nonverbal interactions.

The study was conducted as a 2 (CCT type; hot, cold; within-subjects) × 3 (social condition; alone, mere presence, peer monitoring) mixed within-between subjects design. It was not feasible to conduct the study as a fully within-subjects design due to concerns about time commitment and habituation to the CCT. Thus, for each participant CCTs were administered in two of three social conditions (alone, mere presence, peer monitoring). Counterbalancing of the social condition was achieved through several distinct orders (see Table S2).

Study Procedure

After informed consent and assent, participants received extensive, experimenter-guided instructions for the CCT and completed a comprehension test to ensure that the premise and parameters of the task were clear. Participants were instructed to earn as many points as possible in the CCT because they would be converted to a bonus payment at the end of the study. Any bonus money earned would not apply to the friend. Participants completed the first pair of CCTs (hot and cold, order counterbalanced) within the first social configuration. A ~5-min filler task (word search) was administered after the first CCT to minimize hot-to-cold or cold-to-hot carryover effects. After completion of the first pair of CCTs, participants had a short break and then reconfigured into the second social condition where the procedures were repeated.

Following the CCTs, participants completed self-report measures assessing potential moderators of peer effects: the risk taking and friendship closeness measures described earlier. Participants completed these questionnaires on an electronic tablet or computer, always alone in a room to minimize any potential response biases that could arise from the presence of a peer. Following completion of the questionnaires, participants received remuneration, bonus money, and were debriefed.

Data Analysis

The primary-dependent variable was number of cards turned during each CCT trial. In both the hot and the cold CCT, assignment of cards to gain or loss is a true random process. For the hot task, the number of cards chosen (either until the participant chose to stop, or until they selected a loss card) was totaled for each trial. Because there was no feedback in the cold trials, choice was never artificially cut short by selecting loss cards as it was in the hot task. To make the dependent variable in the hot and the cold CCT more comparable to each other, the cold CCT runs a process in the background (not visible to the participant) in which a sequence of individual cards are "turned over" and if a loss card is turned, their score is truncated at that card. For example, if a participant in the cold CCT decides to turn over 10 cards, the computer randomly chooses 10 cards. If the fifth card is a loss card, the "postprocessing" replaces the number of cards that a participant had indicated that they wanted to be turned over (10 in this example) with the number of cards that actually were turned over before reaching a loss card (five in this example). This processing step ensured that card-turning scores for each trial within the task were equivalently yoked to the odds of each trial.

Omnibus Model

CCT data were analyzed at the trial level without aggregation. Trial-by-trial card turning scores were tagged to coding variables for participant, CCT type (hot, cold), peer configuration (alone, mere presence, peer monitoring), gain amount (10 points, 30 points), loss amount (250 points, 750 points), and number of loss cards (one card, three cards). The omnibus effect of social condition was represented with sum-to-zero contrasts: The first represented the comparison *alone* versus the grand mean of all conditions; the second contrast represented the comparison *peer monitoring* versus the grand mean of all conditions. Thus, the first contrast can inform us whether alone differed from the two peer conditions, whereas the second contrast can inform us whether peer monitoring differs from the two other conditions. The use of these contrasts in the omnibus model allowed us to detect and test differences between social conditions and whether these interacted with age and/or task context (hot or cold CCT). Importantly, to better understand, characterize, and isolate the effects observed in the omnibus model, we then ran specific follow-up models described next.

Participant age was represented in two distinct predictors: *linear age* representing steadily increasing or decreasing effects, and *quadratic age* representing adolescent peaking (or troughing) age effects. Age predictors were created using R's (R Core Team, 2015) poly function, which produces mean-centered and orthogonal linear and quadratic predictors.

Compiled trial-by-trial choice data were submitted to statistical analysis using Bayesian mixed-effects models carried out in R using the brms package (Bürkner, 2016) which provides an interface to Stan (Carpenter et al., 2016). Stan is a state-of-the-art platform for Bayesian data analysis and these models can be run via R using packages including brms, which was used here. The model included predictors that represented main effects of linear age, quadratic age, social condition (represented as the two contrasts described earlier), CCT type (hot, cold), gain amount (low, high), loss amount (low, high), number of loss cards (fewer, more), and interactions among these variables (omitting interactions among linear and quadratic age, and interactions among the card game factors gain amount, loss amount, and number of loss cards). All continuous predictors were mean-centered and standardized, all categorical predictors were coded using sum-to-zero contrasts. We used the default priors of the brms package because they do not influence the results in any substantial way (Cauchy priors and LKJ priors for correlation parameters; Bürkner, 2016), and because we are not aware of any published study using the CCT in combination with a peer presence manipulation, and therefore do not have information from which we could have derived more informative priors.

To account for the repeated-measures nature of the data, the model included a random intercept per participant and random slopes for social condition, CCT type, their interaction, each of the card game factors, each of the interactions of each card game factor with social condition, and each of the interactions of each card game factor with CCT type. We also added all possible random covariance terms between random effects. The model was fit using six chains with 4,000 iterations each (1,000 warm up) and all Bayesian models were inspected for convergence. All primary results are derived from this model. Coefficients were deemed statistically significant if the associated 95% posterior credible intervals were nonoverlapping with zero. The regression coefficients are referred to in units of "*B*" in results.

Follow-Up Models

The omnibus model described earlier included the full data set and allowed identification and stringent statistical tests of key effects of interest (main effects and interactions). Since the omnibus model represents the three levels of the social condition factor as two contrasts, interpretation of main effects and interactions involving social condition can be challenging. Therefore, we followed up the omnibus model with a set of models that compared pairwise subsets of the data to identify the underlying structure of the effects observed in the omnibus model. The follow-up Bayesian mixed-effects models were computed as described earlier but directly contrasted each pair of the social conditions (alone vs. mere presence, alone vs. peer monitoring, mere presence vs. peer monitoring) for the hot and cold CCT conditions separately. Together, the follow-up models decomposed the primary three-way interaction (Social Condition × Age × Hot vs. Cold CCT) to identify the conditions and directionality of the effect.

Descriptive and frequentist statistics were used for post hoc analyses that did not include the mixed within-between factor of social condition. For analyses involving significant continuous age effects, all analyses (omnibus, follow-up, and post hoc) treated age as a continuous variable, but for ease of visualization data were subdivided into four groups of approximately equal size: 13–15 year-olds, 16–18 year-olds, 19–21 year-olds, and 22+ year-olds. Frequentist analyses include standard error of the mean (SEM) calculations, calculated by first aggregating over trials within subject and then computing the group SEM.

Dyad Analyses

A final Bayesian mixed model was conducted to evaluate whether key individual differences variables characterizing the participant completing the CCT, and characterizing the similarities and differences between members of the dyad, moderated CCT performance. See Supporting Information for details on this analysis.

Results

Omnibus Model

Basic Task Effects

As expected, the CCT factors influenced participants' trial-by-trial decisions. Participants selected significantly more cards when the gain amount was high (mean cards turned ± SEM 10 point gain: $M = 7.514$, SEM = .216, 30 point gain: $M = 8.368$, SEM = .176; estimated regression coefficient (B) = .424, lower and upper 95% posterior credible intervals (95% CI) [.299, .548]), when the loss amount was low (250 point loss: $M = 8.675$, SEM = .177, 750 point loss: $M = 7.206$, SEM = .216; $B = -.736$, 95% CI [−.864, −.611]), and when the probability of loss was low (one loss card: $M = 10.603$, SEM = .245, three loss cards: $M = 5.278$, SEM = .146; $B = -2.666$, 95% CI [−2.812, −2.520]). These findings indicate that participants comprehended the trial-by-trial differences in game rounds and adjusted their risk-taking levels in a sensible way.

Participants selected significantly more cards in the hot than cold CCT (hot: $M = 8.352$, SEM = .206, cold: $M = 7.549$, SEM = .204; $B = .391$, 95% CI

[.231, .550]). In addition, there were significant interactions between CCT type and loss amount ($B = -.0839$, 95% CI [−.166, −.00211]) and CCT type and number of loss cards ($B = .116$, 95% CI [.00789, .225]). Assessment of the interactions showed that the large loss amount reduced risky choice less in the hot CCT (large-small loss amount: 13.66% reduction [hot] vs. 22.3% [cold]), and that high loss probability attenuated risky choice less in the hot CCT (large-small loss probability: 48.42% reduction [hot] vs. 53.31% [cold]). These findings suggest that the hot context increased risky choice by reducing the deterrent effects of loss parameters.

Influence of Age on Risky Choice

There was a significant interaction between linear age and CCT type ($B = .215$, 95% CI [.0564, .375]). The interaction was driven by a larger effect of the hot versus cold manipulation on risky choice in younger adolescents that declined with increasing age (Figure 2). Post hoc analyses (significance threshold was Bonferroni corrected for cold and hot comparisons) showed that there was a significant decline in cards turned in the hot condition with increasing age, $r(139) = -.219$, $p = .009$; critical $\alpha = .025$, and no age-related differences in cards turned for the cold condition, $r(139) = -.039$, $p = .649$; critical $\alpha = .025$, a pattern consistent with previous work (e.g., Figner et al., 2009). The quadratic age predictor did not interact with CCT type ($B = -.0197$, 95% CI [−.179, .140]). The grand mean number of cards turned did not vary by linear or quadratic age (linear: $B = -.306$, 95% CI [−.659, .0445], quadratic: $B = .202$, 95% CI [−.159, .564]).

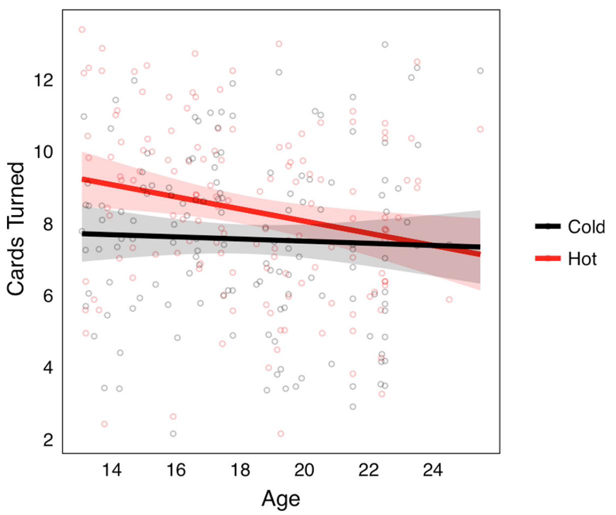

Figure 2. A significant interaction between Columbia Card task (CCT) type and age: Younger participants showed increased risky choice in the hot condition. Fit lines depict linear fit; colored bands indicate within-subjects standard error of the mean; scatter depicts two dots per participant (one for the hot CCT, one for the cold CCT).

Interaction of Age, Social Condition, and CCT Type

We observed a three-way interaction between quadratic (adolescent peaking) age, the *alone versus grand mean* contrast, and CCT type ($B = -.190$, 95% CI [−.356, −.0246]). There were no significant main effects of the social manipulations on risky choice (*alone vs. grand mean* contrast: $B = .0167$, 95% CI [−.149, .180]; *peer monitoring vs. grand mean* contrast: $B = -.0512$, 95% CI [−.230, .126]). There were no significant interactions between the social manipulations and hot versus cold CCT (*alone vs. grand mean* contrast: $B = -.00988$, 95% CI [−.183, .164]; *peer monitoring* contrast: $B = .0450$, 95% CI [−.108, .197]). Three-way interactions between social condition (first or second contrast), age (linear or quadratic) and CCT type were not significant (see Table S3 for full model results). Thus, the social monitoring manipulation did not influence risky choice as a whole, but did so differentially across age and CCT type.

In the omnibus model, we observed a significant three-way interaction between linear age, the *peer monitoring versus grand mean* contrast, and sensitivity to gain amount ($B = .159$, 95% CI [.0301, −.2892]; Figure S2), suggesting that individuals of younger ages are less attuned to gain amount under peer monitoring. However, this effect does not parallel the overall pattern of peer effects, as it was equally evident in the cold and hot CCTs.

Follow-Up Models

To evaluate the complex interaction, we computed follow-up models as described in the Methods. The overall results of these models indicated that both the cold and hot CCT exhibited peer effects, but with different age patterns. In particular, pairwise tests evaluated the specific differences between the three social conditions on hot and cold CCT performance. Table 1 presents the results of the key age analyses and all descriptive data are depicted in Figure 3.

Results indicate the three-way interaction was driven by the combination of a significant decline in risky choice with increasing linear age in the *peer monitoring* > *alone* comparison for the cold CCT

Table 1
Pairwise Follow-Up Statistics Decomposing Three-Way Interaction

CCT	Social condition	Age (linear)	Age (quadratic)
Hot	Alone versus mere presence	$B = -.0364$ CI [−.191, .121]	$B = .116$ CI [−.0388, .272]
Hot	Alone versus peer monitoring	$B = .0288$ CI [−.136, .198]	***B* = .176** **CI [.00716, .345]**
Hot	Mere presence versus peer monitoring	$B = -.0393$ CI [−.219, .143]	$B = -.0611$ CI [−.253, .126]
Cold	Alone versus mere presence	$B = .0149$ CI [−.137, .170]	$B = -.0542$ CI [−.205, .0980]
Cold	Alone versus peer monitoring	***B* = .183** **CI [.008, .360]**	$B = -.0316$ CI [−.208, .148]
Cold	Mere presence versus peer monitoring	$B = -.104$ CI [−.251, .0383]	$B = .00306$ CI [−.154, .159]

Note. Effects were considered significant (bolded) if 95% CIs did not overlap with zero. B = regression coefficient; CI = 95% posterior credible intervals; CCT = Columbia Card task.

(Figure 4a), and a significant adolescent peak in risky choice in the *peer monitoring* > *alone* comparison for the hot CCT (Figure 4b). No pairwise analyses querying the *mere presence* condition yielded a significant effect in either the cold or hot CCT data. Inspection of means (see Figure 3) indicates that risky choice in the mere presence was intermediate to the alone and peer monitoring conditions, although it was not statistically different from either of the other conditions. See Table S4 for additional post hoc analyses.

The pairwise models were also queried for interactions between age, social condition, and trial-by-trial information use about gain amount, loss amount, and odds of loss. For the cold CCT *peer monitoring versus alone* pairwise comparison, there was a significant linear Age × Social Condition × Number of Loss Cards interaction ($B = -.135$, 95% CI [−.245, −.0210]). Although peer monitoring (compared to alone) reduced older participants' risky choices on game rounds with low odds of loss (oldest group $M = 2.99$ card reduction in *peer monitoring vs. alone*), this effect reversed in younger participants specifically when the odds of losing were low (youngest group $M = 0.77$ card increase in *peer monitoring vs. alone*). In contrast, for the high odds of loss trials the developmental differences are attenuated (youngest group $M = 0.39$

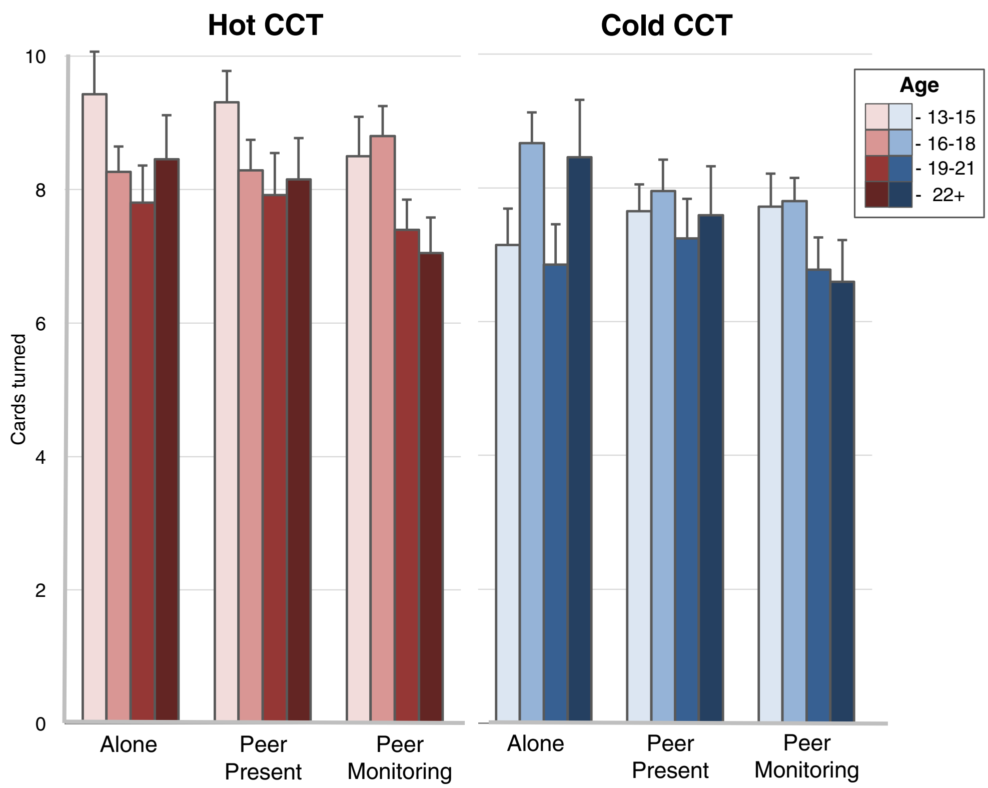

Figure 3. Mean number of cards turned for alone, peer present, and peer monitoring conditions. For display purposes, age is depicted in four subgroups of approximately equal size (13–15: $n = 39$; 16–18: $n = 41$; 19–21: $n = 35$; 21 + : $n = 25$). Error bars denote standard error of the mean.

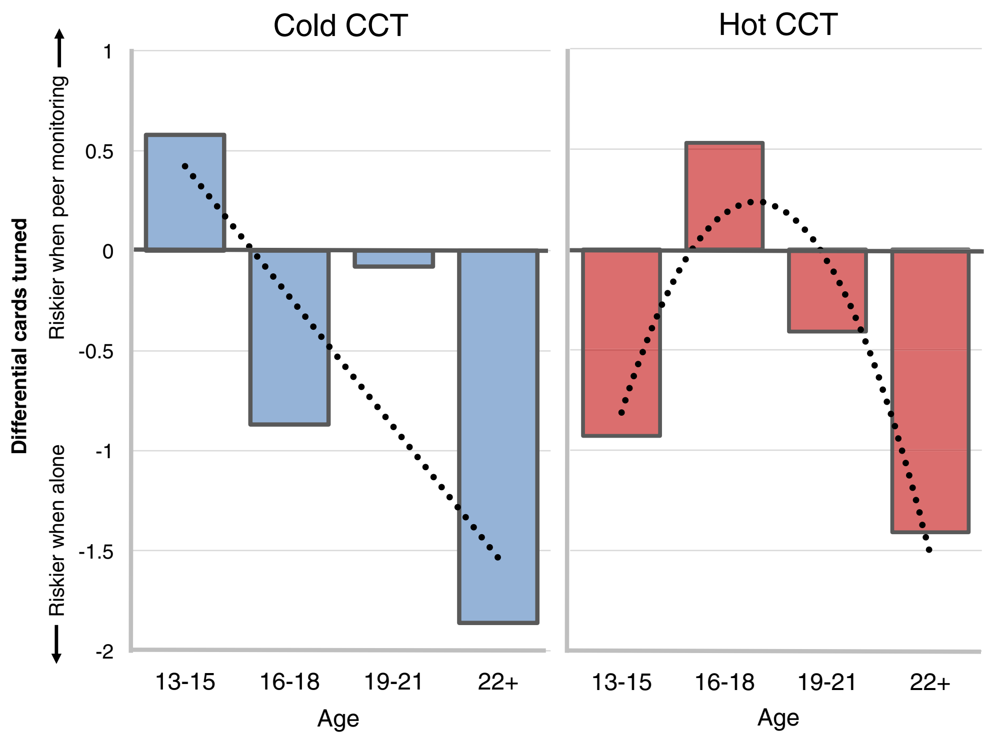

Figure 4. Three-way interaction between social condition, age, and Columbia Card Task (CCT) type. (A) For the cold CCT, younger age predicted heightened tendency to take risks when monitored by peer. (B) For the hot CCT, there was a mid-adolescent peak in the tendency to take risks when peer-monitored. These upticks in risk taking should be interpreted against a backdrop of generally reduced risky choice when in the presence of peers (i.e., predominantly negative difference for *peer monitoring vs. alone* [*y*-axis]). The age binning and fit lines are depicted to facilitate interpretation for descriptive purposes only. Error bars are not depicted because there is no generally accepted way to compute them given the mixed between-within subjects design.

card increase; oldest group $M = -0.73$ card reduction). Thus, peer monitoring influenced risky choice most when the odds of losing were low. There were no significant effects of the gain condition in this contrast, nor were there any significant effects of gain amount, loss amount, or odds of loss on hot CCT peer monitoring effects. This is consistent with the notion that in the cold CCT, peer effects operated more strongly through attenuated loss sensitivity, whereas in the hot CCT, peer effects were more complex as they were not significantly yoked to any of individual trial elements. See Table S5 for full results of the follow-up models.

Dyad Analyses

See Supporting Information for descriptive analyses characterizing the sample on measures of risk-taking propensity and friendship closeness. Primary analyses tested whether risk-taking propensity or friendship closeness moderated the two significant interactions with age observed in the omnibus model, namely the interaction between Age × CCT Type, and the interaction between CCT Type × Age × *Alone Versus Grand Mean* Contrast. The CCT Type × Age interaction showed significant moderation by dyadic differences in friendship closeness (CCT Type × Linear Age × Closeness Difference: $B = -.341$; 95% CI [−.535, −.150]). Inspection of the complex interaction (Figure S1) revealed that the large hot > cold difference on risky choice in early adolescence is more prominent in dyads for whom the participant likes the friend *less* than the friend likes the participant. Note, however, this effect was not moderated by social condition ($B = .0855$; 95% CI [−.147, .319]). Thus, this dyad interaction is evident regardless of whether the friend observed the participants' choices or not. This pattern did not comport with any expected pattern of dyad effects, but we nonetheless provide a speculative interpretation in Supporting Information. None of the other dyadic variables interacted with the CCT Type × Age interaction (participant DOSPERT: $B = -.079$; 95% CI [−.345, .183]; DOSPERT difference score: $B = .047$; 95% CI [−.190, .291]; participant closeness: $B = .107$; 95% CI [−.124, .338]).

None of the dyadic variables significantly moderated the key three-way interaction of the omnibus model (participant DOSPERT: $B = .062$; 95% CI [−.239, .365]; DOSPERT difference score: $B = -.0393$; 95% CI [−.324, .241]; participant Closeness: $B = .00398$; 95% CI [−.269, .276]; closeness difference score reported earlier). See Table S6 for results of the dyad model.

Discussion

The goal of this study was to evaluate theoretically motivated boundary conditions that could influence peer effects on adolescent decision making. Results supported the overall conclusion that peers can increase the risky decisions of adolescents relative to adults. However, this conclusion is qualified by several layers of complexity. The typically expected risk-*increasing* peer effect was very specific in that it only occurred in the youngest participants in the cold and in the middle-late adolescent range in the hot CCT, whereas all other ages and contexts showed a risk-*decreasing* peer effect. We discuss components of these findings next in relation to prevailing conceptions of peer effects.

Decision Type

This study evaluated risky decision making using the CCT. During the CCT, participants viewed face-down cards along with information about the odds of winning or losing, the number of points to be earned by selecting a win card, and the number of points to be lost by selecting a loss card. Critically, participants completed these risky decisions in two distinct decision contexts—in the "hot" context, participants select cards one at a time with immediate gain or loss feedback and a display of cached points. This context provokes arousal, emotion, and enhances risky choice over the "cold" context, in which participants preselect the number of cards they wish to turn without feedback (Figner et al., 2009). The "cold" context relies relatively more on deliberation and mathematical reasoning (Gerrard et al., 1996). Consistent with past work (Figner & Weber, 2011; Figner et al., 2009), we observed a relative absence of age differences in risk taking in the cold CCT, whereas in the hot CCT, younger participants showed increased risk taking that diminished linearly with increasing age. This effect was evident when examining the alone condition in isolation, suggesting that in the absence of peer influence, younger age is associated with increasing susceptibility to the influence of "hot" contexts on risky choice.

Additional analyses identified which card game factors (gain amount, loss amount, loss probability) were treated differently in younger participants in the hot task and led to the uptick in risky choice. We found that younger participants exhibited higher levels of risk taking in the hot task because they were less deterred by the probability of incurring the potential loss associated with riskier choices. These results converge with prior work demonstrating greater tolerance of risk in adolescents' decisions compared to adults' (Defoe et al., 2015; Powers et al., 2018) and further constrains these shifts to affectively engaging contexts such as the hot CCT.

More generally, these findings add to growing evidence that adolescent risky decision making is not ubiquitous but emerges in particular decisional contexts. Our findings also indicate that insensitivity to the odds of losing was most related to the risky shift observed in the younger participants, more than changes in the influence that gain and loss amounts had on risky choice. It would be important for future work on development and risky choice to incorporate designs that examine the construct of loss probability insensitivity.

Peer Influence Effects

This study aimed to deepen understanding of the "key ingredients" of peers that lead to heightened risky choice. One line of work emphasizes the overt reputational gains that could be enjoyed by adolescents whose risks are actively noticed by peers—motivations that presumably are most active during the peer monitoring condition of this study. Other previous work suggests the possibility that the mere presence of peers influences adolescents' decisions (Markus, 1978; Somerville et al., 2013), though the mechanisms underlying mere presence effects are not currently well understood. Participants completed the pair of CCTs (hot and cold) in three different social contexts: when participants were alone, when their peer was physically present in the room but unable to observe choices, and when the peer was physically present and actively monitoring choices.

It is important to note that whereas multiple peers can be involved in decisions in real life, this study involved a single peer. Moreover, in this study, coparticipants were friends self-selected by the participants. Thus, it is not clear whether the present findings would generalize to other "peer" contexts including contexts with unknown peers or multiple peers. It will be important for future work to systematically examine whether manipulating in type of peer context yield distinct peer influence effects.

Peer Monitoring

We observed highly specific effects of the peer monitoring condition (compared to the alone condition) on risky choice: the peer effects varied by age, and did so differently for the hot and cold CCT. Peer monitoring enhanced risky choice in the cold CCT in early adolescents, whereas it decreased risky choice in all older ages, and this effect became stronger with increasing age. In contrast, peer monitoring enhanced risky choice in the hot CCT in mid-late adolescents, but for all other groups the peer monitoring effect had an opposite effect, leading to decreased risky choice. Although peer monitoring was also associated with reduced attention to gain amounts in younger participants, this effect was not further modulated by hot versus cold CCT, and thus did not mirror the complex observed peer effects. Together, these results demonstrate that age differences in peer effects vary depending on the decision type.

Peer effects on cold decisions. The cold CCT is a task that measures risky choices that arise from deliberation and mathematical reasoning. While even the youngest participants showed clear comprehension of the CCT task and logically consistent (i.e., nonrandom) choices, developmental research indicates that the cognitive skills that may have been especially important for the cold CCT continue to become more robust through adolescence. Indeed, Dumontheil et al. (2016) recently demonstrated a reduction in complex reasoning abilities in adolescents during a peer monitoring context compared to alone. Thus, it is possible that especially during early adolescence peer monitoring disrupts the deliberative cognitive processes that the cold task draws on.

Peer effects on hot decisions. Decisions in the hot CCT rely more strongly on excitement, arousal, and "gut" instinct. We found that middle adolescents showed an uptick in risky choice when peers were monitoring choices. This finding is consistent with results from several other studies using this age range and "exciting" decision tasks (e.g., Chein et al., 2011; de Boer et al., 2016). Given that this study evaluated the specificity of peer effects in different decisional contexts, our findings suggest that for middle-to-late adolescents, excitement and arousal are key contextual components for peer effects to emerge. More generally, the within-subject comparison of hot versus cold CCT effects lends strong evidence to the notion that not all decision spaces are equivalently susceptible to peer effects, and, importantly, that peers do not always lead to increased risk taking, but often seem to reduce risk taking. Additional studies are needed, with precise decision tasks and wide age ranges, to further evaluate the interaction of age and decision type on peer influence effects.

Peer monitoring promotes less risky choices in young adults. The findings just described emphasize the *trajectory* of developmental changes in peer influence on risky decisions. That is, the effects of peer monitoring on cold and hot CCT performance indicates that under specific conditions, adolescents may show elevated risky choice behavior compared to adults. However, it is important to scrutinize the pattern of performance in the oldest participants (who serve as an "anchoring" comparison condition), because their choices became consistently and substantially *less risky* during peer monitoring. In fact, the rise in adolescents' risky choice under peer monitoring is not statistically significant on its own; the peer effects observed in younger participants were significant only insofar as they fail to exhibit the comparison pattern of *lessened* risky choice in the older participants. A similar pattern was recently documented by Haddad, Harrison, Norman, and Lau (2014), providing further support to reduced safety as a novel "route" toward adolescent peer influence. Given the complexity of these findings, it is important to infer from this study not that peers induce risky behavior in adolescents—rather, that peers under specific conditions fail to elicit safer choices during adolescence compared to young adulthood.

Why might the older participants make consistently safer choices while being monitored by peers? One possibility is to consider their shift toward safety with peers as a more optimal choice pattern. In the CCT, risky choice (taking more cards) is advantageous only to a point, and participants (on average) tend to select too many cards in both the hot and cold CCT tasks, reducing overall points earned (Figner et al., 2009). Thus, peers shifted young adults' performance toward a more optimal strategy in this decision context.

This pattern is consistent with theory and findings on social facilitation and its mechanisms. Classic work in social psychology has suggested that for certain cognitive tasks, the presence of an audience improves performance (Triplett, 1898). This has been theorized to occur via several possible mechanisms, including enhanced arousal and awareness of one's own behavior, and as a by-product of self-presentation concerns (Tennie, Frith, & Frith, 2010). It is unclear, however, whether these classic social facilitation theories that focus primarily on motor tasks apply to the decision process required to complete the CCT. Although more research is required to evaluate whether peers push adults toward more optimal (and hence, safer in this case) decisions, the present results emphasize that future research focused on adolescent peer effects should not assume that young adults exhibit no influence by peers. It is important that adults be included as a reference group to allow for clearer identification of developmental changes relative to an adult benchmark.

Mere presence of peers

We found that the mere presence condition did not yield significantly altered risky choice in either task and at any age. These findings mirror classic and more recent work demonstrating that audience effects on performance are constrained to active monitoring conditions (Cottrell, Wack, Sekerak, & Rittle, 1968; Powers et al., 2018). The present findings imply that the active monitoring by peers is a critical element of the mechanisms that, under certain circumstances, lead to enhanced risky choice with peers in adolescents more so than adults. A key difference between mere presence and active monitoring by peers is that decision makers can transmit clear messages about their risk tolerance in the monitoring condition, but not the mere presence condition. Though speculative, the specificity of peer effects to the active monitoring condition may suggest that adolescents engaged in reputation management, selectively increasing their risk tendencies when it could have a clear impact on homophily or status. It could also be that active monitoring by peers amplifies reward sensitivity (e.g., Chein et al., 2011) in a way that the mere presence of peers does not, for example, due to anticipated social benefits or shared reward processing (Fareri, Niznikiewicz, Lee, & Delgado, 2012). Future work should more directly measure the expected and actual gains in these dimensions as a result of risky choices in adolescents and comparison age groups.

Friendship quality and risk attitudes did not moderate peer effects

We acquired individual difference data from each member of the dyad to conduct exploratory analyses evaluating whether risk attitudes or friendship closeness of the dyad moderated peer effects. We did not observe significant moderation of the effects described earlier on either variable. Despite their conceptual linkage, laboratory risk-taking tasks often do not correlate with real-life measures of risk taking (e.g., Frey, Pedroni, Mata, Rieskamp, & Hertwig, 2017; Pedroni et al., 2017; Powers et al., 2018). This is perhaps not surprising given that the real-world risk taking (and attitudes toward real-life risk) is multiply determined by a host of factors including nonpsychological factors (i.e., availability of risks; culture-specific punishments).

We also did not find evidence that the difference between risk attitudes within a dyad moderated peer effects. It is crucial to consider that in this study, peers were mere observers who were not signaling their risk preferences. This study acquired data on participants' and peers' *actual* risk preferences, but did not measure the participant's *conception* of their peer's risk attitude. Indeed, recent work has demonstrated that adolescents in particular have inaccurate conceptions of their peer's risk attitudes (Powers et al., 2018). Therefore, this analysis is not a strong test of homophily mechanisms because participants could indeed be targeting homophily, but based on a skewed perception of their peer's risk attitudes. Recent work has demonstrated that when peers send a clear signal of enhanced riskiness, adolescents are more likely to shift toward a riskier decision (Knoll, Leung, Foulkes, & Blakemore, 2017). In the absence of this type of signal, adolescents may rely on their (potentially biased) conceptions of their peers' risk attitudes.

Finally, we also did not observe a significant relation between friendship closeness and susceptibility to peer effects. While some studies suggest that peer influence occurs among *less close* friends (e.g., Heilbron & Prinstein, 2008), others suggest that peer influence occurs among *more close* friends (e.g., Urberg et al., 1997) and therefore we considered analysis of friendship closeness in an exploratory fashion. The questionnaire used to assess friendship closeness (URCS; Dibble et al., 2012) specifically measured the closeness and intimacy between members of the dyad. There are other characteristics of social relationship that could have a tighter link to peer influence that are not measured here, such as friendship stability. Indeed, it has been suggested that more global perceptions of inclusion (Dishion, Capaldi, Spracklen, & Li, 1995; Prinstein & La Greca, 2004) are critical determinants of risky behavior. It will be important for future work to evaluate a broader array of peer- and dyad-relevant variables to generate stronger tests of social closeness and inclusion based moderators.

Limitations

The findings reported herein should be considered in light of their limitations. For one, we did not acquire data on participants' age-normed cognitive abilities or socioeconomic status. Although we have no reason to believe that sampling biases would have resulted in noncomparable characteristics across the measured age range, they cannot be explicitly ruled out. Second, although sampling procedures were carried out equivalently across the age range and were broadly reflective of the population in the greater Boston area, the ultimate balance of participants on race was not perfectly equivalent across age.

The preponderance of research on peer effects on adolescent decisions have used designs similar to this study, contrasting an alone condition with a peer condition (e.g., Chein et al., 2011; Gardner & Steinberg, 2005; Rosen et al., 2016). However, it is important to note that studies designed this way are not capable of disentangling effects of observers generally from effects of peers in particular. Addressing this confound would require a condition in which participants were observed by a nonpeer in order to isolate effects specific to peers from observers in general. Prior work has demonstrated that adolescent peer influence effects on nonrisky decision making is constrained to peer observers in particular (Wolf, Bazargani, Kilford, Dumontheil, & Blakemore, 2015), somewhat mitigating this concern. However, more work is needed to strengthen the inference that peers hold a special role in shaping adolescent risky behavior.

The hot and cold CCT versions do not differ only on the dimension how strongly they involve deliberative versus affective decision-making processes. For example, only in the hot, but not the cold CCT, participants have the opportunity to learn from positive and/or negative feedback and thus may adjust their risk-taking levels accordingly. Figner et al. (2009) empirically addressed this possibility, concluding that learning is unlikely to be responsible for generating key differences between the hot and cold CCTs. Nevertheless, it would be interesting and relevant for future research to investigate whether and how much these differences between the CCT versions contribute to the emergence of age-specific patterns in risk taking and information use and how these factors intersect with peer effects.

Finally, we note that although the age range of study (13–25) is broader than many studies, it does not necessarily capture the poles of adolescent development (Somerville, 2016). Because developmental changes in peer effects within preadolescent and emerging adult stages are also important to characterize, this study should not be considered as comprehensive in characterizing the full scope of peer influence effects from childhood to adulthood.

Conclusions

This study broadened the range of decision types and peer configurations to identify potential boundary effects constraining peer influence on adolescent decision making. We observed a general pattern of *lessened* risk taking under peer monitoring, an effect that reversed to increased risk taking in young adolescents in deliberation-based decisions, and in middle-late adolescents in emotion-based decisions. These subtle peer influence effects are more complex and specific than expected based on previous work demonstrating heightened risk taking in adolescence while monitored by peers. Moreover, we tested whether the mere presence of a peer in the same room was sufficient to evoke peer effects on risky behavior, which the data did not unequivocally support. These results suggest that peer effects on adolescent risk taking are not ubiquitous. Rather, several important decisional and social factors increase, decrease, or even reverse the direction of the impact of peers on adolescent risk taking. With future work, we will advance toward identifying the key "ingredients" that characterize the unique effects of peers on adolescent decisions.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Figure S1. Dyadic Interaction

Figure S2. Peer Monitoring × Gain Amount × Linear Age Interaction

Table S1. Demographic Makeup and Counterbalancing Validation of Final Sample

Table S2. Counterbalancing Orders

Table S3. Full Results of Omnibus Model

Table S4. Frequentist Tests Between Age and Basic Task Conditions

Table S5. Full Results of Follow-Up Models

Table S6. Results of Dyadic Moderation Model

Appendix S1. Index of Missing Data

Appendix S2. Dyad Variables: Descriptive Data

Appendix S3. Dyad Model Specification