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Risk Contagion by Peers Affects Learning and Decision-Making in Adolescents

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Adolescence is a period of life in which social influences—particularly if they come from peers—play a critical role in shaping learning and decision preferences. Recent studies in adults show evidence of a risk contagion effect; that is, individual risk preferences are modulated by observing and learning from others' risk-related decisions. In this study, using choice data and computational modeling, we demonstrate stronger risk contagion in male adolescents when observing peers compared to nonpeers. This effect was only present when the observed peer showed risk-seeking preferences. Moreover, adolescents represented the peers' decisions better than those of adults. Intriguingly, the degree of peer-biased risk contagion in adolescents was positively associated with real-life social integration. Contrary to previous accounts, our data suggest that peer conformity during risky decision-making in adolescence is a socially motivated, deliberative process. Susceptibility to peer influence in adolescence might be adaptive, associated with higher degrees of social functioning.

Keywords: adolescent development, observational learning, risk preference, social cognition, conformity

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Adolescence is a key period of social development across species (Blakemore & Mills, 2014). Teenagers face a marked change in social orientation: they spend an increasing amount of their time with peers of the same age and less time with their parents (Nelson, Jarcho, & Guyer, 2016). Results from animal and human studies suggest that social interactions might have a higher subjective value for adolescents than for adults (Foulkes & Blakemore, 2016). Relatedly, adolescence has been shown to be a period of enhanced susceptibility to social influence (Costanzo & Shaw, 1966; Knoll, Leung, Foulkes, & Blakemore, 2017; Knoll, Magis-Weinberg, Speekenbrink, & Blakemore, 2015).

In addition, adolescence has been associated with enhanced risk-taking behavior. Teenagers are more likely to engage in binge drinking, unprotected sexual behavior, or dangerous driving than adults (Steinberg, 2008; Steketee, Jonkman, Berten, & Vettenburg, 2013; Windle et al., 2008). However, results from laboratory

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experiments using behavioral paradigms to elicit risk preferences have been mixed (Tymula et al., 2012; see Defoe, Dubas, Figner, & van Aken, 2015, for a meta-analysis). Risk-taking behaviors observed in epidemiological research (substance abuse, drunk driving) most often occur in a social context. In contrast, in a laboratory setting, participants are often tested individually, and it is possible that elicited risk preferences in adolescents change as a function of social influences and are learned through peer observations. Indeed, it has been shown that adolescents smoke more and drink more alcohol in the presence of peers, and that having friends who smoke and drink is a predictor of their own substance use (Loke & Mak, 2013; Lundborg, 2006; Tsakpinoglou & Poulin, 2017). Furthermore, in laboratory settings, it has been demonstrated that adolescents engage in more risky behaviors when with peers compared to when they are alone (Albert & Steinberg, 2011; Blankenstein, Crone, van den Bos, & van Duijvenvoorde, 2016; Gardner & Steinberg, 2005), an effect that is abolished by the presence of an adult (Silva, Chein, & Steinberg, 2016). Such specific susceptibility to peer influence has traditionally been interpreted in terms of an imbalance between an overactive impulsive, socioemotional decision-making system, and a still maturing deliberate cognitive control system (Albert, Chein, & Steinberg, 2013; Dreyfuss et al., 2014; Steinberg, 2010).

These prior studies focused on effects of the mere presence of other peers. More recent studies have concentrated on disentangling the contextual factors that influence whether and how peer presence influences decision making (Somerville et al., 2018). However, it is plausible that teens are not just sensitive to the mere presence of peers, but might use them as a source of information and change their own behavior through peer-to-peer observations. Recent work suggests that adolescents are most strongly influenced by other adolescents' opinions when judging the potential risks of a situation and that stereotypes about the social-influence group—"risk-seeking teens"—might interact with social influence on risk perception (Knoll et al., 2015, 2017). However, those studies focused on risk ratings, and it remains to be determined whether and how such peer influences also have an impact on decision-making behavior and learning in teenagers.

To this end, in the current study, we investigate two main research questions: (i) whether observing peers' risky choices becomes behaviorally relevant during decision making and (ii) whether peer influences differentially affect risk preferences and learning in adolescents compared to adults. More specifically, we ask whether potential effects of risk contagion—namely, individuals adopting risk preferences of others—are modulated by the nature of the observed risk preference (risk seeking vs. risk averse) and the age of the social interaction partners. Furthermore, we investigate whether risk contagion in teenagers relates to real-life social and impulsive behavior. To address these research questions, we use a social risk-taking and learning paradigm (see Figure 1) that has been recently applied to study how the observation of others' risky decision behavior affects one's own risk preferences (Suzuki, Jensen, Bossaerts, & O'Doherty, 2016). In this study, we focus on early adolescents (12–15 years old) in comparison with a young adult (20–33 years) sample. To avoid potential confounds of gender differences in pubertal trajectories and their effects on baseline risk preferences (Byrnes, Miller, & Schafer, 1999), we restricted the study sample to male participants.

Based on the demonstration of a risk contagion effect in young adults and the aforementioned findings of social influences on risk preferences in adolescents, we hypothesize that adolescents show greater risk contagion effects after observing risky choice behavior in peers of the same age compared to adults.

Method

Sample

A recent meta-analysis (Defoe et al., 2015) suggested a medium-sized effect of adolescent development on risk-taking measures. Fifty-two young adolescents and 51 young adults were recruited via the TU Dresden Life Span Developmental Neuroscience participant database. A priori exclusion criteria comprised failure to show up for both testing days, human or technical errors during data acquisition, and current diagnosis of a psychiatric condition, as well as missing data $> 50\%$ in any of the subsessions of the experiment. The final sample included $n = 40$ young male adolescents between 12 and 15 years (median age $= 13$) and $n = 46$ young male adults between 20 and 33 (median age $= 26$). Data acquisition was restricted to male participants due to differential pubertal developmental trajectories in female and male adolescents and evidence for baseline gender differences in risk preferences (Byrnes et al., 1999). Self-assessment of pubertal status via the Pubertal Development Scale (Petersen, Crockett, Richards, & Boxer, 1988) indicated that adolescents were in a pre- to late-pubertal state (range: 3–10, median $= 5.5$). In between the two testing days, participants completed the following trait questionnaires at home: the Barrat Impulsiveness Scale (Patton, Stanford, & Barratt 1995), Behavior Inhibition and Behavioral Activation (Strobel, Beauducel, Debener, & Brocke, 2001), Social Network Size (Roberts, Wilson, Fedurek, & Dunbar, 2008), and the Social Phobia and Social Anxiety Inventory (Fydrich, 2002; Turner, Beidel, Dancu, & Stanley, 1989). Participants provided written informed consent. In the case of adolescents, this was additionally provided by their parents. Subjects were compensated with €50 for both testing days and were told that they could win extra money in the experiment. The study was approved by the TU Dresden Ethics Committee.

Procedure

Subjects attended the lab twice, with approximately 10 days ($M = 12.19$, $SD = 5.60$) in between testing days. They underwent the same standardized procedure—consisting of four subsessions (see Figure 1b)—twice, once interacting with a teenage counterpart, once interacting with an adult observee (see Figure 1). More specifically, participants were invited to two group testing days, one of them was a same age session (with participants of their own age group), whereas the other one was a mixed age session (with participants of both age groups). In either case, participants met each other shortly before the testing session and were told that they would interact with each other. Credibility of the cover story was further enhanced by using photos of the participants whom they had just met prior to the testing session in the experiment. The actual experiment was carried out in an individualized setting to prevent influences resulting from the mere presence of peers (Gardner & Steinberg, 2005). All participants received prior stan-

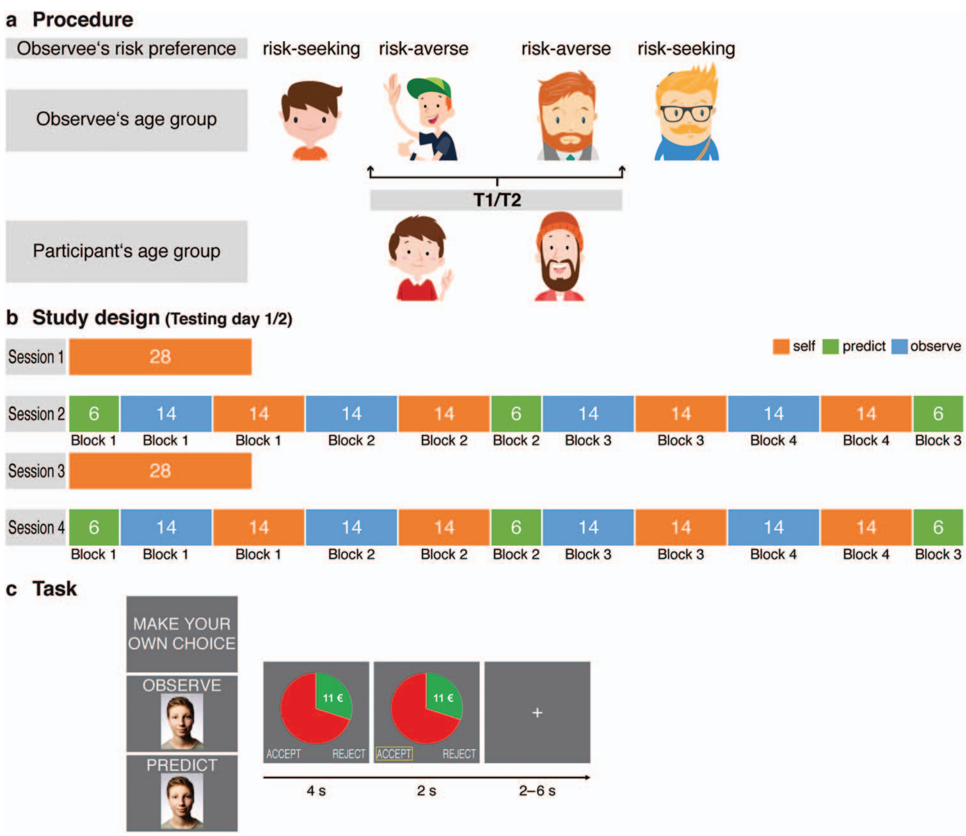

Figure 1. Study design, procedure and task. (a) Study procedure. Young adults and teenagers were invited to two testing days, respectively. On one of the two testing days, participants interacted with two teenage counterparts; on the other testing day, they observed two adult counterparts ("observee"). On each testing day, one of the observees behaved in a risk-averse manner, whereas the other observee behaved in a risk-seeking manner. Order of conditions were counterbalanced across participants. (b) Study design. On each of the two testing days, participants performed four sessions, in which the three trial types (self, observe, predict) were presented in a fixed, block-wise manner: Sessions 2 and 4 involved all three trial types. Sessions 1 and 3 included only "self" trials. Numbers indicate the number of trials per block. Note that for calculating the measure of risk preference (both model-free and model-based measure) in Sessions 2 and 4, choices of all self trials of all three blocks were aggregated. (c) Task. In "self" trials, participants had to decide whether to gamble with the depicted reward probability and reward value or to opt for a safe bet (€5). In "observe" trials, participants observed a confederate ("observee") making choices on the risk-taking paradigm and pressed a button to indicate that they had seen the observee's choice. Depending on the condition, the observee showed risk-seeking or risk-averse behavior (cf. panel a). In "predict" trials, participants had to predict the observee's choices. Cartoons in Figure 1a designed by Freepik and Vecteezy/Freepik. See the online article for the color version of this figure.

dardized instructions about the task and the theoretical concept of pie chart distributions.

Task

The task was administered in the same manner as reported previously (Suzuki et al., 2016). It consisted of repeated mini blocks of three different trial types: (1) self trials in which participants had to accept or reject a monetary gamble, (2) observe trials in which participants had to observe the risk-taking behavior of another individual, and (3) predict trials in which participants had to predict the choices that the observee would make (see Figure 1b). Each of the trial types involved the same basic risky decision-making paradigm (Figure 1c). In this paradigm, participants had to choose between a safe bet (guaranteed €5) and a risky gamble in each trial. The probability of winning the gamble was indicated by a pie chart. In self trials, participants had to choose between the risky gamble ("accept") and the safe bet ("reject") themselves. In observe trials, subjects observed decisions of confederates in the same task. In predict trials, subjects predicted the confederates' decisions in this task. See the online supplemental materials for more information on reward probability and magnitude distributions as well as the payout procedure. See Figure 1a and b for details on the experimental procedure and design. The confederate ("observee") for observe/predict trials differed between Sessions 2 and 4, and was indicated to the participants by the presentation of different photos at the beginning of the session. This allowed us to manipulate the risk preference of the observee: In Session 2, the observee was risk-averse, in session 4, participants observed a risk-seeking counterpart, or vice versa (counterbalanced across participants; see Figure 1a). We instructed participants that the choices they observed were made by one of the other participants they had met at the beginning of the testing session. To support the cover story, a photo of the randomly assigned person appeared at the beginning of each observe/predict block. However, the observees' choices were predefined, as in previous studies (Figure S-1 in the supplemental materials depicts the set of choices shown).

Statistical Analyses

Data were analyzed using MATLAB (2017; The Mathworks, Natick, MA) and R (R Development Core Team, 2008). Two different measures of risk preference were calculated. As a model-free measure, we define participants' risk preferences as the proportion of gambles accepted relative to the (hypothetical) proportion accepted by a risk-neutral agent (Suzuki et al., 2016). Note that the risk-neutral, "optimal" agent chooses to gamble based on comparing the expected value of the gamble (probability of reward by magnitude of reward) with the value of the sure option (€5). The agent accepts gambles that have a higher expected value than the sure option. Thus, positive values in individuals' risk preferences indicate a risk-seeking preference, whereas negative values indicate a risk-averse preference. As a model-based measure of risk preference, we fitted a mean-variance utility function commonly used in behavioral economics and psychology (e.g., d'Acremont & Bossaerts, 2008) to our participants' choices to derive the risk preference parameter α. See the online supplemental materials for details on the mean-variance utility algorithm and the model fitting procedure including a priori simulations. Baseline risk preference was defined based on choice behavior displayed in the first session, before any observed behavior could have influenced preferences. Baseline risk preferences were positively correlated across the first and second test session ($r = .67$, $p < .001$). Our main outcome variable of interest was the risk contagion effect, namely the change in risk preference induced by the observation of the confederate. This was calculated as a difference score between participants' risk preference in the self trials pre- and post-observation (Δ risk preference, i.e., risk preference in Session 1 or 3 minus risk preference in all self blocks of Session 2 or 4 averaged). The degree of contagion was defined as positive when the participant conformed to the observee (Suzuki et al., 2016). We used linear mixed effects models (*lme4* package in R (Bates, Mächler, Bolker, & Walker, 2014; R Development Core Team, 2008) to investigate the effect of the following predictors on the respective degrees of risk contagion: own age group, age group of the observee, risk preference of the observee (risk seeking vs. risk averse) allowing for interactions among all predictor variables. Session number as well as its interaction with the observee's risk preference were included as nuisance regressors. This was done to be able to control for potential order effects of the observee's risk preference. We included subject-specific intercepts and slopes for the within-subject factors age group of the observee and risk preference of the observee (risk seeking vs. risk averse). In a next step, we were interested in potential effects of participants' own baseline risk preference and its interaction with our predictors of interest on risk contagion. Therefore, we included risk preference measured in the first run of self trials in the above-described model. Effects on changes in median reaction times (RTs) pre- versus post-observation were tested using the same model. Reaction times were analyzed for responses given on the self trials. For the RTs analysis, all trials with an RT < 500 ms were removed (mean removed trials averaged over all sessions = 3.21, SD = 5.33). Furthermore, we were interested in age differences in the ability to predict choices of risk-seeking versus risk-averse counterparts. Prediction accuracy was calculated by generating choices of a risk-seeking versus a risk-averse agent using a mean variance utility function (see online supplemental materials: Supplemental Methods, Computational Modeling of Risk Preferences). Choices of the risk-averse agent were simulated using a negative value for the risk preference parameter α; choices of the risk-seeking agent were modeled using a positive risk preference parameter α. Accuracy in the predict trials was coded as true when the participant's prediction corresponded with the simulated choice, and as false when it deviated from it. For statistical analysis, we then used a logistic hierarchical mixed model to explain the accuracy (true vs. false) of the participants' trial-by-trial predictions. The following fixed effects variables were included: own age group, observee's age group, observee's risk preference, and block (1st, 2nd, 3rd *predict* block of the second or fourth session, respectively; see Figure 1b). Session and the interaction of session and obervee's risk preference were again included as nuisance regressors in order to account for order effects. Subject-specific and block-specific intercepts and slopes for the within-subject factors were included as random effects. To obtain p values, degrees of freedom were approximated using Satterthwaite approximation as implemented in the R package *lmerTest* (Kuznetsova, Brockhoff, & Christensen, 2015) for linear regression. A Wald chi-square test, as implemented in the R package *car* (Fox et al., 2017), was applied for logistic regression (*predict* trials). *lsmeans* (Lenth, 2016) was used to perform planned post hoc contrasts on marginal means. Finally, we aimed to analyze correlations of behavioral measures in the task with real-life behaviors. In order to circumvent problems with multiple testing, we calculated composite measures of two constructs, namely impulsivity and social integration. For the factor impulsivity we aggregated z-values of the mean score on the Barrett Impulsiveness Scale (Patton, Stanford, & Barratt, 1995) and of the overall Behavioral Activation score (Strobel et al., 2001; comprising the subscores Fun Seeking, Drive and Reward Sensitivity). As a proxy for inner social network size (Roberts et al., 2008), participants were asked to list all individuals they were in direct private contact with (personal encounters, phone calls, texting, emails, letters, messenger) during the last week. The number of listed individuals has been shown to correspond to an individual's support clique (Dunbar & Spoors, 1995; Roberts et al., 2008). Z-Scores of the inner network size were aggregated with z-scores of the social phobia and anxiety inventory (SPAI; Fydrich, 2002; Turner et al., 1989) to build the composite factor social integration. Note that SPAI z-scores were reversed before aggregating, such that high values on the social integration factor correspond to a high degree of real-life social connectedness and integration. Outliers (± 2 SD, $n = 2$) were removed before correlations were computed.

Results

First, we compared baseline risk preference (i.e., risk preference in the first session, prior to the exposure to social influences; see Figure 1) between the two age groups. Both groups showed risk aversive behavior at baseline (Figure S-2). We observed that teenagers were more risk averse than adults (two-sample *t* test, $t = 3.88$, $p < .001$; Figure S-2), an effect that replicates previous findings (Tymula et al., 2012). Other than the raw choice data (model-free measure), we also used a mean-variance model to analyze the data (model-based measure, see Methods and online supplemental materials).

Across groups, we found a significant effect of risk contagion: In both age groups, risk preferences shifted toward the observee's risk preference as shown by significantly positive difference values of data from the pre- versus post-observation session (one-sample *t* test against zero, $t = 8.70$ $p < .001$; Figure S-3). Follow-up analyses showed that the risk contagion effect was significant within each age group ($m_{teens} = .042$ ($\pm .091$), $t_{teens} = 5.91$, $p < .001$, $m_{adults} = .030$ ($\pm .061$), $t_{adults} = 6.71$, $p < .001$) as well as when conditions with risk-seeking and -averse observees were considered separately ($m_{risk\text{-}seeking} = .037$ ($\pm .087$), $t_{risk\text{-}seeking} = 5.64$, $p < .001$, $m_{risk\text{-}averse} = .034$ ($\pm .064$), $t_{risk\text{-}averse} = 6.98$, $p < .001$). The risk contagion effect was also present when looking at the model-based measure of risk preference, α (one-sample *t* test against zero; $m_{entire\ sample} = .002$ ($\pm .007$), $t_{entire\ sample} = 5.75$, $p < .001$, $m_{teens} = .002$ ($\pm .008$), $t_{teens} = 2.91$, $p = .004$, $m_{adults} = .002$ ($\pm .005$), $t_{adults} = 5.90$, $p < .001$). Thus, our results replicate previous findings in younger adults (Chung, Christopoulos, King-Casas, Ball, & Chiu, 2015; Suzuki et al., 2016) and show a risk contagion effect in both age groups. As shown in Figure S-3, both adolescents and younger adults adapt their decision behavior after having observed another person's risk preference.

In a next analysis step, we asked whether the risk contagion differs as a function of one's own age group, observee's age group, and risk preference of the observee. Consistent with our hypothesis, we observed a significant three-way interaction effect of age group (teen vs. adult) × observee's age group (teen vs. adult) × observee's risk preference (risk seeking vs. averse) on risk contagion ($F = 5.82$, $p = .017$). Separate analyses for the factor observee's risk preference showed a significant two-way interaction between one's own and observee's age groups for risk-seeking confederates ($F = 4.37$ $p = .038$), but not for risk-averse confederates ($F = .18$, $p = .68$). As Figure 2a depicts, this was due to peer effects on the degree of risk contagion specifically in the risk-seeking observee condition in adolescents: Adolescents showed significantly more risk contagion after observing a risk-seeking teen than a risk-seeking adult ($t = 2.20$, $p = .033$). This peer effect was significantly stronger in the risk-seeking than in the risk-averse observee condition ($t = 2.58$, $p = .011$). Relative to adults, teens showed more risk contagion after observing risk-seeking teens ($t = 2.83$, $p = .006$), whereas risk contagion did not differ between the age groups after observing a risk-seeking adult. These peer effects were not apparent in the risk-averse observee condition (all *t*s $< .287$, all *p*s $> .774$). In sum, we found specific peer effects on risk contagion in adolescents after the observation of a risk-seeking teenager.

Furthermore, we were interested in whether the observed effects were related to participants' own risk preference at baseline. Thus, we included risk preference in the first session, before observing any partner, into the mixed model. The crucial three-way interaction of one's own Age group × Observee's age × Observee's risk preference reported above remained significant ($F = 11.12$, $p = .001$, Table S-3). Furthermore, we did not observe a significant association of the peer effect in the risk-seeking condition with own baseline risk preference in adolescents ($r = -.149$ $p = .359$, Table S-4). This indicates that teenagers' risk contagion effect

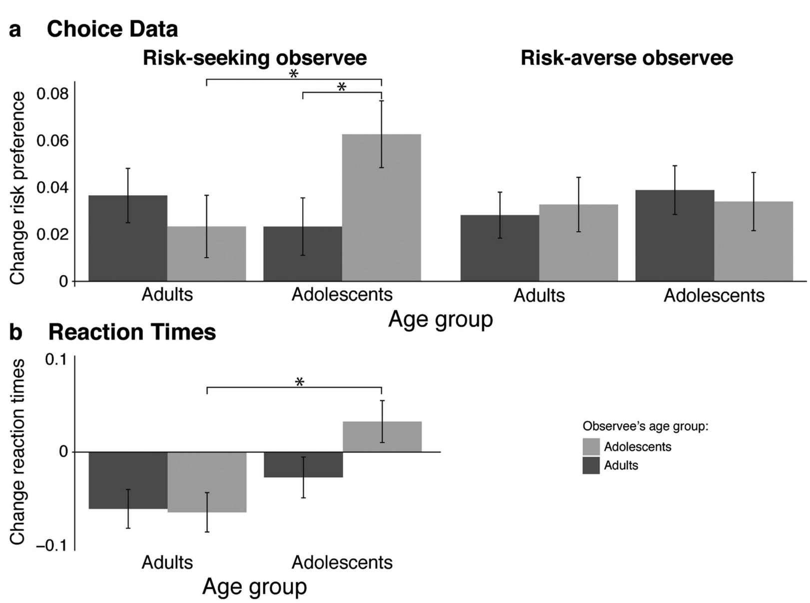

Figure 2. Effects of risk contagion. (a) Degree of risk contagion as a function of one's own age group, observee's age group, and observee's risk preference. (b) Changes in RT (post- minus pre-observation). Young adults did not differ in their RTs as a function of the observee's age group. Teenagers showed a difference in RTs depending on the observee's age group: Teenagers were slower when making their decisions after the teenager observee condition compared to after the adult observee condition. We plot adjusted means and standard error of the mean (*SEM*) (*lsmeans* package in R). * $p < .05$.

after observing risk-seeking peers may be independent of baseline risk preferences. Interactions of risk contagion with baseline risk preference were however present in other conditions (see supplemental materials and Tables S-3 and S-4 for details and the complete output of the model). Peer effects in the risk-seeking observee condition were replicated in the model-based measure of risk-taking, α, derived from computational modeling, based on a mean-variance utility function (see online supplemental materials for details).

We also analyzed age and peer effects on RTs in the self trials (post- vs. pre-observation), as a proxy of deliberative vs. impulsive decision making. We repeated the same mixed model that had been used to predict changes in choice behavior to predict changes in median RT. We found a main effect of participants' age group ($F = 4.71$, $p = .032$) as well as a significant interaction of participants' age group with the age group of the observee ($F = 4.10$, $p = .045$; see Figure 2b and Table S-5 for full output of the model). Post hoc contrasts revealed slower RTs in teenagers after observing other teenagers as compared to adults ($t = 3.15$, $p = .002$). No such own age effect was found in adults ($t = 1.15$, $p = .253$). These results may suggest that adolescents deliberate more after observing risk preferences of their peers compared to adults.

In the next analysis step, we were interested in how successfully participants learned to predict the observee's risk preferences in the predict trials. A mixed model analysis of participants' trial-by-trial predictions revealed a significant effect of the factor block ($\chi^2 = 998.78$, $p < .001$; Figure 3a), indicating that participants learned about the observee's risk preference over the course of the experiment. The main effect of the observee's risk preference was significant ($\chi^2 = 4.80$, $p = .029$); participants learned to predict risk-seeking preferences more accurately. Furthermore, we observed a significant effect of age group ($\chi^2 = 16.96$, $p < .001$) and an interaction of the factors own age and block ($\chi^2 = 103.59$, $p < .001$). See Table S-6 for results of the full model. Separate post hoc analyses for each of the blocks showed a higher accuracy in predicting the observee's risk preferences in adults compared to adolescents in in the second ($z = 7.37$, $p < .001$; Odds Ratio 3.66) and the third block ($z = 7.37$, $p < .001$, Odds Ratio 4.25). Most interestingly, we also found a significant interaction of the factors block, own age, and observee's age on prediction accuracy ($\chi^2 = 9.47$, $p = .009$). Separate analyses for each block showed a significant effect of the observee's age group in adolescents in the third block ($z = 3.79$, $p < .001$). No such effect was observed in adults ($z = 1.18$, $p = .24$). As shown in Figure 3a, these results suggest that adolescents learned more effectively when the observee was a peer as compared to an adult.

The observee's risk preference also had an impact on prediction accuracy ($\chi^2 = 4.80$, $p = .028$), and an interaction of observee's age group, observee's risk preference, and block was observed ($\chi^2 = 7.84$, $p = .02$). Post hoc contrasts revealed that this was due to a significantly better prediction of a risk-seeking teenage observee's behavior in the last block ($z = 2.12$, $p = .03$; see online supplemental materials). There was no age-related difference in the first blocks nor in the risk-averse observee condition (all $zs < 1$, all $ps > .58$). This might indicate that teenagers' choices are more readily associated with more risk-seeking attitudes.

In the next analysis step, we aimed to establish whether the ability to learn about the intentions of others is associated with the degree of risk contagion. Therefore, we included individual risk contagion scores (Δ risk preference) in the above-described logistic model on accuracy in the predict trials, collapsing across observee's risk preferences. This analysis revealed a significant association of prediction accuracy and risk contagion ($\chi^2 = 6.05$, $p = .01$). Most interestingly, we also observed a significant three-way interaction of own age group, observee's age group, and the risk contagion score ($\chi^2 = 18.00$, $p < .001$; for the output of the full model, please refer to the supplemental results, Table S-7). As post hoc tests, we compared the slopes of the regression function using the function *lstrends* in R package *lsmeans* (Lenth, 2016). We found that the association of accuracy in the predict trials and risk contagion was positive when teenagers interacted with teens (see Figure 3b). That is, teenagers who are better at learning to predict the behavior of other teenagers conform more with them. On the contrary, when teenagers interacted with adults, the asso-

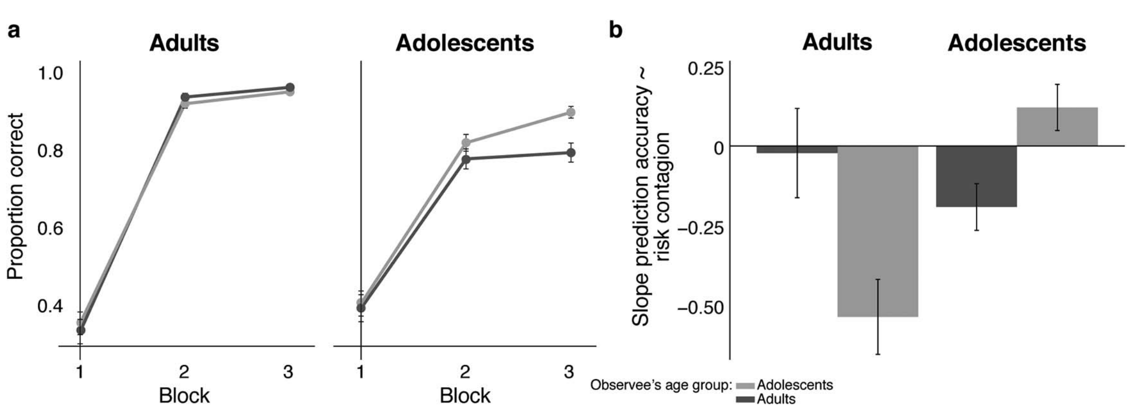

Figure 3. (a) Performance in the predict trials. The observee's age group had an effect on overall prediction accuracy in teenagers, but not in young adults. Teenagers learned to predict other teenager's choices more effectively than adults' behavior. (b) Slopes of the regression function, predicting performance in the predict trials by the risk contagion effect. Teenagers who learned well to predict other teenagers' behavior showed a stronger risk contagion effect with them. Teenagers who learnt well to predict adults' behavior showed less risk contagion with adults.

ciation was negative (Figure 3b) and significantly different from the teenage observee condition (z = 3.05, p = .002). Thus, teenagers who learn about adults' choices well conform less with them. Young adults showed a more negative relationship of prediction accuracy with risk contagion when interacting with a teenager as compared to an adult (z = 2.81, p = .005). To summarize, the association of learning about others' behavior with conformity depends both on one's own age as well as the other's age.

In a last but important analysis step, we asked whether adolescents' peer effects in risk contagion were associated with real-life behaviors. Thus, based on the predicted values of our model, we calculated a peer-bias score in the risk-seeking observee condition (that is, the difference in risk contagion after observing a teenager minus risk contagion after observing an adult). We correlated these with the composite scores of social integration and impulsivity as derived from questionnaire measures (see Methods), respectively. We found a positive correlation of the peer bias in risk contagion with social integration, a factor comprising both low social anxiety and high social network size (r = .44, p = .012; see Figure 4). The peer-biased contagion effect was however not significantly associated with the impulsivity measure (r = −.052, p = .76). In adults, no significant correlations with trait measures were observed (rs ≤ |.26|, ps ≥ .1). Together, this speaks against the notion that the peer effect in risk contagion is associated with impulsivity. Instead, risk contagion by peers might be an adaptive process in adolescents, associated with higher degrees of sociability.

Discussion

The present study examined whether the observation of risky decision-making behavior in peers versus nonpeers differentially affects risk preferences and learning in adolescents as compared to adults. At baseline, young adolescents were more risk averse than young adults. Consistent with our predictions, we observed a stronger risk contagion effect in teenagers after they had observed their own peers. Moreover, this effect was only present when the observed peer showed risk-seeking behavior, but not when he showed risk-averse preferences. Interestingly, the peer versus nonpeer manipulation not only affected risk preferences in teenagers but also had an impact on social learning: Adolescents were better at learning to predict the preferences of their own peers compared to nonpeers, whereas no such effect was present in adults.

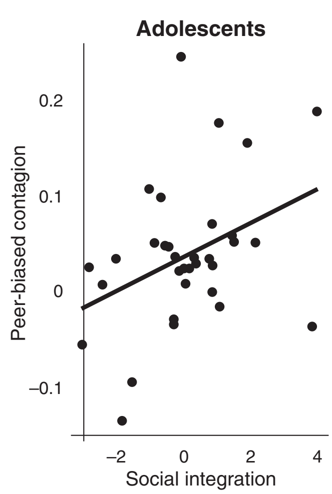

Figure 4. Association of peer-biased risk contagion (risk-seeking observee condition) with real-life social integration in adolescents. Adolescents who had a higher score on a factor comprising low social anxiety and high social network sizes showed a stronger peer effect in the risk-seeking observee condition.

Our findings replicate previous results in an adult sample (Suzuki et al., 2016), showing that risk preferences can be systematically changed by observing and learning from others' risk-taking behavior. Going beyond these findings, we show that the degree of risk contagion is stronger during adolescence, a developmental period characterized by substantial social–affective transformations (Crone & Dahl, 2012). Notably, our results indicate that teenagers and adults do not differ per se with regard to how much their own risk-taking behavior was influenced by the observation of another person. Instead, we demonstrate that risk contagion in adolescents is specific for interacting with risk-seeking peers. This resonates with previous research on risk judgments indicating that young teenagers tend to adjust their risk assessments more after observing the assessment of other teenagers as compared to adults (Knoll et al., 2015). Moreover, a recent study suggested that teenagers were more strongly influenced by other teenagers only when other teenagers rated a situation as more risky, an observation that the authors interpret in terms of a stereotype effect (Knoll et al., 2017). The question of how the evaluation of riskiness (and peer conformity therein) is related to the risk contagion effect, is an interesting venue for future studies.

One interpretation of our risk contagion effect could be that the presence of peers primes a reward sensitive motivational state that increases the likelihood of risky behavior in teenagers. In fact, peer effects on adolescents' decision-making have previously been associated with an impulsive, reactive decision-making system (Albert et al., 2013; Dreyfuss et al., 2014; Steinberg, 2010). In line with this, neuroimaging studies suggest that risk taking and peer influence in adolescents are associated with enhanced activity in reward-related areas such as the ventral striatum (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Galvan, Hare, Voss, Glover, & Casey, 2007; Steinberg, 2007). The results of our RT analysis speak against this notion (compare also Van Hoorn, Crone, & Van Leijenhorst, 2017). We show that adolescents take more time when making choices after observing peers compared to adults, which is inconsistent with an impulsive response to risky peer behavior. Moreover, we did not find evidence for an association of peer-induced risk contagion with trait impulsivity in adolescents. Rather, peer-biased risk contagion was positively correlated with social integration. Thus, our data speak in favor of a socially motivated, deliberative process underlying risk contagion in teenagers. Consistent with this idea, in young adults, the risk contagion effect was shown to modulate the neural representation of risk in the caudate through connectivity with the dlPFC, a region specifically implicated in deliberative, goal-directed choice and action planning (Suzuki et al., 2016). Interestingly, the observed peer-biased contagion effect in adolescents was associated with higher levels of a social integration score describing social network size and low social anxiety. While we cannot infer causal directionality from this correlation, it can be speculated that susceptibility to peer influence when making decisions in this task might be an adaptive process, associated with higher degrees of social connectedness and integration. The latter are both key requirements of successful adolescent development, whereas high degrees of social anxiety during adolescence have been shown to be predictors of subsequent psychopathology in a longitudinal study (Stein et al., 2001).

Why are adolescents specifically influenced by risk-seeking peers? This might be explained by common beliefs about adolescents being more risk prone (Buchanan & Holmbeck, 1998), causing conformity in this direction. In fact, the results from trials in which subjects had to predict the observee's choices point to such a stereotype about adolescents: Both age groups predicted risk-seeking choices in adolescents more accurately than risk-averse choices. In line with such a stereotype effect, adolescents have been shown to overrate the likelihood of risky behavior in popular peers. The extent of such misperception predicted future substance consumption, pointing toward a link between risk (mis-)perception and risk contagion (Helms et al., 2014). An alternative interpretation could be that risk contagion is strongest under conditions in which observed behavior deviates most from teenagers' own baseline behavior. Indeed, at baseline, teenagers were more risk averse than adults and showed strongest contagion effects in the risk-seeking peer condition. Such a "conflict"-induced change of preferences would be consistent with the observed RT effects pointing to a deliberate adjustment of choice behavior toward the preferences of others in teenagers. Speaking against this interpretation, however, is that initial risk preferences were not associated with the shift in preferences in the risk-seeking peer condition and that peer effects in the risk-seeking condition were still present in an analysis where we adjusted for baseline risk preference.

At first glance, the pronounced risk-averse preferences in teenagers might seem surprising given several findings that point in the opposite direction (Braams, van Duijvenvoorde, Peper, & Crone, 2015; Chein et al., 2011; van Duijvenvoorde et al., 2015) and given the prevalent stereotypes (Helms et al., 2014; Knoll et al., 2017). However, our result replicates previous findings using a similar paradigm (Defoe et al., 2015; Tymula et al., 2012). According to a recent meta-analysis, age differences in risk preferences might be dependent on the task used to measure risky behavior. For instance, adolescents have been shown to be more risk-seeking than other age groups in tasks where immediate feedback is provided (Defoe et al., 2015). Here, we explicitly chose a task without immediate feedback to rule out any effect of learning from reward feedback (Suzuki et al., 2016). Apart from the discrepancies related to the use of different paradigms across studies, it is also conceivable that the observed shift in baseline risk preferences might be due to differences in the relative subjective value of the monetary incentives. For instance, the sure option of €5 used in our study might count more for a teenager than for a young adult, which may lead to more risk-averse behavior. Finally, it has been argued that clinically significant real-life risk-seeking behaviors like substance abuse are less present in neuro-typical adolescents than in clinical populations (Bjork & Pardini, 2015). In the current study, we had carefully screened participants before inclusion and excluded teens with any indication of a past or present psychiatric condition. All in all, this discussion strongly supports the recent call for more attempts to characterize individual differences in adolescent development to gain a more nuanced understanding of neurocognitive changes during adolescence (Foulkes & Blakemore, 2018).

Interestingly, the observation of risky choice in peers not only influences risk preferences in teenagers but also has an effect on learning others' risk preferences (for similar findings of peer presence on feedback learning, see Silva, Shulman, Chein, & Steinberg, 2016). Results of our predict trials demonstrate that adolescents learn about their peers' risk preference more effectively than about adults' risk preference. Moreover, we found an association of performance in the predict trials with the risk contagion effect. How well teenagers learned about the choices of other teenagers was positively associated with the peer contagion effect. On the contrary, a more accurate representation of adults' behavior was associated with less contagion in teenagers after having observed an adult. Taken together, these findings could be interpreted in terms of a greater motivational relevance of observing peer behavior, which leads to a more accurate representation of the observee's behavior in the predict trials, a stronger wish to conform, and eventually to a stronger contagion effect in the self trials. Certainly, it has been argued that heightened peer influence might be grounded motivationally, namely in adolescents being particularly sensitive to peer rejection (Buchanan & Holmbeck, 1998; Rodman, Powers, & Somerville, 2017; Sebastian, Viding, Williams, & Blakemore, 2010; Somerville, 2013) or social acceptance (Chung et al., 2015). Our study design might have fostered such motivational schemes, as participants met each other personally and were also made to believe that their own choices were shown to, and thus could be directly observed by, the other participants. This is important in light of a recent study showing that peer presence alone might not be sufficient to trigger conformity in teenagers (Somerville et al., 2018). On a more general level, our findings are in line with an emerging literature pointing to substantial developmental differences in social influences on learning (Bolenz, Reiter, & Eppinger, 2017; Rodriguez Buritica, Eppinger, Schuck, Heekeren, & Li, 2016).

A potential limitation of the current study is that we deliberately restricted our sample to male participants. This was done to avoid the confounding influence of baseline differences in risk-taking that might result from different pubertal trajectories in boys and girls. Moreover, the adolescent group in this study consisted of early adolescents and young adults. Risk taking and peer effects have both been shown to change over the course of adolescence as well as during adulthood (Gardner & Steinberg, 2005; Knoll et al., 2015), and one previous study indicated that peer-biased conformity might be specific to early adolescents (Knoll et al., 2015). Whether and how the presented findings generalize needs to be evaluated in future studies, including life span samples of both sexes. Given that measures of risk preference depend on the specific task used (Defoe et al., 2015; Frey, Pedroni, Mata, Rieskamp, & Hertwig, 2017), it will also be important to investigate risk contagion using different risk-taking paradigms as well as self-report measures. Finally, it should be noted that by including the predict trials, in which accurate predictions about the observee's behavior were incentivized, we might have explicitly encouraged deliberation about the observee's behavior. This setup might have particularly provoked conformity with peers' choices.

It is tantalizing to connect the results of this study with real-life risk-taking behaviors in teens (e.g., reckless driving, unprotected sex, substance abuse), which are frequently subject to peer influence. Our data might suggest that these behaviors peak during adolescence because teenagers are more prone to social contagion effects by peers who engage in these risky behaviors than they are to being influenced by adults. However, it should be noted that even after contagion, adolescents did not act in a risk-seeking manner on an absolute level and were still less risk-seeking than adults. One caveat for the interpretation of the real-life implications of the current findings is the lack of reciprocity/social interaction of the participants. Furthermore, in our study, there was a relatively high degree of social distance present between the peers: Participants had not met before and had no reason to anticipate that they would ever meet again. It is plausible but remains to be elucidated as yet whether under more naturalistic conditions, for example when interacting with friends or peer role models, risk preferences may change even more dramatically.

The relationship of risk contagion and real-life risk-taking behavior is yet to be investigated, ideally in a longitudinal manner and with tasks that include direct social interactions. In this vein, understanding social influences on adolescent risk-taking behavior is valuable for preventing maladaptive behaviors and disease (Reiter, Heinz, & Deserno, 2017). However, for future studies, we deem it equally important to focus not only on potentially maladaptive consequences, but also on the possible beneficial effects of peer contagion in adolescents. In the current work, peer-biased contagion was associated with a higher degree of social connectedness. Along similar lines, a recent study has shown peer influences in children and adolescence in the domain of prosocial decision making, indicating that younger age groups are more likely to be positively socially influenced than adults (Foulkes, Leung, Fuhrmann, Knoll, & Blakemore, 2018). These and our findings might have implications for real-world settings. For instance, when designing educational interventions in the classroom, it might be particularly effective to involve peers in co-teaching and as role models for desired behaviors (Paluck, Shepherd, & Aronow, 2016). Clearly, more research is needed in this domain and future studies should more specifically address the question of how different peer relationships affect learning and decision-making in social networks.

In sum, we found a stronger risk contagion effect in adolescents when they observed their own peers. Moreover, this effect was only present when the observed peer showed risk-seeking preferences. Importantly, this peer-biased risk contagion effect was associated with higher degrees of sociability in adolescents. Interestingly, the social manipulation also had an impact on learning: Adolescents were better at learning to predict the preferences of their peers compared to nonpeers, whereas no such effect was present in adults. Taken together, our results are consistent with the idea that adolescence is a period of heightened sensitivity to peer influence. They show that the need to conform to peer behavior changes preferences toward more risk-seeking behavior and leads to improvements in social learning.

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