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Characterizing how social contexts shape risky decision making across adolescence

A dissertation presented by

Yelina Yiyi Chen

to

The Department of Psychology

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in the subject of

Psychology

Harvard University

Cambridge,

Massachusetts

April 2025

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Characterizing how social contexts shape risky decision making across adolescence

Abstract

Adolescence has been a focus in scientific research due to the dynamic social and cognitive development that unfolds during this transitional period between childhood and adulthood, as individuals begin to navigate a more complex social environment. Two of the characterizing features of this period are heightened rates of risk taking and elevated importance of peer relationships. While adolescent risk taking and susceptibility to peer influence are often viewed as negative and potentially harmful, this dissertation examines risk as a neutral concept, adopting the definition of risk as outcome variability from the judgment and decision making literature. Papers 1 and 2 used an economic decision making paradigm and computational modeling to assess age-related changes in risk preferences and the underlying decision processes, while Paper 3 used longitudinal data to expand our understanding of how fluctuations in social support in real life may impact adolescent risk taking, using both behavioral experiments and self-report survey measures. Paper 1 found early adolescence to be a window of heightened sensitivity to social contexts that require adjudicating between self- and peer-interest in risky decisions. Peer observation over Zoom did not evoke additional age-related differences in risk preference. Paper 2 found that individuals in general overestimated their friends' risk preferences, and that older adolescents and young adults were more adept at flexibly taking friends' perspectives in decision making. Paper 3 found that within-person fluctuations in perceived close friend support were not associated with levels of risk preference in adolescents, whereas between-person levels of perceived close friend support had a stronger association with

risk preference among younger adolescents. Taken together, these findings shed light on social and cognitive mechanisms that unfold at different stages during adolescence that underlie individuals' risky decision making.

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General Introduction and Background

Adolescence is a developmental period beginning around the onset of physical puberty and ending around the assumption of adult roles (e.g., Spear, 2000). It is also a period of escalated rates of participation in health risk behaviors (Boyer, 2006; Eaton et al., 2010; Steinberg, 2008) and self-reported risk taking propensity (Tervo-Clemmens et al., 2024). During adolescence, individuals' social landscape becomes more complex, as they begin to spend more time with peers than with their parents (Barnes et al., 2007) and start to adopt more other-focused, prosocial behaviors (Crone & Dahl, 2012). This evolving social environment allows them more agency and thereby opportunities to take risks, which can be motivated by and impact their relationship with peers (Blakemore, 2018; Blakemore & Mills, 2014). Many cognitive processes involved in decision making that requires incorporating multiple sources of information undergo unique tuning during adolescence (Hartley & Somerville, 2015). Since adolescents' risky decisions typically occur in rich, social environments, it is important to study how peers, the social group that takes on heightened importance during this period, shape individuals' risk preferences. The social-cognitive processes underlying risky decision making unfold in ways that may drive age-related differences in sensitivity to peer influence across adolescence, which are key to investigate in order to derive a comprehensive account of adolescent risk taking.

Defining Risk

When investigating the social-cognitive mechanisms underlying risk taking during adolescence, it is important to appreciate the multifaceted nature of risk in the context of this

developmental period. Though commonly construed as referring to harmful behaviors that ought to be prevented in lay discourse, risk taking is necessary for "leaving the nest" (Natterson-Horowitz & Bowers, 2020) and discovering new niches and opportunities (Sercombe, 2014; Willoughby et al., 2013) that give rise to meaningful experiences essential for adolescents to develop into independent adults (Nelson et al., 2016). In this dissertation, risk taking is defined as taking an action for which the outcome is variable, with greater variability indicating more risk (Weber et al., 2004), following the judgement and decision making literature. This definition of risk does not presuppose positive or negative consequences, making it well-suited for providing a comprehensive account of developmental changes in the processes underlying risky decision making.

Age Patterns in Risk Taking from Laboratory Studies

Experimental data from laboratory studies have shown a range of age patterns in risk preference, including elevated risk preferences during mid-adolescent years (Burnett et al., 2010; Cauffman et al., 2010; Figner et al., 2009), declining risk preferences (Paulsen et al., 2012), and stable risk preferences across adolescence (Van Leijenhorst et al., 2008). A meta-analysis by Defoe et al. (2015) found that adolescents made riskier choices than adults in experimental decision-making tasks, with a medium effect size.

Many experimental manipulations can contribute to whether an adolescent peak in risk preferences is observed in laboratory studies. For instance, drivers of heightened risk taking in adolescence include explicitly stated vs. ambiguous probabilities of outcomes in the tasks and the presence vs. absence of immediate feedback on the outcome of the choices, and whether there

are others present when individuals made decisions (Blankenstein et al., 2016; Defoe et al., 2019; Gardner & Steinberg, 2005; Tymula et al., 2012; Van Leijenhorst et al., 2008). Description-based tasks where the probability and outcome information is available to participants are less likely to yield an elevation in risk taking in adolescence compared to experience-based tasks where such information must be learned through trial-and-error (Rosenbaum et al., 2018). When synthesizing literature in this line of work, it is important pay particular attention to relevant task features and their constraints on the generalizability of the relationship observed between age and risk preference.

Cognitive Processes Underlying Prosocial Risky Decisions

Many social and cognitive processes that lay the foundation for risky decision making involving peers are still developing as adolescents become young adults. For example, perspective taking continues to develop through late adolescence (Dumontheil et al., 2010), and prosocial behaviors – voluntary acts intended to benefit others (Eisenberg et al., 2005) – that are at least partly motivated by maximizing one's own gains have been shown to increase with age during adolescence through the development of perspective taking (Crone & Achterberg, 2022; Güroğlu et al., 2014; Overgaauw et al., 2012; Steinbeis et al., 2012). Incorporating intentionality and social contexts in strategic fairness decisions (i.e., fairer offers may maximize payoff through being less likely to be rejected) also increases with age during adolescence (Güroğlu et al., 2009). Therefore, older adolescents might have an advantage over younger adolescents in making strategic decisions that require incorporating considerations of both social and financial consequences in economic decision-making tasks commonly used in research in this area.

On the other hand, early adolescence also emerged from past research as a special period of sensitivity in the development social cognition: the anticipation of social evaluation begins to induce heightened arousal and self-conscious emotions (Somerville, 2013) around this time, and individuals are more impacted by social feedback (Rodman et al., 2017) and others' perspectives in prosocial decision making (van den Bos et al., 2011). Specific age-related patterns characterizing the development of prosocial behaviors have not been consistent in past research (see Do et al., 2017 for a review) which may be attributed to the variety of social contexts evoked by varying experimental paradigms, as prosocial behavior is increasingly sensitive to social contexts with age (Güroğlu et al., 2014). Taken together, various lines of research point to rich age-dependent variances in adolescents' cognitive processes and sensitivity to social-contextual information that may influence their risky decisions, and a more granular, high-resolution account that is also generalizable is needed.

Peer Influence on Risky Decision Making during Adolescence

Peers influence on decision making has long been a topic of interest in developmental science and psychology more generally (e.g., Andreoni & Miller, 2002; Gardner & Steinberg, 2005). Lay conception of "peer influence" often has a connotation that a peer is actively encouraging risk taking, which is not the definition we adopt – in this dissertation, peer influence refers to peer being part of the decision context, including but not limited to direct encouragement. During adolescence, individuals begin to spend more time with their peers and less time with their parents (Barnes et al., 2007), thereby shifting from family- to peer-oriented social groups with less parental supervision (Rubin et al., 2008; Steinberg & Morris, 2001). Thus, peers as the most prominent social group that adolescents spend most of their time

with (Brown, 2004), are an important part of the context of risky decisions during adolescence, as adolescents are especially sensitive to peer rejection and value acceptance in their social group (Masten et al., 2011; Rodman et al., 2017; Silk et al., 2012).

Given the importance of peers during adolescence, one possible mechanism underlying elevated rates of risk taking is through miscalibrating peers' risk preferences, which in tandem with a desire to assimilate to higher status peers (homophily, Brechwald & Prinstein, 2011), may lead adolescents to inflate their own default preference. Some researchers have suggested adolescents' heightened risk taking does not stem from their judging risky scenarios as less risky than other age groups, but rather their tendency to benchmark their assessment of risk with their peers' (Knoll et al., 2015a). There are many real-life cases of homophily in health risk behavior: perceived peer substance use predicted the extent and onset of individuals' own consumption in adolescents aged 10-15 years (D'Amico & McCarthy, 2006), and having friends who smoke or drink has been shown to predict these behaviors in adolescents aged 11-18 years (Loke & Mak, 2013). This potential mechanism could explain these behaviors, though currently little is known about the degree to which these targets of homophily deviate from reality (i.e., peers' actual preferences), and whether this miscalibration varies across age.

Risk taking may also be viewed as an attempt to reconnect with one's social group when an individual experiences feelings of loneliness and exclusion (Tomova et al., 2021). A sense of belonging is a fundamental human need (Baumeister & Leary, 1995) and social isolation has been shown to cause social craving (Tomova et al., 2020). Adolescents' risky decisions can be motivated by and impact their relationship with peers (Blakemore, 2018; Blakemore & Mills, 2014). Therefore, the special value adolescents place upon social acceptance renders feeling supported by peers an important piece to consider in the study of the social-motivational

mechanisms underlying adolescent risk taking. Even though past research has shown that mood fluctuations can affect individuals' decision making (Cecchi et al., 2022), little is known about the role that perceived social support, which may give rise to changes in feeling states, plays risky decision making, or age-related changes in the association between the perceived social support and risk preference during adolescence.

Studying Peer Influence in the Lab

There are a number of ways of involving peers in the lab when studying peer influence on individuals' decisions, including direct peer observation (e.g., Smith et al., 2015; Powers et al., 2018; Somerville et al., 2019), mere presence of the peer (e.g., Chein et al., 2011; Powers et al., 2018; Somerville et al., 2019), social exclusion (e.g., Sebastian et al., 2010; Masten et al., 2011), peer evaluation (e.g., Gunther Moor et al., 2010; Rodman et al., 2017) and impacting peer outcomes (e.g., peers win or lose money due to participants' choices (Powers et al., 2018).

Among these factors, peer outcome is of particular interest in this dissertation, as adolescents' risky decisions often take place in social settings and rarely have consequences for themselves only. Prior work has shown that when a friend stood to benefit from a participant's choices, adolescents shifted their risk preferences regardless of the friend witnessing the decision or not, whereas adults did so to a greater extent while being observed (Powers et al., 2018). Little is known, however, about when the decision context entails an adjudication between maximizing peer outcomes and their own, how adolescents would modify their preferences compared to when peer outcomes are not impacted.

Due to methodological heterogeneity, including differences in sample sizes and composition, analytical approaches, and definitions of age groups, it has been challenging to synthesize a coherent pattern from previous findings on age-related changes in peer influence on risky decision making during adolescence. Let us take prior research on the impact of peer observation, a widely examined form of peer influence, on adolescent risk taking as a case study. Research in this area has amassed mixed results with respect to the direction of this influence on adolescent risk taking. Some work has shown that adolescents take more risks when observed by peers (Smith et al., 2015; van Hoorn et al., 2017; Gardner & Steinberg, 2005), while others found such patterns only within specific experiential conditions (Reynolds et al., 2014; Somerville et al., 2019) or not at all (Hinnant et al., 2019; Powers et al., 2018).

A meta-analysis (Powers et al., 2022) found that across different laboratory studies on this subject, adolescents are on average 1.3 times (Hedge's g = .16) more likely to take a risk when peers are observing compared to when they are not, and that this effect is mainly driven by the co-occurrence of peer observation and active encouragement from peers, one of the many situational experimental conditions examined in the meta-analysis. In the context of the average effect size in social psychological research (r = .21, equivalent to Cohen's d/Hedges' g = .43), this effect is reliable but subtle (Powers et al., 2022; Richard et al., 2003). The authors identified several factors that may have contributed to the effect size being small, including large variability in sample sizes across studies (N = 13 to N = 452), inconsistent definitions of the adolescent age range, and reduced precision of the analysis resulting from individual data points being unavailable from some studies. These factors indeed highlight some of the common obstacles in presenting a unified account of age-related change in peer influence on risk taking during adolescence in general. In addition, the common practice of arbitrarily binning ages into

categories prior to model fitting makes it challenging to synthesize across studies that categorized age groups differently.

The Current Research

This dissertation aims to bridge the gaps in our understanding of age-related changes in how different social contexts involving peers influence risky decisions during adolescence. The analytical approaches used in this work present a high-resolution account of how risk preferences changes with age in social-motivational contexts by 1) applying statistical methods sensitive to nonlinearity in the data, modeling age as a continuous variable and thereby sidestepping issues that commonly occur in categorical treatment of age; 2) using computational models to quantify risk preference and elucidate decision processes, complementing behavioural measures; 3) leveraging longitudinal data which allow for the separation of interindividual differences and intraindividual fluctuations in predictors of interest through statistical modeling.

Paper 1 builds on the line of research on how affecting peer outcomes may influence adolescents' risky decisions by using two distinct social-motivational contexts with differing consequences for peers. Paper 2 investigates how beliefs about peer preferences are incorporated into risky decision making by quantifying the degree of calibration between actual and assumed peer preferences in real-life friend dyads. Paper 3 explores age-related differences in the association between perceived close friend support and risk preference in a longitudinal dataset, separating in within- and between-person effects. Together, these studies advance our understanding of how the peer-relevant social contexts shape risky decision making across adolescence, and reveal windows of sensitivity to different peer-relevant factors.

Paper 1: Social contexts requiring adjudication between self- and peer-interest differentially alter risk preferences across adolescence

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In press at *Open Mind*

Abstract

Adolescence is a period of escalated rates of risk taking and a dynamic social landscape with peers taking on an important role in shaping one's decisions. Choosing to engage in risk rarely impacts only the decision maker, but also those around them. With a cohort of typically developing adolescent and young adult friend dyads (N = 128, 11-22 years), the current study investigates how peer-relevant social contexts influence risk preferences at different ages using a computational decision making task. We adapted a computational expected utility model to account for weighing the friend's outcome as part of one's utility calculation when deciding between assigning the risky option to oneself or one's friend. Compared to participants' baseline risk preferences absent of any friend involvement, we found age-related changes in risk taking when the preferred option can only be assigned to oneself or one's friend but not to both. Exploratory, data-driven analyses using behavioral measures and the computationally derived risk preference parameter revealed that overall, early adolescence is a period in which individuals assigned more weight to their friends' outcomes and were willing to forego personal

benefits to a greater extent. Active observation by friends had no additional, age-dependent impact on participants' risky choices. These results indicate early adolescence to be a period of sensitivity to social contexts evoking prosocial gestures that are costly to oneself.

Introduction

Adolescence, the phase of life between childhood and adulthood that starts with physical puberty (e.g., Spear, 2000), has long been a focus in public health and policy due to it being a period of escalated rates of participation in health risk behaviors (Boyer, 2006; Eaton et al., 2010; Steinberg, 2008) and self-reported risk taking propensity (Tervo-Clemmens et al., 2024). A meta-analysis of laboratory based risky decision tasks showed that adolescents take more risks than adults (Defoe et al., 2015), in line with public health data. In continuing to understand the mechanisms underlying heightened risk taking during adolescence, it is beneficial to zoom out and appreciate its multifaceted nature. In adolescence, people begin to spend more time with their peers and less time with their parents (Barnes et al., 2007), thereby shifting their social groups from family- to peer-oriented, with less parental supervision (Rubin et al., 2008; Steinberg & Morris, 2001). This evolving social environment allows them more agency and thus opportunities to take risks that impact their and their peers' wellbeing, which may in turn influence their relationships (Blakemore, 2018; Blakemore & Mills, 2014).

The present study examines possible roles that peers play in shaping risk-taking during adolescence. Adolescents increasingly value peer acceptance (Brown, 2004; Nelson et al., 2005; Guyer et al., 2012; Rodman et al., 2017; Silk et al., 2012; Somerville et al., 2013), and start to adopt more other-focused, prosocial behaviors (Crone & Dahl, 2012). The social

consequences of one's risky acts for one's peers could be a potent factor in shaping adolescents' behavior (Powers et al., 2018), and several motives may underlie peer-related shifts in decision making. For example, they are prone to behave in a riskier manner around peers they perceive, correctly or incorrectly, as more risk accepting (Knoll et al., 2015b; Prentice & Miller, 1993). Peer involvement may also give rise to increased risk taking because it might amplify the neural responses signaling potential rewards (Albert et al., 2013; Chein et al., 2011), though the evidence is mixed (Hinnant et al., 2019). Prosocial motivations to help others could also underlie increased risk taking in adolescents in social contexts in which risk leads to beneficial outcomes for others (Do et al., 2017). Moreover, the expression of these motives may vary across adolescence due to these evolving social dynamics (e.g., Lam et al., 2014), and/or the still-changing neurocognitive processes influencing decision making more generally (Hartley & Somerville, 2015).

In an effort to delineate how different social contexts shape adolescents' risk preferences, the present study induces differing social consequences of risky behavior between pairs of friends and uses computational analyses to isolate whether and how they shape risk preferences across adolescence to young adulthood. Risk taking hereafter is defined following the Judgement and Decision Making literature, as taking an action for which the outcome is variable, with greater variability indicating more risk (Weber et al., 2004), as opposed to the lay conception that risk refers to harmful behaviors that ought to be minimized.

The present study uses two "friend outcome" conditions that manipulate whether engaging in a risky act is differentially advantageous to oneself relative to one's friend. One condition (*Identical*) involves participants making a risky decision that will subject their friend to the same outcome as themselves to mimic situations in which individuals are engaged in risks

with joint outcomes (e.g., making a risky but potentially rewarding move in a team sport, signing your student band up for a contest). The other condition (*Opposite*) sets up opposing outcomes for the dyad. There is a risky and a safe option – one of which is preferred to the participant – and the participant must decide whether to assign that option to themself or their friend. This mimics situations in which taking a risk could disadvantage a friend (e.g., running for student body president when your friend is also running). Prior work has shown that when a friend stood to benefit from a participant's choice, adolescents shifted their risk preferences regardless of the friend witnessing the decision or not, while adults did so to a greater extent while being observed (Powers et al., 2018). The current study advances this prior work by using two distinct social-motivational contexts to examine whether individuals' prosocial behavior persists when social consequences of their risky decisions vary in how the participant's choice impacts their friend's outcome.

In the present study, the social outcomes described above were embedded within a second social context manipulation – whether those decisions were made while the friend actively observed the participant's choices. Prior work has examined whether adolescents take more risks when peers were present and observing an individual's choices, as is observed in real-world scenarios like driving (Eaton et al., 2010; Gardner & Steinberg, 2005). While several studies have found an increase in risky choice behavior under observation (Gardner & Steinberg, 2005; Smith et al., 2015; van Hoorn et al., 2017), a recent meta-analysis has found that the basic effect of observation was rather small and context-dependent (Powers et al., 2022). The present study uses friend observation to examine the extent to which participants are more likely to maximize their friend's potential gains when they are actively observing the choice. Incorporating this condition is poised to clarify the underlying motives of the decision maker. If

an individual chooses to give a peer an advantageous option more when they are watching, it implies a reputational motive is underlying the prosocial act.

Thus, the current study aims to investigate age-related changes from adolescence to early adulthood in how peer outcome in different social contexts influences individuals' risk preferences, compared to when the decision only impacts oneself. Peers in this study were age- and gender-matched friends rather than strangers to evoke the possibility of genuine relational motives. To measure risky decisions, we used an economic decision making task in which participants first chose between risky (the option with more variable outcomes) and safe options absent friend involvement, allowing us to compute their baseline risk preferences. We then introduced the *Identical* and *Opposite peer outcome* conditions described above. A computational model was used to derive estimates of risk preferences at baseline (absent friend involvement), and in each of the peer outcome conditions, further stratified by whether the friend was observing the choices. By evaluating age-related changes in risk preferences in these contexts under *observation* or *no observation* by the friend, we can learn what kinds of social considerations and potential consequences might motivate individuals to shift their decisions across adolescence.

Methods

An extended version of this project is preregistered at https://osf.io/9brsg/

Participants

Participants (age range: 12.0-22.8 years) were recruited through an existing database, advertisements, and community outreach. Participants were required to be based in the United

States, fluent in English, and have access to computer set-up to complete the study. Individuals meeting these inclusion criteria were then asked by researchers to invite a friend of the same sex and within a year of the same age to contact the lab to indicate their interest in co-participating. If their friend was also eligible and interested in the study, the pair was tested. During the screening process we excluded potential participants who had learning disabilities, and who had previously participated in a peer-related study in the lab. Within each friend pair, we collected fully mutual data in all conditions – each individual took on the role of the primary decision maker and the role of friend (for the other person in the dyad).

Overall, 128 participants took part in this study in pairs (N = 37 adolescent pairs, ages 11.98-17.46 years; 18 pairs female and 19 pairs male; N = 27 young adult pairs; ages 18.16-22.82 years, 14 pairs female, 13 pairs male; 15.6% Asian, 6.3% Black or African American, 10.2% two or more races, 0.8% other, 0.8% Native Hawaiian or Pacific Islander, 66.4% White. One participant from the adolescent group identified as gender non-conforming and was the peer partner of a male-identifying participant, and one participant from the adult group identified as transgender male and was the peer partner of a male participant.

Male and female pairs were distributed evenly across the age range (logistic regression with age predicting gender, B = -0.014, p = .789*)* and pairs had an average age difference of 0.46 years (min = 0.01, max = 1.39, SD = 0.33). The distribution of average parental education level as a proxy for socioeconomic status (SES) was not related to age (linear regression, B = -0.016, p = .439), indicating SES is balanced across age. Participants provided informed written consent/assent, and parents/caregivers of minors gave written permission for their participation. The Committee for the Protection of Human Subjects at Harvard University approved this research.

Sample Size and Exclusions

Sample size was determined prior to data collection based effect sizes from Powers et al. (2018): The effect size (r = .32) for the significant comparison between adults and adolescents in the influence of age on risk aversion (Alpha) when facilitating positive outcomes for peers, and effect sizes ranged between r = .25-.32 for age effects within the adolescent subgroup (continuous age-related changes). Using the lowest effect size r = .25, a power analysis using the package *pwr* in R (v1.3.0, Champely et al., 2020) showed that N = 123 participants would be needed for 80% power to detect this effect size in the current study. Our study deviates from Powers et al., (2018) in analytical framework. Due to the nonparametric nature of spline terms from the GAM models, we could not perform a power analysis reflecting the nonparametric analyses used without making strong (parametric) assumptions about the functional form of the smooth. Powers et al. (2018) was selected for its conceptual relevance, and therefore, discussion of power should be considered more illustrative than prescriptive.

Part 1 of the study included usable data from N = 128 participants. Part 2 of the study included usable data from N = 123 participants (3 participants failed the comprehension checks and did not call the experimenter, and 1 additional pair that had technical issues resulting in data loss, were excluded).

Risky Decision Making Task

Participants completed an economic decision making task consisting of different choice options varying in monetary payout and odds of winning, which had been used in previous

studies to quantify individuals' risk preferences in adult (Chung et al., 2015; Levy et al., 2010; Sip et al., 2015; Tymula et al., 2012, Powers et al., 2018) and adolescent samples (Tymula et al., 2012, Powers et al., 2018). We adopt the definition of risk taking from the decision making literature (e.g., Weber et al., 2004) based on outcome variability (i.e., riskier options are those with more variance in potential outcomes), an approach that is agnostic with respect to whether risks are good or bad.

On each trial, participants selected between two choice options displayed on the left and right sides of the screen (Figure 1) varying in risk: a) a safe option "100% chance of winning $5" and b) a risky lottery option (10%, 25%, 50%, 75%, or 90% probability of winning [$5, $10, $20, $30, $40, $50, $100]; Tymula et al., 2012, Powers et al., 2018) depicted with a pie chart indicating the odds of winning and losing. Each probability was paired with each amount totaling 35 trials per condition, with the order of trials randomized. The safe and risky options were counterbalanced to appear on the left and right sides of the screen at equal frequency. For all conditions, participants indicated their choice in self-paced timing by pressing one of two keyboard buttons, at which point the trial ended; there was no immediate feedback on the outcome of the risky choice.

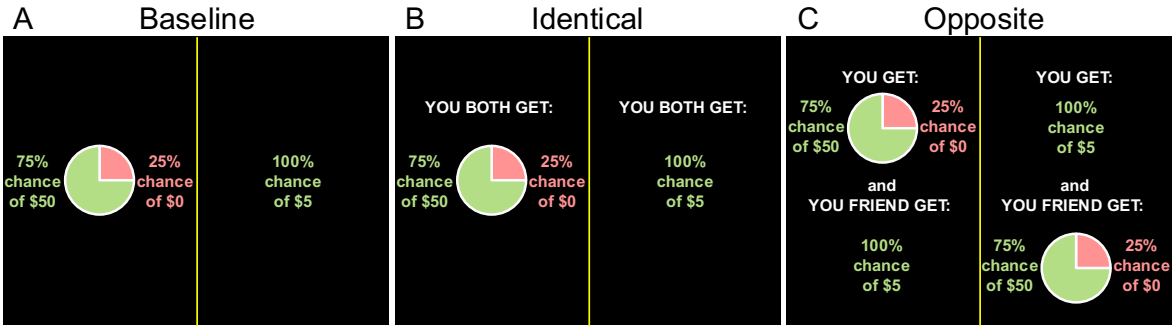


Figure 1. Example trials from different conditions in the experimental task. A) Baseline: a choice between a safe option (100% chance of winning $5) and a risky option (75% chance of winning $50, 25% chance of winning $0). B) Identical: participant and friend receive the same outcome chosen between the two options described. C) Opposite: one person receives the safe or risky option, and the other will receive the unchosen option.

Participants were instructed that they and their friend would receive a fixed percentage of the cumulative amount of money they earned through their choices as a bonus, with a computer simulating the chosen lotteries to determine earnings. Participants in the "friend" role were paid the percentage from the Identical and Opposite condition based on choices made for them by the participant in the primary decision maker role.

Experimental Procedure

Following screening and consenting, each participant first completed an online testing session from their individual computer ("Part 1") on Qualtrics in which they completed several iterations of the risky decision making task individually (described below). Once both participants in a dyad had completed their individual session, the friend dyads co-participated in the second part of the study ("Part 2") on Zoom with the experimenter, where each friend logged in separately. Screen sharing and camera status was manipulated to control whether the decision maker's friend was observing them in real time (Observed vs. Unobserved).

Part 1: Individual Participation

Each participant in the pair completed Part 1 separately and not necessarily on the same day. Participants received detailed instructions and underwent comprehension checks which assessed their comprehension of the probability graphics used in the study before they could start

the self-paced task. They completed the following conditions in pseudorandomized order. In each condition, participants viewed the same risky options described above under the following conditions:

1. Baseline: Participants completed risky decision making task described above with outcomes for themselves only (Figure 1A). The purpose of this condition was to establish participants' individual risk preferences. We also collected data on what participants predicted their friend would choose in this condition, which was only used here as part of the input for the computational model for the Opposite condition (detailed in model-based estimation of risk preferences section below).
2. Identical: Participants completed the risky decision making task described above knowing that their selection would apply to both themselves and their friend (Figure 1B). The purpose of this condition was to show how participants' risk preferences changed relative to Baseline, when their decisions would subject their friends to experiencing the same outcome.
3. Opposite: Participants completed the risky decision making task described above and selected an outcome for themselves with the knowledge that the unselected option would apply to their friend (Figure 1C). The purpose of this condition was to show how participants' risk preferences changed relative to Baseline, when participants either had to keep or give their preferred option to their friend.

Part 2: Dyad Co-participation

The second part of the study was conducted with each member of a dyad plus the researcher meeting on Zoom. Friend observation was manipulated as follows: For the Observed

conditions, both the participant and their friend had their cameras on, and the participant shared their screen so that their friend could observe them making decisions in real time. For Unobserved conditions, the screen was not shared, and the friend would turn off their camera.

To examine the impact of friend observation in both the identical and the opposite contexts, this part of the study included four conditions: Observed Identical, Unobserved Identical, Observed Opposite, Unobserved Opposite. These conditions were administered in interspersed blocks with randomized order.

Dependent Measures:

1. Model-based estimation of risk preferences: we fit a probabilistic choice model with two free parameters to each participant's choices for each condition to quantify individual risk preferences (Gilaie-Dotan et al., 2014; Levy & Glimcher, 2011; Levy et al., 2012; Levy et al., 2010). As in Powers et al. (2018), we modeled the expected utility of each option with a power utility function:

$$EU = pv^{\alpha} \qquad (original\ model)$$

Where *v* is the amount of money on a given choice and *p* the probability associated with winning that dollar amount. Alpha is the estimated parameter of interest for risk preference, where risk is defined as outcome variability (Weber et al., 2004), i.e., the possible outcome with greater uncertainty is the riskier choice. Alpha < 1 indicates an agent is risk averse with a concave utility

function, preferring the safe option to a risky option with equal expected value (EV; dollar amount multiplied by the probability of winning that option). Overall, prior work has shown that most people are risk averse on average (Glimcher, 2008; Platt & Huettel, 2008). A score of Alpha > 1 indicates an agent is risk seeking with a convex utility function, preferring the risky option to the safe option with equal EV. Alpha = 1 indicates a risk neutral agent with a linear utility function, who is agnostic between the safe and risky options with the same expected value. In Supplementary Material, we compared the Expected Utility model with the alternative Prospect Theory (Tversky & Kahneman, 1992) models, and demonstrated that, consistent with previous studies (Levy & Glimcher, 2011; Levy et al., 2012; Tymula et al., 2012; Powers et al., 2018), the Expected Utility model is favorable and therefore used for all reported analyses.

These valuation processes require three inputs each (probability, value, and Alpha). Additionally, the Opposite condition required an adaptation of the model to integrate the utility of the chosen option (the one participants assigned for themselves) relative to the utility of the unchosen option (the one participants assigned to their friend). Thus, we adapted the expected utility model to reflect this adjudication.

The probability and value inputs for the friend were derived from the options themselves. For the Alpha parameter computing the utility of the option assigned to their friend, we estimated the participant's conception of their friend's risk preference using additional data collected in Part 1 in which participants predicted their friend's trial-by-trial choices. These data were acquired similarly to the Baseline condition during the study's Part 1 but instead participants answered the question "What do you think your Friend would choose?". This permitted calculating what the participant believed was their friend's Baseline risk preference ($Alpha_{friend}$).

In addition, a new parameter *w* was added as follows, rendering the expected utility of a chosen option as a weighted average for oneself and one's friend:

$$EU = (1-w)p_{self}{v_{self}}^{\alpha} + w\left(p_{friend}{v_{friend}}^{\alpha_{friend}}\right) \qquad (revised\ model)$$

Where p_{self} and v_{self} are the probability and amount of money associated with the option participants intend to choose for themselves and p_{friend} and v_{friend} are associated with the unchosen option which would be assigned to their friend. Alpha is still the free parameter to be estimated for participants' risk preferences, and Alpha_{friend} is participants' estimated risk preference for their friend, which is an individualized constant derived from fitting the original model on each participant's predicted friend choices in the Baseline condition (see Supplemental Materials for report on age trends in Alpha_{friend}). $\text{Weight}_{\text{friend}}$ (*w)* represents how much one's utility is based on one's own outcome relative to how much one incorporates their estimation of their friend's outcome and is bounded between 0 and 1. The larger it is, the more the participant values the utility of their friend's outcome relative to their own.

With both the original and revised model, we fit each trial within a condition from a given participant to a logistic function that computes the probability of the participant choosing the risky option on that trial given the expected utility of the safe and the risky option, with a maximum likelihood procedure:

$$P(choose\ risky\ option) = \frac{1}{1+\exp\left(\beta\left(EU_{safe}-EU_{risky}\right)\right)}$$

Where EU_{safe} is the expected utility of the safe option and EU_{risky} is the expected utility of the risky option. Beta is the inverse decision noise, which indicates the likelihood of the participants choosing the option with the higher expected utility as a theoretical rational agent would. Higher Beta estimates indicate the participant's choices are more yoked to expected utility, whereas lower Beta indicates more stochastic choices that are less yoked to expected utility.

Parameter recovery showed that both models recovered robustly. Model comparison showed that both outperformed alternative models for their respective conditions. See Supplemental Materials for more detail on these two procedures.

The computational models were fitted to each participant's data individually rather than hierarchically to avoid any a priori age assumptions having undue influence on the subsequent age-based analyses. Defining age groups during this step is incompatible with our goal of avoiding the need to arbitrarily group participants based on age bands. This is consistent with prior developmental work that also did not adopt a hierarchical framework (e.g., Master et al., 2020; Nussenbaum et al., 2022; Powers et al., 2018). Fitting the computational model to participant data individually without pre-imposed age boundaries allows the generalized additive models to capture age-related change in a continuous and nonlinear manner in our statistical inferences.

Model-based exclusions

For the analyses described above that use the Alpha, for Baseline and any condition involving the Identical context, we excluded participants with Alpha exceeding 3.32, which is the maximum theoretical recoverable value based on our choice set; for conditions involving the

Opposite contexts, we excluded participants whose Alpha exceeded 2 or $Weight_{friend}$ lower than 0.000001. This threshold is set based on two considerations. First, the choice behavior generated by Alpha above 2 were barely distinguishable from each other, with the maximum difference in one choice (see Supplemental Materials for more details). Second, the revised model showed the best parameter recovery for Alpha in the range of 0 to 2 (correlation between simulated and fitted alpha in the range of [0,2]: $r = 0.78$, $Weight_{friend}$: $r = 0.73$). We also excluded participants whose AIC from the computational model was equal to or exceeded the AIC value for someone with chance behavior from that condition. Model based exclusion resulted in exclusion rate of less than 10% (See Supplemental Materials).

For completeness, we included results using a non-model based alternative measure to Alpha, proportion of risky choices (calculated as the number of risky options chosen divided by total number of trials within a condition for each participant), in Supplemental Materials. This measure does not take into account the relative utility of the options on each trial and is thus a more coarse-grained measure than Alpha. However, it is not subject to model-based exclusions and provides a sketch of the raw data. We also report a set of sensitivity analyses in Supplement Materials, demonstrating that these exclusions did not alter the inferences substantively from using the full sample.

2. Measure of simulated earnings: Simulated earnings were computed for each participant for each condition by calculating the sum of the expected value (EV) of each selected choice option. Simulated earnings were modeled as proportions of the total possible earnings (calculated as the sum of all highest-EV choices) using a Beta distribution to better reflect the distribution of the data and improve the accuracy of the model fit and generalizability. Therefore, the test statistic is expressed in *z*-values and the resulting plots with *y*-axis on a logit scale.

Analysis

The research questions under investigation aim to capture the risk preferences in adolescents and adults and the degree to which different social-motivational contexts influenced their risky decision making. The research questions and analytical plans for each are described below following a description of how all analyses treat age. For all group analyses, the random effect structure treated participant as nested within a dyad (each representing a friend pair) to account for any dependencies related to the data being collected on pairs of friends.

Treatment of Age

Because risk preferences have been found to follow a nonlinear pattern from childhood to adulthood (Casey et al., 2011; Cauffman et al., 2010; Figner et al., 2009; Galvan et al., 2007), we adopted an exploratory data driven approach sensitive to nonlinear age related changes. Specifically, we fit a generalized additive model (GAM) (Hastie & Tibshirani, 1986, 1990) using the *gam* function from the *mgcv* package (v1.8.38, Wood, 2003, 2004, 2011, 2017) to examine the effect of age as a continuous predictor on the dependent variables (DVs).

In order to identify age windows where the GAM model shows significant changes in the DV with respect to age as the only predictor, we computed the first derivatives of the GAM curve (spline) along the *x*-axis (age), which quantified the slope of the curve at each given age, using the *gratia* package in R (v0.7.3.7, Simpson, 2022). The derivatives were evaluated along 100 points along the *x*-axis and Simultaneous Confidence Intervals (CIs) corrected for multiple comparisons. Quantifying the age windows at which the Simultaneous CIs of the first derivative

did not include 0 reveals the slope across age was significant. Positive values indicate a positive slope or an increase in the DV, negative values indicate a negative slope or a decrease in the DV, and 0 indicates the DV remains constant.

To compare the age pattern for different levels of a categorical variable, GAM fits a nonlinear function for each level of a categorical variable (factor smooth interaction) without providing a direct statistical test for the interaction between the smoothed variable and the categorical predictor of interest. Therefore, we used the *plot_diff* function from the *itsadug* package (v 2.4, van Rij et al., 2022) to inspect the relative difference between fit estimates of each pair of conditions (i.e. Identical vs. Baseline, Opposite vs. Baseline) and compute 95% simultaneous CIs around it. Age bands where the simultaneous CI did not contain zero are interpreted as periods of significant differences between the conditions.

We applied the analytical methods above to evaluate our central research questions:

1. How do risk preferences change across age from adolescence to young adulthood? We fit a GAM and examined the first derivatives as described above to test the effect of age as a continuous predictor and characterize age-related changes in choices made in the Baseline condition.

2. Does offering identical or opposing outcomes for oneself and one's friend change one's risk preferences, compared to when the outcome only concerned oneself? Are there age-related differences in this effect? We fit a GAM and used factor smooth interactions as described above to examine the effect of age as a continuous predictor and characterize age-related changes in choices made in the Identical and Opposite conditions compared to Baseline. We did not conduct direct comparisons between the Opposite and the Identical context because the two

conditions are not matched on low-level features (the Opposite context had more information to consider and thus likely required greater cognitive demand to simulate the two different scenarios for self and friend).

3. Does being observed by friends change participants' risk preferences and simulated earnings in Identical and Opposite contexts? Are there age-related differences for this effect? We fit a GAM using age as a continuous predictor and a 4-level factor predictor "Condition" (Observed-Identical, Unobserved-Identical, Observed-Opposite, Unobserved-Opposite) and used factor smooth interactions described above to evaluate age-related changes due to observation within the Identical and Opposite contexts, respectively. This was done instead of testing the interaction of Identical and Opposite conditions and observation, due to the aforementioned difference in cognitive demand between the Identical and Opposite context.

4) Are there age-related changes in $Weight_{friend}$ (how much the friend's outcome was taken into account in one's decision)? We used the same analytical approach outlined in 1) to investigate effects of age on how much individuals factor their friend's utility into their decisions. This analysis is naturally constrained to the conditions fit with the revised model, i.e., the Opposite context conditions in which each member of the dyad receives different outcomes, as the $Weight_{friend}$ is not part of the original model. The original model fit best for the Baseline and Identical context conditions, and the revised model fit best for the Opposite context conditions (See Supplemental Materials)

Results

Baseline Risky Decisions

This set of analyses evaluated the relationship between risk seeking and age, and between simulated earnings and age, in the Baseline condition. The sample was risk averse on average (Mean Alpha = 0.55, *SD* = 0.23), in line with prior results in different populations including adolescents (Blankenstein et al., 2016; Gilaie-Dotan et al., 2014; Kahneman & Tversky, 1979; I. Levy et al., 2010; Pratt & Zeckhauser, 1987; Tymula et al., 2012). Simulated earnings indicated participants incorporated expected value into their choices (Mean simulated earnings: $614.52 out of $662.50 maximum earnings, *SD* = 63.74). The simultaneous CI of the first derivative of the spline included 0 at all ages for both Alpha and simulated earnings. This indicates that participants' risk preferences and the extent to which they maximized potential payouts remained consistent across the age range of 12.0-22.8 years.

Age-Related Shifts in Risky Choice invoked by Identical Friend Outcome

Examining the Identical condition tested whether joint outcomes (risky choice having the same impact on oneself and one's friend) influences risk preferences relative to one's baseline. There were no differences in Alpha between the Identical condition and Baseline overall, or age-related changes (Mean of Identical vs. Baseline: 0.59 vs. 0.55; $B = 0.04$, $t = 1.61$, $SE = 0.03$, $p = .108$). The same was true when examining the proportion of simulated earnings (Mean of Identical vs. Baseline: .93 vs. .92; $B = 0.08$, $z = 0.76$, $SE = 0.11$, $p = .448$). This indicates that individuals judge risk similarly when it stands to benefit oneself only, and oneself and one's friend.

Age-Related Shifts in Risky Choice invoked by Opposite Friend Outcome

1) Risk seeking

In the Opposite condition, participants' choices caused their friends to receive their unchosen option. Analyses determined the extent to which participants changed their Baseline risk preferences when their friend stood to reap the opposite of what they chose for themselves. Overall, participants were relatively more risk accepting for themselves when it meant that their friend would otherwise have to accept the risky option (Mean of Opposite vs. Baseline: 0.69 vs. 0.55; $B = 0.14, t = 5.25, SE = 0.03, p < .001$). There was a significant age-related difference in this tendency, such that the overall effect was evident during ages 12.3 to 15.1 years (Figure 2). Participants' risk preferences were not significantly different for Opposite and Baseline conditions in the rest of the age range. Thus, from early to mid-adolescence, individuals were relatively more risk accepting when they had to decide whether to keep their preferred option or assign it to their friend instead.

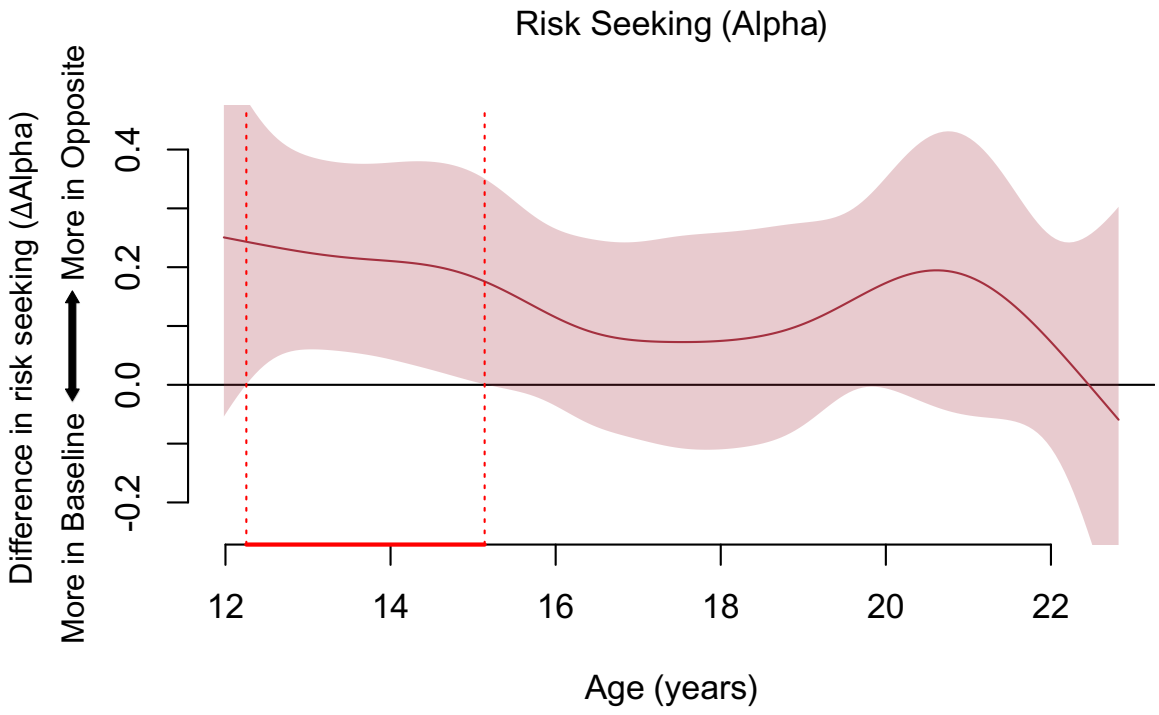


Figure 2. Age-related patterns of risk seeking: difference of fit estimates of the GAM model. Positive values indicate risk seeking is greater at Opposite than Baseline, negative values indicate the reverse, and 0 indicates risk seeking is not significantly different across the conditions. Shaded area represents 95% simultaneous CIs of the difference between fit estimates at each age point. Dotted red lines show that between ages 12.3-15.1 years, the 95% simultaneous CIs do not include 0, indicating significant age-related changes.

2) Simulated earnings

To examine the effect of the Opposite condition vs. Baseline on simulated earnings, we used the same analytical approach as above. Compared to Baseline, participants earned less in the Opposite condition, when their decisions caused their friends to receive the opposite of their own choices (Mean of Opposite vs. Baseline: .79 vs. .92; B = -0.81, z = -7.89, SE = 0.10, $p <$ .001).

There was a significant age-related difference in the proportion of simulated earnings between age 12.0 and 22.1 years (Figure 3). Participants from this age range earned less in the Opposite condition than in the Baseline condition and this difference diminished with increasing age. Thus, from early adolescence to young adulthood, individuals incurred personal loss when they faced the choice of keeping their preferred options or assigning those to their friend instead.



Figure 3. Age-related patterns of proportion of simulated earnings: difference of fit estimates of the GAM model. Negative values indicate the amount earned was less for Opposite than Baseline, positive values indicate the reverse, and 0 indicates the simulated earnings are not significantly different across the conditions. Shaded area represents 95% simultaneous CIs. Dotted red lines show that between ages 12.0 and 22.1, the 95% simultaneous CIs do not include 0, indicating significant age-related changes.

3) How much friend outcome weighs into choices ($Weight_{friend}$) in the Opposite condition

In the Opposite condition, there was a linear decline in how much the friend's outcome weighed in individuals' decisions ($edf = 1, F = 5.89, p = .017$, Figure 4). The younger the participant, the more they factored their friend's outcome into their risky decision and consequently downweighed their own.

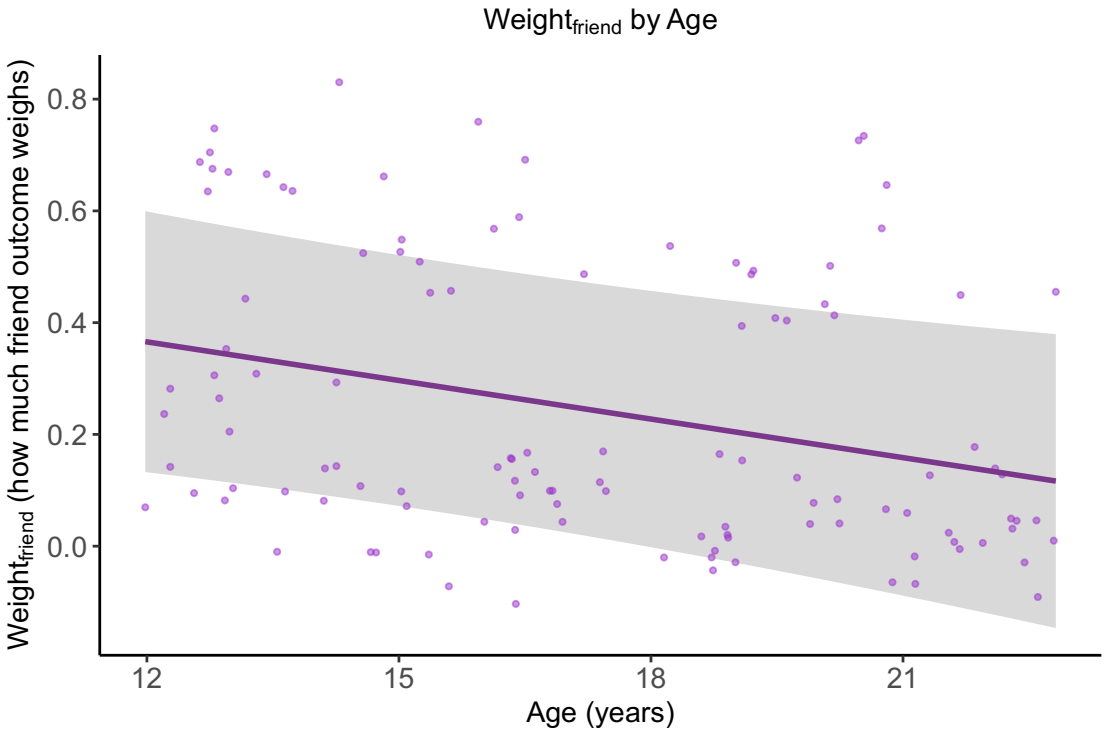


Figure 4. Age-related changes in Weight$_{friend}$. The purple line with shaded area representing 95% CI represents the model expected value for the weight assigned to the friend's outcome across the age range. Dots represent individual data points.

Age-Related Shifts in Risky Choice Evoked by Friend Observation

1) Risk seeking

Based on estimates of Alpha, participants were relatively more risk seeking in the Observed Identical condition, when friends watched them make decisions that yielded the same outcomes for them both, than in the Unobserved Identical condition, when the participants made the same type of decision when not being observed (Mean of Observed vs. Unobserved: 1.04 vs. 0.94; $B = 0.10, t = 2.65, SE = 0.04, p = .008$).

In the Opposite context, there were no significant differences when directly comparing Observed vs. Unobserved conditions (Mean of Observed vs. Unobserved: 0.69 vs. 0.69; B = -0.001, t = -0.04, SE = 0.04, p = .971).

No age-related differences were found for the effects of observation in either Identical or Opposite contexts.

2) Simulated earnings

There were no main effects or age-related differences on the proportion of simulated earnings as a function of observation in either the Identical context (Mean of Observed vs. Unobserved: .95 vs. .95; B = -0.003, z = -0.02, SE = 0.10, p = .981) or the Opposite context (Mean of Observed vs. Unobserved: .75 vs. .77; B = -0.09, z = -1.06, SE = 0.08, p = .289). Having participants' friends observe their choices led to an overall slight rise in risk seeking, but this overall effect was consistent across conditions and ages.

3) Friend outcome weight ($Weight_{friend}$) in the Observed Opposite condition

There were no main effects of observation on age-related changes in how much friends' utility was factored into one's decisions (Mean of Observed vs. Unobserved: 0.34 vs. 0.33; B = 0.02, t = 1.16, SE = 0.02, p = .249).

Discussion

The goal of this study was to examine how social contexts shape risky decisions in individuals varying in age from early adolescence to young adulthood. Using an economic decision task and dyads of friends making decisions in social contexts where their choices differentially impacted themselves and their friends, with a subset of the contexts involving

friend observation, we delineate how these factors differentially impact participants' risky choices. We found that these social contexts variably motivated participants to adjust their decisions relative to their own baseline risk preferences. Analyses of continuous age that were sensitive to nonlinear changes isolated the age windows of sensitivity in which their risk preferences were modulated by the social contexts. Overall, we observed early adolescence to be an age of particular susceptibility to these forms of social influence: individuals were more willing to take disadvantageous risks to protect their friends, which cost them earnings. This effect was further corroborated in computational modeling analyses showing that more weight was placed on their friend's outcome in younger participants. This suggests that early adolescents are willing to yield their baseline preferences to offer an advantage to their friend, even if it means incurring more risk than they are naturally inclined to take when the outcome only impacted themselves.

Baseline risk preferences

In the Baseline condition, the outcome of risky choice solely concerned oneself. As with several previous risky decision making tasks (Braams et al., 2019; I. Levy et al., 2010; Powers et al., 2018; Tymula et al., 2012), in ours, taking risks (the option with variable outcomes) was on average more economically advantageous than not doing so. This design was intended to encourage participants to make risky choices, since people are overall risk averse (Blankenstein et al., 2016; Gilaie-Dotan et al., 2014; Kahneman & Tversky, 1979; I. Levy et al., 2010; Pratt & Zeckhauser, 1987; Tymula et al., 2012), which is the case in our sample as well. We did not observe any age-related changes in risk aversion or the extent to which participants maximized earnings. This lack of age-related changes in risk taking is in line with some prior work showing

that when by themselves, adolescents and adults do not differ in their levels of risk taking (Blankenstein et al., 2016; Gardner & Steinberg, 2005; Van Leijenhorst et al., 2008).

That said, there is heterogeneity in age patterns in risk taking across laboratory tasks, despite an overall trend toward adolescents taking more risks than adults (Defoe et al. 2015). For example, Tymula et al. (2012) and Blankenstein et al. (2016) showed adolescents preferred fewer risky options than adults. Potential factors contributing to not observing an adolescent peak in risk preferences include the probabilities used in this study being known rather than ambiguous, and the absence of immediate feedback on the outcome of the choices, both of which have been suggested as drivers of heightened risk taking in adolescence (Blankenstein et al., 2016; Defoe et al., 2019; Tymula et al., 2012). Description-based tasks like the current task (where the probability and outcome information is available to participants) are less likely to yield an elevation in risk taking in adolescence compared to experience-based tasks where such information is learned through trial-and-error (Rosenbaum et al., 2018). Future, well-powered studies are needed to clarify which age-related changes in risk preferences are robust.

Influence of friend outcome

In the Opposite context, participants faced the dilemma to keep or assign their preferred option to their friend. This manipulation elicited a robust shift in risky choices. Participants overall were relatively more risk accepting but earned less in this context compared to Baseline when decisions only concerned themselves. This implies their objective was not solely maximizing earnings and that social considerations were at play. Age-related changes in risk preferences were observed at ages 12.3-15.1 years, where participants were relatively more risk

accepting and willing to take more economically disadvantageous risks, presumably to improve their friend's outcome.

The fact that younger adolescents prioritize peers' outcomes is a testament to the potency of peer relationships at this age. The earlier age window aligns with past work showing that early adolescents are more sensitive to social feedback (Rodman et al., 2017), the perspectives of others in prosocial decision making (van den Bos et al., 2011), and that anticipation of social-evaluative contexts can induce heightened arousal and self-conscious emotions (Somerville, 2013). Thus, participants in this age range might be more motivated to shift their behavior in a direction that benefited their friend due to newly heightened concern for positive standing with peers.

Further, emerging research suggests that cognitive and neurodevelopment through adolescence ushers in more sophisticated strategic cognition that allows for calibration of behavior to multiple, sometimes competing, information streams to maximize goal-directed actions (Hartley & Somerville, 2015; Jacobs & Klaczynski, 2002; Wilbrecht & Davidow, 2024). Applied to this particular study, we speculate that an increasing capacity for this form of strategic cognition could help a decision maker optimize self- and friend-accommodating motives simultaneously. The older adolescent participants' choices also shifted toward accommodating their peers, but more selectively and while losing fewer earnings. Young adolescents' tendency to downweigh self-focused outcomes in favor of peer-focused outcomes could therefore reflect an ongoing fine-tuning of strategic choice behavior.

We modified the computational model of expected utility to mirror the adjudication between assigning a risky option to oneself or one's friend. A new parameter, $Weight_{friend}$, was introduced to reflect how much participants weighed their friend's possible outcome into their

choice about who will receive the risky option. The original model that did not incorporate the friend's outcome was not able to reliably capture participants' behavior in the Opposite context (see Supplemental Materials). Thus, treating the friend's outcome as if it is part of one's own utility calculation is an important factor for modeling a decision process that involved opposing interests between friend and self. The data thus suggest that participants were optimizing for two sources of utility: financial and social, and that they took their friend's preference into account in their decision making process. This is in line with past work demonstrating that social-motivational contexts ought to be taken into account in understanding heterogenous (across decision contexts and individuals) patterns in altruistic (sacrificing recourses to benefit others) behaviors (Andreoni & Miller, 2002).

The revised computational model provided additional insight in age-related changes in how much people weighed their friends' outcome in the Opposite condition. Weighing friends' outcomes declined linearly with increasing age. This finding dovetails with the finding that participants earned less in this condition, and this difference diminished with increasing age. Together, these findings show that younger participants placed more weight on their friends' outcomes and were willing to forego personal benefits to a greater extent than older participants.

Studies have shown that strategic prosocial behaviors (in which being prosocial is at least partly motivated by maximizing one's own gains) increase with age during adolescence through development in perspective taking (Crone & Achterberg, 2022; Güroğlu et al., 2014; Overgaauw et al., 2012; Steinbeis et al., 2012). In the Opposite condition, with increasing age, participants lost less money compared to the Baseline condition, suggesting older participants were more strategic and mindful of the payout when changing their preferences. This result also echoes the finding from Powers et al. (2018) that participants incurred losses to protect their friend when

their friend could potentially suffer loss due to their decision. Our findings suggest that it is not only when a friend might incur an actual loss (e.g., in Powers et al. (2018) the friend could lose money) – even when the worst outcome is not gaining or losing anything, it was sufficient to elicit prosocial motives.

The upper limit of this age-related effect (22.1 years) was near the upper bound of the sample (22.8 years), and therefore should be interpreted with caution as the sample was sparser at the bounds. Future research could evaluate the reliability of this finding by collecting a wider range of ages. Alternatively, it could be that this effect diminishes completely into adulthood, which might reflect better strategizing among the oldest participants in this sample, whose earnings did not decrease in the Opposite condition as younger participants' did.

The Identical condition did not induce significant change in risky choices compared to Baseline. Both the participant and their friend could receive what participant deemed the "better" option, so there were no competitive social motives to factor in. This interpretation is additionally supported by the fact that in the Identical condition, the original model outperformed the revised model (see Supplemental Materials), indicating the parameter that weighed in potential friend outcome as a competing source of utility did not improve fit to choices. Thus, in the Identical condition, the lack of tradeoff between maximizing one's own gains and one's friend's presumably failed to elicit the prosocial motives observed in the Opposite condition. This highlights the specificity of early adolescent prosocial motives as being limited to circumstances in which there is an opportunity to feature prosocial gestures that are costly to oneself. This is in line with past work showing the strategic environment (e.g., social contexts), interacts with individual preferences, especially when decisions might impact players in an

unequal fashion, because they might influence whether self-interest or prosocial considerations prevails (Fehr & Schmidt, 1999).

Friend Observation

Friend observation induced an overall relative increase in risk acceptance but no age-related differences when there were identical outcomes for the dyad. Since Powers (2018) observed age-related changes with an in-person setup in a similar context, we speculate that the observation effect might have been diluted in our study due to dyads not being in the same room physically and no direct encouragement. One possibility is that observation over Zoom evoked a weaker sense of the friend's presence, thereby alleviating the participants' concerns for potentially awkward post-task interactions that might have occurred if the friend co-participated in lab and watched the participant assign them less favorable options. A meta-analysis showed that direct encouragement from the peer produced a larger effect size for observation effect compared to the subtle effect size in its absence (Powers et al., 2022). Future work evaluating peer influence on risk taking online should ascertain the influence of these hypothesized factors and consider emerging literature on how virtual platforms such as Zoom impact interpersonal interaction.

It is unclear what underlies the overall increase in risk acceptance caused by friend observation in the Identical context. It is possible that the potential excitement and arousal from having their friend as an audience boosted risk acceptance, as it has been shown that sharing an outcome equally with a friend elicited greater subjective rating of excitement and arousal than a non-friend (Fareri et al., 2012). Future research could incorporate physiological measures to

explicitly test whether arousal bolsters risk acceptance when a friend who stands to win by one's decision is observing, and whether that generalizes to other contexts.

There were also no overall or age-related changes caused by observation when the dyads received opposite outcomes. Observation also did not impact how much participants weighed friend outcome into their decision in this context, further supporting this inference. It is worth noting that participants knew their friend's take-home pay would (partially) reflect the advantageousness of choices assigned to them by their friend. This may have been sufficient to evoke a latent sense of accountability irrespective of active observation.

Limitations and Future Directions

Our analytical approach was data-driven and exploratory in nature with the aim to capture age-related shifts without imposing a presupposed shape. Instead, we treated age continuously and used tools sensitive to nonlinear patterns which sidesteps assumptions of linearity and definitional issues related to categorical treatment of data. We hope this approach will contribute to a detailed account of how risky decision making changes from early adolescence to early adulthood. However, this study is limited by investigating age-related changes in risky choices cross-sectionally. Future work should explore this behavior in a longitudinal sample. We also did not explore the degree of intimacy or stability of friendship between the dyads. Incorporating this variable into future work could enrich understanding of friend dynamics in further shaping the influence of peers on decisions about risk.

An additional consideration concerns our choice set, for which on average, the risky option was more economically advantageous. This type of choice set is commonly used to

combat participants' natural tendency for risk aversion. This might have limited our ability to examine risk in disadvantageous contexts. Future work could use a different set of choices varying the advantageousness of risks to further disentangle these concepts. Additionally, our choice set did not include risky choices in the loss domain, due to feasibility concerns for overly long study sessions and the potential for attrition over multiple sessions. The loss domain could provide crucial insight in how friend outcome might shape adolescents' risky choices differently, however, and is an important avenue for future studies to examine.

Conclusion

This study used analyses of continuous age and both computational and behavioral measures to chart the changes in risky decision making from early adolescence to young adulthood under different social-motivational contexts. We found that opposite outcomes for oneself and one's friend elicited a robust shift in risk preferences in comparison to when risky choices only impacted oneself, and that younger adolescents are more sensitive to the influence of this social context, incurring more losses and disadvantageous risks. This suggests that overall, early adolescence is a period in which motivation is high to exhibit behaviors that showcase self-sacrifice that benefits peers, highlighting the potency of the social environment during this time of life.

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Paper 2: Developmental emergence of complex prosocial motives and their influence on risky decision making

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In preparation.

Abstract

Humans hold beliefs about others' preferences, which can inform a range of decisions including those involving risk. However, the accuracy of these beliefs, and the weight placed on our own preferences versus someone else's for a decision that impacts both individuals, remains poorly understood. It is particularly relevant to characterize the role of beliefs about peer preferences in decision making during adolescence, a phase of the lifespan where peers take on a heightened importance and have an outsize impact on risky decisions. Using a sample of typically developing friend dyads (N = 128, 12.0-22.8 years), we collected fully mutual data on decision preferences in an economic risky decision making task with safe (certain) and risky (more variable outcomes) options that varied in their expected value. We modeled the adjudication between one's own and friend's outcome with a modified expected utility model and characterized age-related changes with Generalized Additive Models. On average, participants overestimated their friend's preference for risky choices across the full span of ages that were tested. In addition, we analyzed age-related changes in decision making for risky

choice scenarios in which one of the two individuals must receive a nonpreferred option, both when following their genuine preferences and when taking the perspective of their friend. Participants aged 16-22 years weighed their friend's outcome more, and earned less, when taking their friend's perspective compared to their own. Young adults were willing to shield their friends from unwanted risks even when no monetary incentive was on the line. Together, these findings highlight late adolescence to early adulthood as a heightened period for prosocial considerations.

Introduction

The manner in which peers shape risky decision making has long been a topic of interest in developmental science and psychology more generally (e.g., Andreoni & Miller, 2002; Gardner & Steinberg, 2005). After all, making a risky decision often has consequences not only for oneself, but also for the peers one surrounds oneself with. While peers could influence risky decisions in an overt manner through active encouragement (Powers et al., 2022; Simons-Morton et al., 2014; Wagemaker et al., 2020), they could also shape decisions in more subtle ways. A multitude of motives may drive an individual to modify their expressed preferences when peers are involved, such as concerns of peer evaluation and social reputation (Braams et al., 2019; Rodman et al., 2017; Somerville, 2013; van Hoorn et al., 2016).

Layered beneath the overt ways that peers could shape decisions about risk are a set of beliefs about the preferences and desires of one's peer. Beliefs about peers' risk preferences could shape risky choices involving the peer, even when those assumptions are miscalibrated relative to their actual preferences. The present study measures the degree of (mis)calibration of beliefs about peer preferences and characterizes how they are utilized in computations

surrounding decision contexts where self- and friend-preferences might be at odds with each other (e.g., when a choice option is scarce and believed to be desired by both parties, and one must decide between keeping it or giving it to their peer). Understanding *how* beliefs about peer preference gets incorporated into the risky choice computation process can help shed light on the higher-level question of motives behind *why* peers influence decision making differentially across development.

The dynamic social landscape during adolescence, a developmental period beginning around the onset of physical puberty and ending around the assumption of adult roles (e.g., Spear, 2000), paired with ongoing cognitive development, makes it a phase uniquely suited to study how beliefs about peer preferences are incorporated in these decisions. One cognitive mechanism required in weighing the pros and cons of prosocial decisions is perspective taking, which continues to develop through late adolescence (Dumontheil et al., 2010). Another is the incorporation of intentionality and social contexts in strategic fairness decisions (e.g., preferring fairness in order to maximize payoff, in case unfair offers get rejected), which increases with age in adolescence as well (Güroğlu et al., 2009). Making choices that maximize a peer's outcome at the expense of one's own may require cognitive control (Steinbeis et al., 2012), which also increases with age (Somerville & Casey, 2010). Thus, various processes that lay the foundation of the computations involved in these decisions develop well into adolescence, making it an opportune period to study risky decisions involving differing outcomes for self and peers, as information on age-related changes would contribute to a more thorough account of how beliefs about peer preferences shape individuals' decisions.

We predict that during adolescence, individuals will weigh potential outcomes of one's choice for their peer more heavily relative to their own. Specific age-related patterns

characterizing the development of prosocial behaviors (voluntary acts intended to benefit others (Eisenberg et al., 2005)) have not been consistent in work to date (see Do et al., 2017 for a review). Some have argued this is due to discrepancies in the social contexts evoked by varying experimental paradigms, as prosocial behavior is increasingly sensitive to social contexts with age (Güroğlu et al., 2014).

Despite this variability, consequences for peers are likely to encourage adolescents' prosocial risk taking on several grounds. Peers become the dominant social group that adolescents spend most of their time with (Brown, 2004). Adolescents are also especially sensitive to peer rejection and value peer acceptance (Masten et al., 2011; Rodman et al., 2017; Silk et al., 2012). Thus, in addition to the developmental patterns of the aforementioned cognitive processes, the importance of peer relationships during adolescence also renders this age window particularly rich with age-dependent variances in individual's beliefs about peer's preferences in risky decisions.

The present study examines how implicit assumptions about peers' preferences impact risky choice in a sample that spans from early adolescence to early adulthood. We collected mutual data from real-life friend dyads about their own wishes, and their predictions of their peers' preferences. These predictions were used as input in a computational model developed specifically for contexts that induce conflicting self- and friend-interests, permitting analyses on how one chooses differently from their own versus their peer's perspective. Peer dyads in this study were age- and gender-matched friends in real life rather than strangers to evoke the possibility of genuine relational motives. The study aims to characterize three specific facets of how implicit beliefs on peer preferences change across age:

1) The accuracy of beliefs about risk preferences of the peer.

2) Whether participants would like their peer to prioritize themselves or the participant's own wishes.

3) When participants are explicitly told that their peer's preference conflicts with their own, whether participants were willing to relinquish their original preferred option so their friend could receive it.

Methods

The data that support the findings for this study are openly available at https://osf.io/ku38b/?view_only = 6add6a92f0144ce090ab1cdefab165b1. See "project data + analysis" for data and analysis code.

Participants

Participants were recruited in same-sex peer dyads who identified one another as friends (N = 128, age range: 11.98-22.82 years, N = 37 adolescent pairs, ages 11.98-17.46 years; 18 pairs female and 19 pairs male; N = 27 young adult pairs; ages 18.16-22.82 years, 14 pairs female, 13 pairs male). One participant from the adolescent group identified as gender non-conforming and was the peer partner of a male-identifying participant, and one participant from the adult group identified as transgender male and was the peer partner of a male participant. Male and female pairs were distributed evenly across the age range (logistic regression with age predicting gender, B = -0.014, p = .789) and pairs had an average age difference of 0.46 years (min = 0.01, max = 1.39, SD = 0.33). The race/ethnicity composition was 15.6% Asian, 6.3% Black or African American, 10.2% two or more races, 0.8% other, 0.8% Native Hawaiian or Pacific Islander, 66.4% White. The distribution of average parental education level as a proxy for socioeconomic status (SES) was not related to age (linear regression, B = -0.016, p = .439), indicating SES is

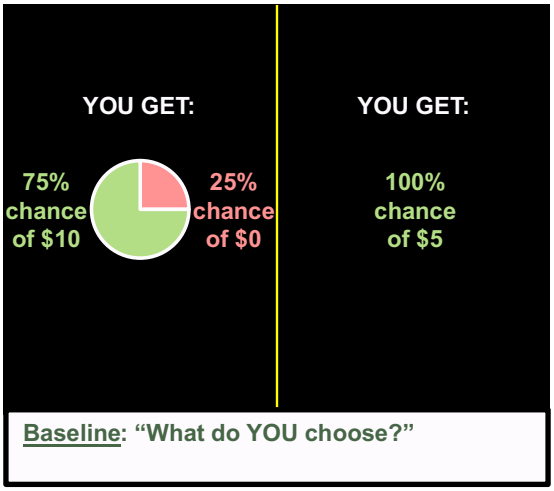
balanced across age. Participants were excluded if they did not have access to a computer with a camera, and if they were diagnosed with learning disability or received special services at school. Participants provided informed written consent/assent, and parents/caregivers of minors gave written permission for their participation. The Committee for the Protection of Human Subjects at Harvard University approved this research.

Risky Decision Making Task

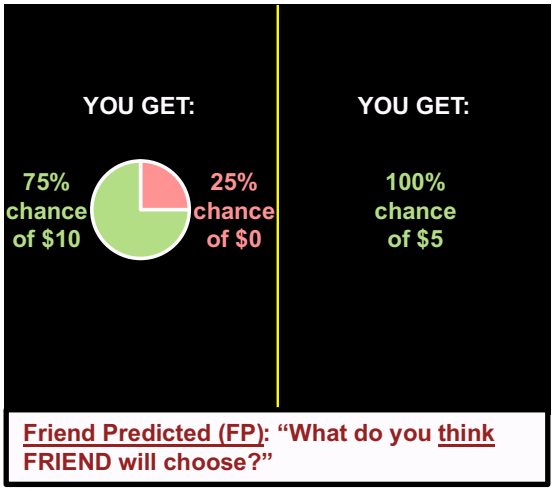
Participants completed an economic decision making task consisting of different choice options varying in monetary payout and odds of winning, which has been used in previous studies to quantify individuals' risk preferences in adult (Chung et al., 2015; Levy et al., 2010; Sip et al., 2015; Tymula et al., 2012, Powers et al., 2018) and adolescent samples (Tymula et al., 2012, Powers et al., 2018). On each trial, participants selected between two choice options displayed on the left and right sides of the screen (Figure 5) varying in risk: a) a safe option "100% chance of winning $5" and b) a risky lottery option (10%, 25%, 50%, 75%, or 90% probability of winning [$5, $10, $20, $30, $40, $50, $100]; Tymula et al., 2012, Powers et al., 2018) depicted with a pie chart indicating the odds of earning the amount displayed or earning $0. The safe and risky options were counterbalanced to appear on the left and right sides of the screen at equal frequency. Each probability was paired with each amount totaling 35 trials per condition, with the order of trials randomized. There were 5 conditions in total (for details, see Figure 5 and section "Condition" below). Participants indicated their choice in self-paced timing by pressing one of two keyboard buttons, at which point the trial ended; there was no immediate feedback on the outcome of the decision.

Participants were instructed that they and their friend would receive a fixed percentage of the cumulative amount of money they earned through their choices as a bonus in all conditions except for the Friend Predicted condition, with a computer simulating the chosen lotteries to determine earnings. Participants in the "friend" role were paid the same percentage in all conditions except for the Friend Predicted and Desired Opposite conditions (i.e., conditions where participants' choices were conjectures) based on choices made for them by the participant in the primary decision maker role.

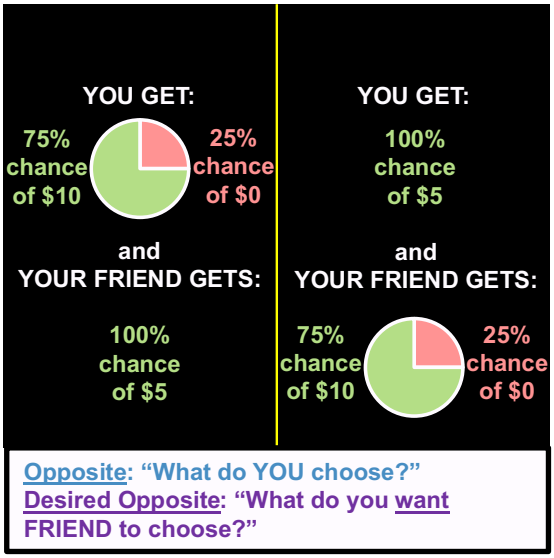
A. Baseline



B. Friend Predicted



C. Opposite and Desired Opposite



D. Preference Revealed

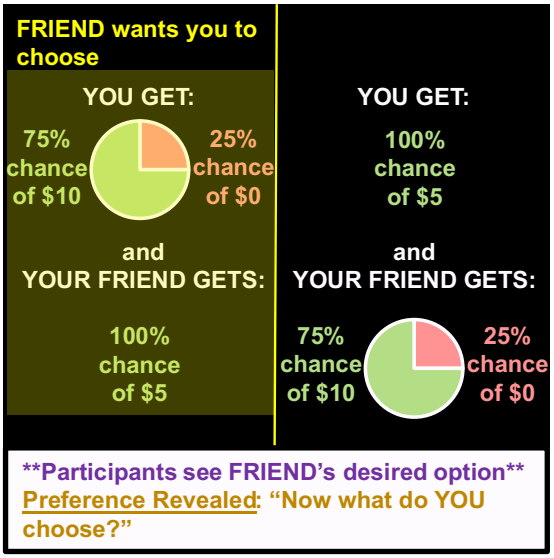


Figure 5. Example trials from different conditions in the experiment. The black sections indicate what participants saw in different conditions. The questions they were asked are displayed below. The safe option is always 100% chance of winning $5, and the risky option is the pie chart. In this example trial, the risky option is 75% chance of winning $10 and 25% chance of winning $0. In the A) Baseline condition, participants indicated their own risk preferences. In the B) Friend Predicted condition, participants predicted what their friend will choose. In the C) Opposite condition, participants view "opposing" choice options and select whether they or their friend will receive their preferred option, and in the (C) Desired Opposite condition, participants indicate what they would like their friend to choose. Finally, in the D) Preference Revealed condition, participants first were shown friend's actual preference in the yellow box, and then were asked to choose whether they or their friend will receive the friend's preferred option.

Experimental Procedure

Following screening and consenting, each participant completed an individual online testing session on Qualtrics. Following comprehension checks, they completed several iterations of the risky decision making task in a pseudo-randomized order. Once both participants in a dyad completed their individual session, they logged in separately on Zoom and co-participated synchronously for the second part of the study (Preference Revealed condition) with an experimenter. Screen sharing and camera status was manipulated to control whether the participant in the "friend" role was observing the participant in the decision maker role in real time. Observation did not induce any effects on risky choice (See Supplementary Materials). The Preference Revealed condition (described below) therefore included both observed and unobserved trials.

Conditions

Baseline: Participants saw the graphics in Figure 5A while they answered the question: "What do YOU choose?" (Figure 5A). The Baseline condition is meant to capture participants' baseline risk preferences.

Friend Predicted: Participants saw the same graphics as Baseline but instead answered the question: "What do you think your FRIEND will choose?" (Figure 5B). The Friend Predicted condition is meant to capture participants' beliefs about their friend's risk preferences.

As both members in a dyad took on the role of decision maker and friend, contrasting these two conditions permits analysis on the accuracy of predicted risk preferences for friends.

Opposite: Participants selected an outcome for themselves with the knowledge that the unselected option would apply to their friend (Figure 5B), answering the question: "What do YOU choose?" (Figure 5C). The Opposite condition required participants to choose between keeping their preferred option or assigning their preferred option to their friend.

Desired Opposite: Participants saw the same graphics as in the Opposite condition but instead were asked to imagine the screen from the friend's perspective and answered the question: "What do you want your friend to choose?" (Figure 5C). This condition served two purposes. First, participants are shown these responses in the next condition (Preference Revealed) as an explicit indicator of their friend's preference. Second, contrasting participants choices in this condition with the Opposite Condition permitted analysis of whether participants preferred that their friend be generous to them (i.e., give the participant their preferred option) or whether participants thought their friend should be generous to themselves (i.e., assign the participant's preferred option to themself). Participants were told "later on in the study, [FRIEND NAME] will see what you wanted her to choose."

Preference Revealed: Participants saw the same choices as in the Opposite condition (twice due to the observation manipulation, which gives us two opportunities to see whether the original preferences were relinquished) over Zoom. On each trial, they saw the text "your friend wants you to choose: " and a yellow box indicating their friend's actual preference (which they indicated in the Opposite condition with themselves as the decision maker). Then they made their choices, answering the question: "What do YOU choose?" (Figure 5D).

Analysis

Treatment of Age

Because risk attitudes have been found to follow a nonlinear pattern of age-related change from childhood to adulthood (Casey et al., 2011; Cauffman et al., 2010; Figner et al., 2009; Galvan et al., 2007), we adopted an exploratory data driven approach with analyses that are sensitive to nonlinear age related changes. Specifically, we fit generalized additive models (GAM) (Hastie & Tibshirani, 1986, 1990) using the gam function from the *mgcv* package (v1.8.38, Wood, 2003, 2004, 2011, 2017) to examine the effect of age as a continuous predictor on the dependent measures.

To compare the age pattern for different levels of a categorical variable, GAM fits a nonlinear function for each level of a categorical variable (factor smooth interaction) without providing a direct statistical test for the interaction between the smoothed variable and the categorical predictor of interest. Therefore, we used the *plot_diff* function from the *itsadug* package (v 2.4, van Rij et al., 2022) to inspect the relative difference between fit estimates of each pair of conditions (i.e. Friend Predicted vs. Baseline, Desired Opposite vs. Opposite, odds of relinquishing safe options vs. risky options for trials with conflicting preferences and for a subset of these trials with equal EV for safe and risky options) and compute 95% simultaneous CIs around it. Age bands where the simultaneous confidence interval (CI) did not contain zero are interpreted as periods of significant differences between the conditions.

For all group analyses, the random effect structure treated participant as nested within a dyad (each representing a friend pair) to account for any dependencies related to the data being collected on pairs of friends.

Model Fitting

We fit a probabilistic choice model with two free parameters to each participant's choices for Baseline and Friend Predicted conditions to quantify individual risk attitudes (Gilaie-Dotan et al., 2014; Levy & Glimcher, 2011; Levy et al., 2012; Levy et al., 2010). As in Powers et al. (2018), we modeled the expected utility of each option with a power utility function:

$$EU = pv^{\alpha} \qquad original\ model$$

Where *v* is the amount of money on a given choice and *p* the probability associated with winning that dollar amount. α (Alpha) is the estimated parameter of interest for risk attitude, where risk is defined as outcome variability (Weber et al., 2004), i.e., the choice with a wider range of potential outcomes is the riskier outcome. In the present task, the choice depicted with a pie chart (i.e., two possible outcomes with varying potential financial impact) is the risky choice. Alpha < 1 indicates an agent is risk averse with a concave utility function, preferring the safe option to a risky option with equal expected value, calculated as the dollar amount multiplied by the probability of winning that option.

The Opposite and Desired Opposite conditions required an adaptation of the expected utility model to incorporate the utility of the unchosen option assigned to the friend relative to that of the chosen option for oneself. This adjudication was reflected in the parameter *w* ($Weight_{friend}$):

$$EU = (1-w)p_{self}{v_{self}}^{\alpha} + w\left(p_{friend}{v_{friend}}^{\alpha_{friend}}\right) \qquad revised\ model$$

Where p_{self} and v_{self} are the probability and amount of money associated with the option participants intend to choose for themselves and p_{friend} and v_{friend} are associated with the unchosen option assigned to their friend.; α_{friend} was estimated from the Friend Predicted condition with the original model, representing one's assumed friend's baseline risk preference. $Weight_{friend}$ (*w)*

represents how much one's utility is based on one's own outcome in contrast to how much one incorporates their estimation of their friend's outcome and is bounded between 0 and 1. The larger it is, the more the participant values the utility of their friend's outcome relative to their own. Alpha is still the free parameter to be estimated for participant's risk attitude. Both Alpha and $Weight_{friend}$ were analyzed as Dependent Variables as important aspects of risky choices in the Opposite vs. Desired Opposite contrast.

With both the original and revised model, we fit each trial within a condition to a logistic function that computes the probability of the participant choosing the risky option on that trial given the expected utility of the safe and the risky option, with a maximum likelihood procedure:

$$P(choose\ risky) = \frac{1}{1 + \exp\left(\beta\left(EU_{safe} - EU_{risky}\right)\right)}$$

Where EU_{safe} is the expected utility of the safe option and EU_{risky} is the expected utility of the risky option. Beta is the inverse decision noise.

Parameter recovery showed that both models recovered robustly ($r > 0.7$, see Supplementary Materials for more details). Model comparison showed that the original model outperformed revised models for contexts where the risky choice was solely consequential for oneself (Baseline, Friend Predicted), and the revised model outperformed original model for contexts where one member of the dyad must receive the nonpreferred option (Opposite, Desired Opposite, Preference Revealed; See Supplemental Materials).

Model-based exclusions:

Participants were retained in analyses whenever possible, so exclusions are condition dependent. For the Baseline and Friend Predicted conditions, we excluded participants with Alpha exceeding 3.32, which is the maximum theoretical recoverable value based on our choice set. For the Opposite and Desired Opposite condition, we excluded participants whose Alpha exceeded 2 or $Weight_{friend}$ lower than 0.000001. This threshold was set based on two considerations. First, both the revised model and the original model showed the best parameter recovery for Alpha in the range of 0 to 2 (correlation between simulated and fitted alpha in the range of [0,2]: original model: r = .94, revised model: $r = 0.78$, $Weight_{friend}$: $r = 0.73$). Second, the simulated choice behavior generated by Alpha values ranging from 2 through 3.32 was indistinguishable (see Supplemental Materials for more details). We also excluded participants whose AIC from the computational model was equal to or exceeded the AIC value for someone with chance choice behavior from that condition. Model based exclusion resulted in exclusion rate of less than 8% (see Supplemental Material). Note, these exclusions only apply to analyses of Alpha and $Weight_{friend}$ as dependent variables, i.e., all data were included in analyses of other dependent variables.

Dependent Measures

1. Alpha and $Weight_{friend}$: Model-based estimation of how risk seeking an individual is and how much they weigh their friend's utility relative to their own (see Model Fitting section).

2. Proportion of risky choices: We additionally report analyses of risky choice behavior, calculated as the number of risky options participants selected for themselves divided by total number of trials within a condition for each participant, as a simple behavioral readout of risk

preference. This measure is not as sensitive to changes in risk attitudes as Alpha, as the computational model takes into account the relative utility of the options on each trial, which Proportion of Risky Choices cannot capture. However, Proportion of Risky Choices is not subject to model-based exclusions described above, and thus presents a comprehensive sketch of risky choice behavior.

3. Measure of simulated earnings: Simulated earnings were computed for each participant for each condition by calculating the sum of the expected value (EV) of each selected choice option. Simulated earnings were modeled as proportions of the total possible earnings (calculated as the sum of all highest-EV choices) using a beta distribution to better reflect the distribution of the data and improve the accuracy of the model fit and generalizability. Therefore, the test statistic is expressed in *z*-values and the resulting plots with *y*-axis on a logit scale.

4. Relinquishing preferred options: We identified trials where the participant's friend wanted the participant to assign them the option which the participant actually wanted for themselves. This was achieved by comparing trials with the same probability and money combinations from participants' Opposite condition (*what do you choose?*) and their friend's Desired Opposite condition (*what do you want your friend to choose?* Figure 5C). An example of conflicting preferences would be I assign the safe option to myself in the Opposite condition while my friend assigned the safe option to themselves in their Desired Opposite condition (i.e., they wanted me to assign the safe option to them and the risky option to myself, contrary to my preference). Then, we evaluated in Preference Revealed condition, when they encounter these trials again and were made aware of their friend's wishes, whether they would relinquish their original preference to accommodate their friend's preference (coded as 1) or not (coded as 0). In contrast to all other analyses that started with N = 128 participants, the Preference Revealed

condition started with usable data from N = 123 participants (3 participants failed the comprehension checks and did not call the experimenter, and 1 additional pair that had technical issues resulting in data loss, were excluded).

Results

Accuracy of Friend Predicted Risk Seeking

This analysis evaluated the relationship between age and the discrepancy between how risk seeking participants predicted their friend to be and how risk seeking their friend actually was by comparing model-derived Alpha, indexing risk preference, from the Baseline condition and the Friend Predicted condition. Participants, on average, estimated their friend to be more risk seeking than the friend's actual risky choices indicated (Mean Alpha in Friend Predicted vs. Baseline: 0.63 vs. 0.55, $B = 0.08$, $t = 2.59$, $SE = 0.03$, $p = .010$). Evaluating this question with the behavioral readout Proportion of Risky Choices, we did not observe this difference (Mean Proportion of Risky Choices in Friend Predicted vs. Baseline: .52 vs. .49, $B = 0.10$, $z = 1.64$, $SE = 0.06$, $p = .101$). 95% simultaneous CIs around the fit estimates for both Alpha and Proportion of risky choices indicated that there were no age-related differences in the tendency to overestimate their friend's risk preferences.

Perspective Taking: Desired Opposite vs. Opposite

To examine how the desired outcome for oneself changes when the decision was made from one's friend's vs. one's own perspective, we compared the Desired Opposite condition

(*what do you want your friend to choose for themselves and you?*) and Opposite condition (*what do you choose for you and your friend*?). We analyzed the changes in participants' risky choices for themselves. Overall, participants chose the same option from their and their friend's perspective 39% of the time (95% CI [38%-41%]). Below we report results on different aspects that characterized their risky choice behavior: risk preference (Alpha), how much individuals value their friend's outcome relative to their own ($Weight_{friend}$), and to what extent they were maximizing their monetary payouts (simulated earnings).

1) Alpha

Overall, the computational index of risk seeking was similar when choosing from one's own and one's friend's perspectives. There were no main effects of condition or age-related changes in Alpha (Mean Desired Opposite vs. Opposite: 0.75 vs. 0.69. $B = 0.06$, $t = 1.31$, $SE = 0.05$, $p = .193$) derived from the revised computational model (Equation 2). This indicates consistency in risk seeking when thinking of themselves or their friends as the decision maker. Analysis using Proportion of Risky Choices instead of Alpha also did not show a difference between the two conditions (Mean Proportion of Risky Choices in Desired Opposite vs. Opposite: .54 vs. .56, $B = -0.03$, $z = -0.37$, $SE = 0.07$, $p = .709$).

2) $Weight_{friend}$

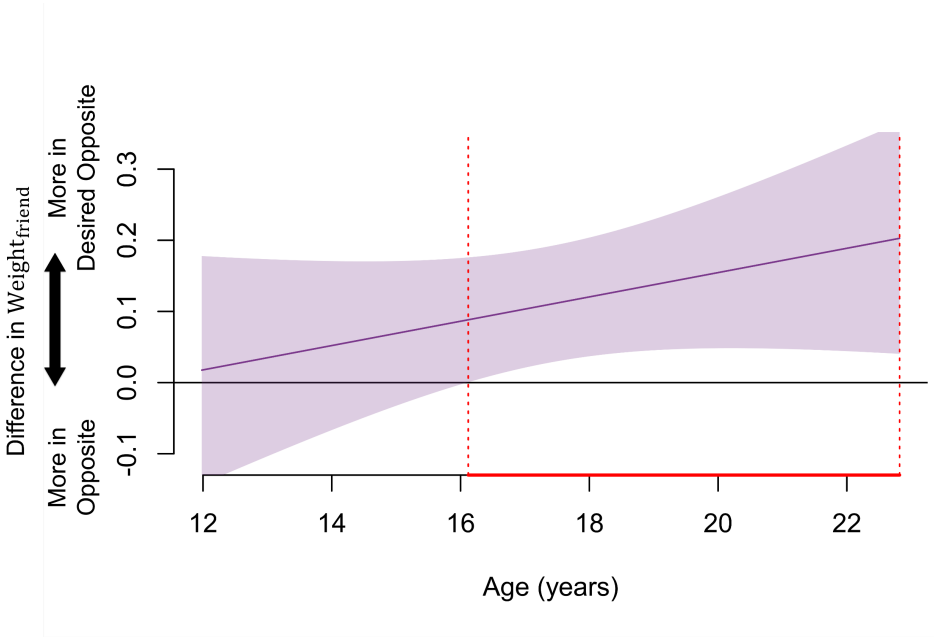
Next, we evaluate the difference in how much the friend's outcome is weighed in one's decision relative to their own using the computational parameter indicating the weight placed on the friend's outcome. There was a main effect of condition (Mean Desired Opposite vs. Opposite: 0.46 vs. 0.35, $B = 0.11$, $t = 3.23$, $SE = 0.03$, $p = .001$), indicating participants, on

average, weighed their friend's outcome more when they made decisions from their friend's perspective than from their own. There was a significant age-related difference in this tendency between 16.1-22.8 years, and $Weight_{friend}$ was not significantly different between the conditions for the rest of the age range. During late adolescence and into early adulthood, individuals weighed the utility of the option assigned to one's friend more heavily when taking their friend's perspective (thinking what decisions they would like their friends to make), compared to from their own perspective (Figure 6A).

3) Simulated Earnings

Participants earned less overall in the Desired Opposite condition (Mean Desired Opposite vs. Opposite: 0.68 vs. 0. 80, B = -0.44, z = -3.58, SE = 0.12, $p < .001$), when they took their friend's perspective in assigning options to themselves, relative to the Opposite condition when they were taking their own perspective. There was a significant age-related difference in this effect between age 15.4-22.8 years, indicating older adolescents and young adults assigned options to themselves that had lower expected values while taking friends' perspective compared to their own (Figure 6B).

A.



B.

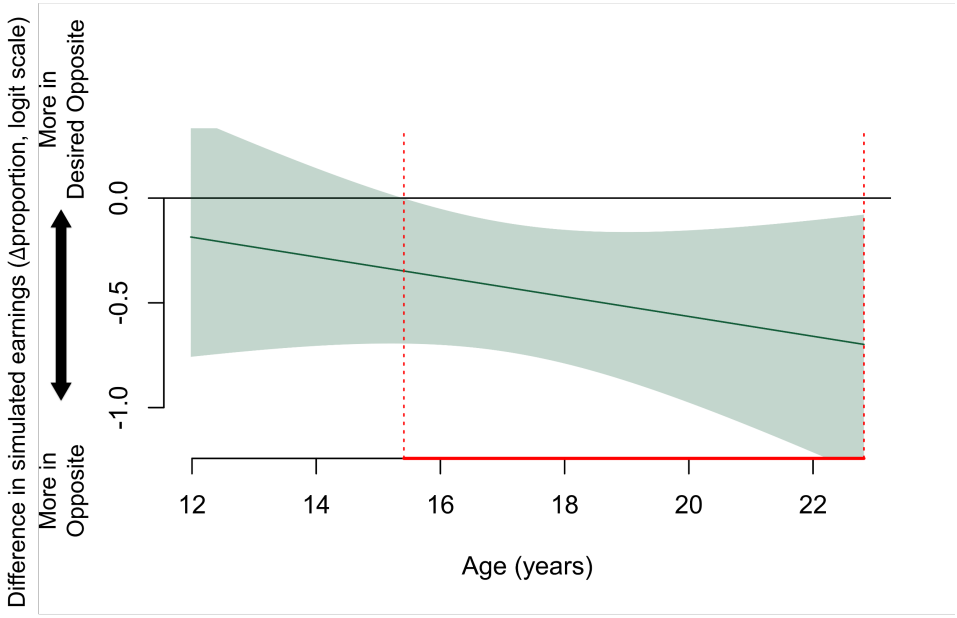


Figure 6. Age-related patterns of risky choice: difference of fit estimates of the GAM model. Shaded area represents 95% simultaneous CIs of the difference between fit estimates at each age point. A) Weight$_{friend}$: dotted red lines show that between 16.1-22.8 years, the 95% simultaneous CIs do not include 0, suggesting people in this age window weighed their friend's outcome more when taking friends' perspective as decision maker compared to their own. B) Proportion of simulated earnings: dotted red lines show that between 15.4-22.8 years, the 95% simultaneous CIs do not include 0, indicating a significant negative difference, suggesting individuals in this

age window earned less when taking friend's perspective as decision maker compared to their own.

Relinquishing preferred option when confronted with conflicting friend wishes

To evaluate whether there are age-related patterns in the willingness to relinquish one's preferences after learning they conflicted with one's friends', we analyzed the extent to which participants switched their original selection on trials with conflicting preferences (55.16% of total trials), so their friend could have their preferred option, and age-related changes in this tendency using a logistic GAM. The binary DV was derived from contrasting what participants selected in the Preference Revealed condition with what they selected in the Opposite condition. Individuals relinquished their preferred option with a 30% probability on average (95% CI: [28%-31%]). The GAM model did not reveal significant age differences in how likely an individual is to yield to their friend's wishes (*edf* = 1.00, chi-square = .58, p = .447).

Next, we examined the directionality of participants' relinquishing their preferred options to accommodate their friend's preferences. Are individuals more likely to accommodate their friends when it entails switching from an originally preferred risky option to a non-preferred safe option, or from an originally preferred safe option to a non-preferred risky option? Overall, people were more likely to relinquish their original preference if it entailed giving up their originally preferred safe option than if it required relinquishing their originally preferred risky option (Mean probability of relinquishing when originally preferred safe vs. risky option: 0.32 vs. 0.28, B = -0.49, Z = -5.57, SE = 0.09, p<.001). There was a significant age-related difference between 19.8-22.8 years old, where people were more likely to relinquish their originally

preferred safe option and receive friends' undesired risky option, compared to switching in the opposite direction (Figure 7).

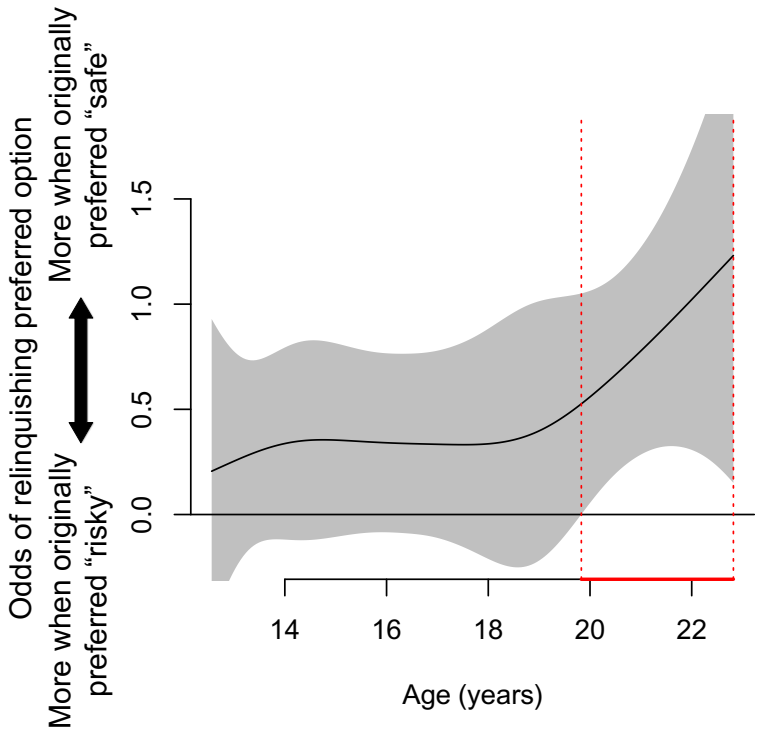


Figure 7. Age-related patterns of odds of relinquishing preferred option on trials where there was a conflict between self- and friend preferences. Shaded area represents 95% simultaneous CIs of the difference between fit estimates at each age point. Dotted red lines indicate between ages 19.8 and 22.8 years, the 95% simultaneous CIs do not include 0, indicating significant age-related changes. Positive difference indicates participants were more likely to relinquish if they originally preferred the safe option than if they originally preferred the risky option. Negative difference indicates the opposite. Zero indicated there is no difference between the odds of switching in either direction.

Since risky options are, on average, more advantageous in our choice set by design to encourage individuals to overcome their natural risk aversion, it is not possible to disentangle prosocial motives from monetary motives from the effect described above. Thus, we conducted additional exploratory analyses to develop a better understanding of the potential motives behind

the willingness or reluctance to relinquish one's preferences that might vary with age. Specifically, we examined the question above in a subset of trials where the expected value (EV) of the safe and risky options were equivalent (these trials were evenly distributed across age, see Supplemental Materials). The rationale for this analysis is that relinquishing a preferred option on equal-EV trials would not be driven by a motive to maximize earnings. Rather, it would indicate that a prosocial motive alone was sufficient to overcome their initial preferred level of risk aversion on these trials. Analyses therefore reflect age-related changes (and directionality) in the tendency to relinquish a preferred risky or safe option to a friend when that friend wanted it (Analyses on the unequal-EV trials are reported in Supplemental Materials).

We found a significant age window between 19.8 and 21.5 years where individuals were more likely to relinquish their preferred safe option to their friend and receive the equal-EV risky option themselves instead than switching in the opposite direction (Figure 8). We infer that when the potential for monetary gain is held equal, participants from this age range adjusted away from their preferred level of risk aversion because they wanted to shield their friends from unwanted risks.

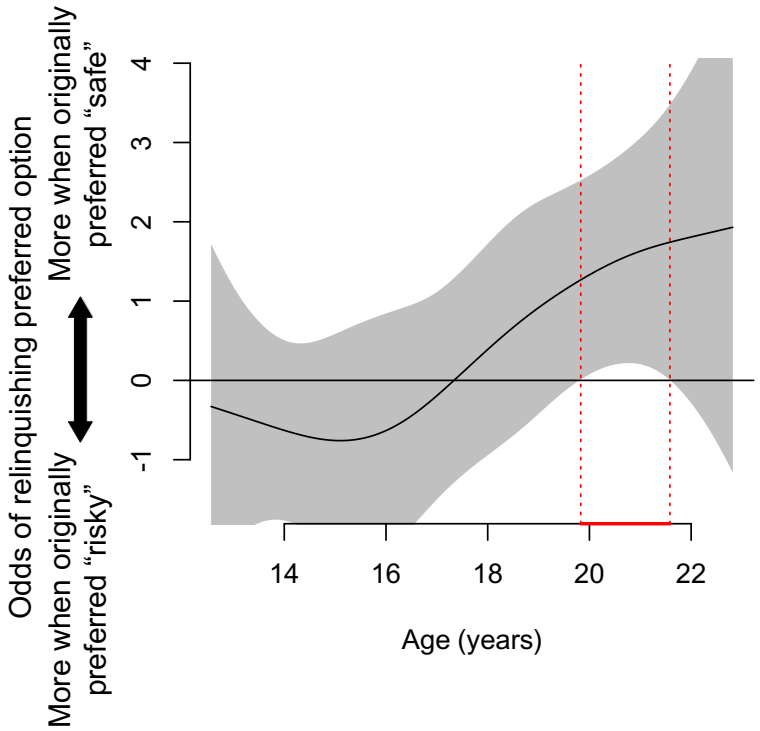


Figure 8. Age-related patterns of odds of relinquishing preferred option on trials where the EV of the risky and safe options are equivalent AND there was a conflict between self- and friend preferences. Shaded area represents 95% simultaneous CIs of the difference between fit estimates at each age point. Dotted red lines indicate between ages 19.8 and 21.5 years, the 95% simultaneous CIs do not include 0, indicating significant age-related changes. Positive difference indicates participants were more likely to relinquish if they originally preferred the safe option than if they originally preferred the risky option. Negative difference indicates the opposite. Zero indicated there is no difference between the odds of switching in either direction.

Discussion

The present study examined how beliefs about peers' risk preferences get incorporated into individuals' decision making differentially across age from adolescence to young adulthood. By collecting real assessments of peer preferences and peers' beliefs about these preferences and developing a computational model to quantify the degree to which these beliefs influence risky choice, we position ourselves to identify how these beliefs shape risky choice across

adolescence. We found that participants -- regardless of age -- slightly overestimated their friend's risk preference. In a social context that entailed adjudicating one's own outcome against one's friend's, people on average, and mid-late adolescents and young adults in particular, altered their own risky choice behavior when taking their peer's perspective in a direction that downweighed their own utility relative to the peer's and earned less than when taking their own perspective. When participants were explicitly made aware of their peer's conflicting preferences, young adults were more likely to relinquish their preferred safe option even when there were no potential monetary gains. Taken together, these findings reveal how, in addition to overt ways peers may shape adolescent risky choice, belief-based mechanisms are differentially important across adolescence in shaping risky decisions. Prosocial strategies that reflect utilization of more sources of information and more complex underlying motives emerge through the transition from adolescence to early adulthood.

Miscalibrated beliefs about peers' risk preferences

The current study collected mutual data on risk preferences, which permitted quantification of the degree of calibration between the actual vs. believed risk preferences of each member of a dyad. Results showed that participants overestimated their friends' risk preferences. This was consistent across the age range from early adolescence to early adulthood. Overestimating peers' risk preference could amplify risk taking by creating a miscalibrated target. Given the special value adolescents place on social acceptance and avoiding rejection (Masten et al., 2011; Rodman et al., 2017; Silk et al., 2012), their desire to assimilate to higher status peers (homophily, Brechwald & Prinstein, 2011) combined with the tendency to overestimate how risk seeking their friends are could motivate them to "overshoot" on their own

risky behavior. Indeed, it has been argued that adolescents' heightened risk taking does not stem from their judging risky scenarios as less risky than other age groups, but rather their propensity to align their assessment of riskiness with their peer's (Knoll et al., 2015a). This potential mechanism could explain many real-life cases of homophily in adolescent health risk behavior. For instance, perceived peer substance use, in adolescents aged 10-15 years, predicted with the extent and onset of their own consumption (D'Amico & McCarthy, 2006), and having friends that smoke or drink strongly predicts these behaviors in oneself in 11-18 year olds (Loke & Mak, 2013). Our result extends this line of work by highlighting how the target of homophily may deviate from reality and thereby inflate levels of risk seeking.

The lack of age-related differences in the degree of miscalibration was somewhat unexpected, as we had imagined adolescence to be a time of heightened susceptibility to miscalibration based on prior work (Brechwald & Prinstein, 2011) more so than young adults. However, there are hints from the intervention literature suggesting similar miscalibrations could influence engagement of health risk behaviors in young adulthood. In college students, who have been shown to overestimate peer heavy alcohol consumption (Perkins & Berkowitz, 1986), normative feedback -- explicitly showing individuals the base rates for drinking behavior (the actual norm on campus) in conjunction with one's own actual and perceived drinking level to facilitate comparison of one's own behavior relative to norms -- is an effective strategy to curb heavy drinking behavior (Lewis & Neighbors, 2006; Neighbors et al., 2004). This implies that health risk behavior in young adults may also arise from a miscalibrated belief that "everyone is doing it." The present study extends our understanding of peer influence by highlighting how miscalibrated beliefs about others' risk preferences could be a covert route of peer influence in adolescents and young adults alike. Additionally, it indicates the potential of normative

approaches in helping them refrain from excessive risk taking by informing them what the actual "typical" behavior is in their social group.

Wanting your friend to prioritize their own wishes

The present study constructed "opposite" decision contexts in which participants made risky choices that assigned risky and safe options to themselves and their peer. Moreover, participants made these choices from their own perspective and from their friend's *("What do you want your friend to choose?").* These scenarios set up a potential conflict needing adjudication, between wishing one's friend would assign themselves the option they prefer (i.e., prioritizing their own wishes when they are the decision maker) and hoping the friend would assign oneself one's favored option. To evaluate the strategies employed across our developmental sample, we created and validated a computational model that quantified the weight placed on the friend's outcomes relative to one's own. Comparing trials in which participants decided "as themselves" versus the decisions they would like their friend to make (henceforth, decisions from friend's perspective), permitted evaluation of how individuals wish their friend to behave if it were the friend's turn to allocate the options.

We found that mid-late adolescents and young adults, when deciding from their friend's perspective, assigned more weight to the friend's outcome, consistent with a strategy of letting the friend choose what is best for themselves, even though this entails decreased earnings for oneself. By contrast, individuals of younger ages showed similar choices across the two decision frames, indicating consistency in wanting to keep one's preferred option, regardless of deciding from whose perspective. This age-related shift in strategy, shown by the age-related decrease in

earnings and increased weights participants placed on their friend's utility relative to their own, suggests a dynamic period of developing prosocial considerations from mid-late adolescence to early adulthood. Güroğlu et al. (2014) has shown that social context information takes on an increasingly important role in shaping prosocial behavior in four age groups (9-, 12-, 15-, 18-year-olds). Additionally, strategic prosocial behaviors (in which being prosocial is at least partly motivated by maximizing one's own gains) has been shown to increase with age during adolescence, supported through development in perspective taking (Crone & Achterberg, 2022; Güroğlu et al., 2014; Overgaauw et al., 2012; Steinbeis et al., 2012). We extend this body of work by suggesting one of the mechanisms behind this behavioral shift in older adolescents and young adults may arise from increased weighing of peer outcome relative to one's own.

Since our choice set makes it, on average, advantageous in terms of EV to pick the risky option for oneself, the fact that participants, on average, earned less but were *not* differentially risk seeking when deciding from their friend's perspective compared to their own could signal more "irrational" choices were made, such that the risk seeking level stayed constant, but the risks taken were *disadvantageous,* causing decreased earnings. However, maximizing one's utility necessitated considerations on both monetary and social fronts so this shift could be strategic in gaining social benefits. As participants knew the decisions in this condition would be seen by their friend later, we hesitate to attribute the motive behind age-related increase in weighing the friend's outcome to be purely selfless (i.e., wanting to maximize friends' outcome at their own expense). Rather, reputational concerns could also be motivating this shift in behavior. Fairness concerns could also be at play; from the decision maker's point of view, fairness could look like: "I prioritize myself when I am the decision maker, and I want my friend to prioritize themselves when they are the decision maker. It's fair we both prioritize ourselves."

This could happen in parallel with reputational motivations as well, as being fair can be strategic in gaining reputational benefits, and strategic fairness in decisions increases with age in adolescence (Güroğlu et al., 2009). Overall, these findings suggest increasingly refined decision strategies, potentially motivated by multiple social considerations, resulting in "wanting the best" for one's friends.

Young adults were more likely to relinquish preferred safe options if their friend also wanted them

The third goal of the study was to observe shifts in individuals' choice patterns, across age, when one faces conflicting preferences between oneself and one's friend. To address this question, we explicitly showed participants their friend's preferred options in the Preference Revealed condition. We found that participants were willing to relinquish their preferred option and let their friend receive it about 30% of the time, and there were no age-related changes to this rate. However, young adults were more likely to accommodate their friend's wishes when it required them to adopt nonpreferred risky option (and give up a preferred safe option) than to give up a preferred risky option.

There was a natural confound here, because the risky options tended to have a higher EV. Examining trials in which the expected values of the risky and safe options were equal, results that young adult participants shielded friends from their undesired risks held, absent any potential monetary gains. These findings show a later emerging prosocial tendency to prioritize friends' preferences in face of an overt conflict within the dyad's preferences.

The finding that young adults shielded friends from unwanted risks even when there were no potential monetary gains could suggest that costly prosocial behaviors follow a more protracted developmental trajectory. The significant age window for this pattern of relinquishing original selection appeared later in the age range compared to the age window for wanting friends to choose what is best for themselves. We speculate this could be due to differential willingness to actually give up one's preference relative to responding hypothetically. Perhaps actually relinquishing one's preference required more a more deliberate decision strategy to override the desire to maximize one's own payout. This costly prosocial behavior may require still-developing executive functioning or cognitive control (Güroğlu et al., 2014; Luengo Kanacri et al., 2013; Steinbeis et al., 2012). Flexible and sophisticated decision strategies increase with age with experience (Jacobs & Klaczynski, 2002); integrating across multiple sources of utility and simulating self- and friend-outcome requires late-developing brain areas that support complex cost-benefit analyses, such as the lateral prefrontal cortex (Hartley & Somerville, 2015). Therefore, older participants might be at a developmental stage more positioned for complex prosocial considerations and suppressing self-interest for social gains. Future work may test this proposal with a targeted design and a longitudinal sample.

At first glance, this late emerging window for prosocial concerns is surprising as our previous (Chen et al., in press) results showed early adolescence to be a particular age window where individuals take on self-sacrificing choices to benefit their friends. However, the decision contexts and the contrast therein are different in these two studies: early adolescents were most impacted by the decision context changing from one that only concerned themselves to one that required adjudicating between self- and friend-interest. In the present study, the trials being contrasted to probe whether individuals were willing to relinquish their initial preference upon

learning their friend wanted them all happened in the latter decision context. Young adults were more pliant to this "ask" compared to adolescents, whereas they were least impacted by the social context shift in our previous study. We conjecture this could signal either different priorities and consequent strategizing, or increasing deftness navigating complex social contexts and decisions to sustain one's relationships, as adolescents age into adulthood.

Limitations and Future Directions

The conclusions of this research should be contextualized relative to its limitations. First, we used a cross-sectional sample to evaluate age-related changes, which limits our ability to examine developmental trajectories. Future studies should explore these questions in a longitudinal sample. Our analyses used data-driven and exploratory modeling approaches, aiming to capture fine-grained age-related changes without presupposing any shape for the trajectory. Our results would benefit from replications using similar approaches that treat age continuously. We also did not explore the degree of intimacy or stability of the pairwise friendships, which could influence the quality or strength of prosocial motives. Future research with a much larger sample size may have the statistical power to examine how the strength or durability of friendships influence risky choices in addition to the effects of age, which were the focus here. Our choice set made risky options on average more advantageous in terms of EV, in order to encourage participants to overcome natural risk aversion. However, this choice may have limited our ability to dissociate payout maximization and prosocial motives in certain analyses. Future work could use a different set of choices varying the level of advantageousness of the risky options.

Conclusion

Beliefs and desires about peers' risk preferences may factor into individuals' risky decisions. However, as a covert route to peer influence, it has been underexplored in past research. By collecting fully mutual dyadic data on predicted and actual risky choices and using a computational account of weighing one's own and one's friend's utility, we were able to bring to the surface the intricate interplay between the beliefs, desires and choices of the dyads. We found that through the transition from adolescence into adulthood, several complex changes unfold, which add nuance to how our beliefs and others' preferences are incorporated into our choices. Although even young adults are susceptible to biased beliefs about their friend's risk preferences, a wider array of angles and strategies that factor in prosocial considerations emerge through the adolescent transition. Building on this work, future studies could characterize the social-cognitive processes that are co-developing with risky decision making to reveal the developmental mechanisms of these relatively late emerging prosocial strategies.

Acknowledgements

This work was partially supported by the Oscar M. Ruebhausen Fund at Yale Law School and Harvard University. We thank Alexandra Rodman for guidance on statistical methods, Juliet Davidow and Katherine Powers for modeling guidance, Erik Kastman for technical assistance, and Taylor Heffer, Hedy Kober, Camille Phaneuf, Elizabeth Phelps, and Gideon Yaffe for helpful discussion.

Paper 3: Age-related changes in the link between social support and risk preferences across adolescence

Yelina Yiyi Chen, Tianxiang Li, Patrick Mair, Leah H. Somerville

In preparation.

Abstract

Relationships with peers take on heightened importance during adolescence and shape individuals' risk preferences. Complex motivational mechanisms underlie peer influence on adolescents' risky decisions. It is possible that peer influence on adolescents' risk preferences stems from a need for social support, which may be especially salient during this time of life. Though past research has shown that fluctuations in mood can impact the valuation process in decision making, little is known about the developmental changes in the influence of fluctuations in feeling supported by one's friend group on risk taking. In this study, we explore age-related changes in how social support might influence individuals' risk preferences by isolating within- and between-person variability in perceived social support and examining its association with risk seeking, using both an experimental task and a self-report survey. We found that between-person levels of perceived close friend support are associated with risk preferences, and that the strength of this association decreases with age.

Introduction

Adolescence is a period of development between childhood and adulthood that starts with the onset of puberty and ends with the assumption of adult responsibilities (Spear, 2000) It is a period of life marked by a heightened tendency of risk taking (Boyer, 2006; Eaton et al., 2010; Steinberg, 2008), as well as dynamic changes in individuals' social environment in terms of its complexity and shifting focus: adolescents, compared to children, spend more time with their peers than family (Barnes et al., 2007; Larson, 2001). Peer relationships take on a heightened importance during adolescence, as adolescents are especially sensitive to peer evaluations and exclusion (Rodman et al., 2017; Sebastian et al., 2010b; Silk et al., 2012; Somerville et al., 2013); social rejection has been associated with negative mental health outcomes, such as anxiety and depression in this population (Prinstein & Aikins, 2004; Williams, 2007). Risk taking can impact not only adolescents themselves but also the wellbeing of their peers, which may in turn influence their relationships (Blakemore, 2018; Blakemore & Mills, 2014). Taken together, the link between adolescents' sense of social connectedness, as reflected by their peer relationships, and their risk taking behavior is intricate and important to understand.

During adolescence, individuals start to adopt more other-focused, prosocial behaviors (Crone & Dahl, 2012). In the previous two chapters, we have demonstrated that there are varying sensitivities across age during adolescence to the social context of risky decisions involving considerations of how individuals' choices impact their friends' outcome. Specifically younger adolescents were more prone to altering their risk preference to protect their friends from undesirable risks, while older adolescents and young adults were more likely to change their choices when prompted to consider desired allocations from their friends' perspective. A common theme in both cases was that participants factored their assumed preference of their

friend into their computation, to the extent of overriding their original preferred levels of risk, depending on the context. Potential motives underlying these behavioral shifts include, most prominently, strategic motives such as reputational concerns and more "pure" prosocial motives to benefit a friend despite undesired risks to oneself.

Considering this motive question in the context of adolescents' social lives, a hitherto underexplored perspective is that risk taking may be viewed as an individual's attempt to reconnect with their social group, as a result of loneliness and social exclusion (Tomova et al., 2021). A fundamental human need is that for social belonging (Baumeister & Leary, 1995), and social isolation has been shown to cause social craving (Tomova et al., 2020). Given that during adolescence, individuals place special value on social acceptance and are especially affected by peer evaluation and rejection (Masten et al., 2011; Rodman et al., 2017; Sebastian et al., 2010b; Silk et al., 2012), feeling supported by peers can be a crucial link in the social-motivational mechanisms underlying adolescent risk taking. If motives behind adolescents' elevated levels of risk taking include reinforcing friendship bonds and regaining a sense of connectedness, then we may expect that feeling unsupported by one's friends would lead to an increase in one's propensity to take risks. Decision science examining mood effect on risk preference has shown that mood fluctuations affect our valuation process in valence-specific ways (Cecchi et al., 2022) but little is known about how risk attitudes are affected by mood fluctuations induced by the presence or absence of social support.

The present study explores the link between feeling socially supported and risk preference during adolescence by examining both the interindividual and intraindividual effect of perceived social connectedness. In other words, we examine how both the average level of social support and deviations from one's personal typical level are distinctively associated with risk

preference. The dataset is part of an ongoing parent study, Studying Adolescents in Realtime (STAR) study, which utilizes an accelerated longitudinal cohort design and is uniquely positioned to investigate this previously underexamined avenue. This design makes it possible to include a wider age range within a relatively shorter period of time compared to typical longitudinal studies, and repeated measurements within individuals permits the application of statistical methods that disaggregate within- and between-person effect of social support on risk preference. This approach allows us to answer the following two central questions:

1. Do fluctuations in perceived social support relative to individuals' personal typical level of perceived social support track with variabilities in their risk preferences over time?

2. Do individuals with higher levels of perceived social support tend to take fewer risks? Are there age-related patterns in the association between social support and risk seeking?

If a desire to strengthen friendship bonds underlies adolescents' susceptibility to peer influence on their risky decisions, then lower levels of perceived support from one's social group would motivate them to take more risks. Therefore, we predict that feeling less supported than one typically does would be associated with higher risk preferences at a given time point. Furthermore, we predict that participants with lower overall levels of perceived social support will have higher risk preferences, relative to those with higher levels of overall perceived social support, and that the strength of this association will become stronger later during adolescence.

Methods

Sample

The sample consists of $N = 124$ participants aged 11.58 - 17.85 years ($N = 67$ female, $N = 57$ male, Figure 9). These individuals completed both the social support measure and the risk taking questionnaire during the same visits. Among them, $N = 90$ participants ($N = 50$ female, $N = 40$ male, Figure 10) completed the experimental risky decision making task during the same visit that they completed the social support measure. The exact duration of each participant's participation varied, averaging approximately one year (see Tables 1, 2 and Figures 9, 10).

Table 1

Number of participants with 1, 2, 3, 4, 5, or 6 visits at which they completed both the DOSPERT and the SSC questionnaires

Number of Visits	Number of Participants
1	19
2	26
3	8
4	52
5	14
6	5

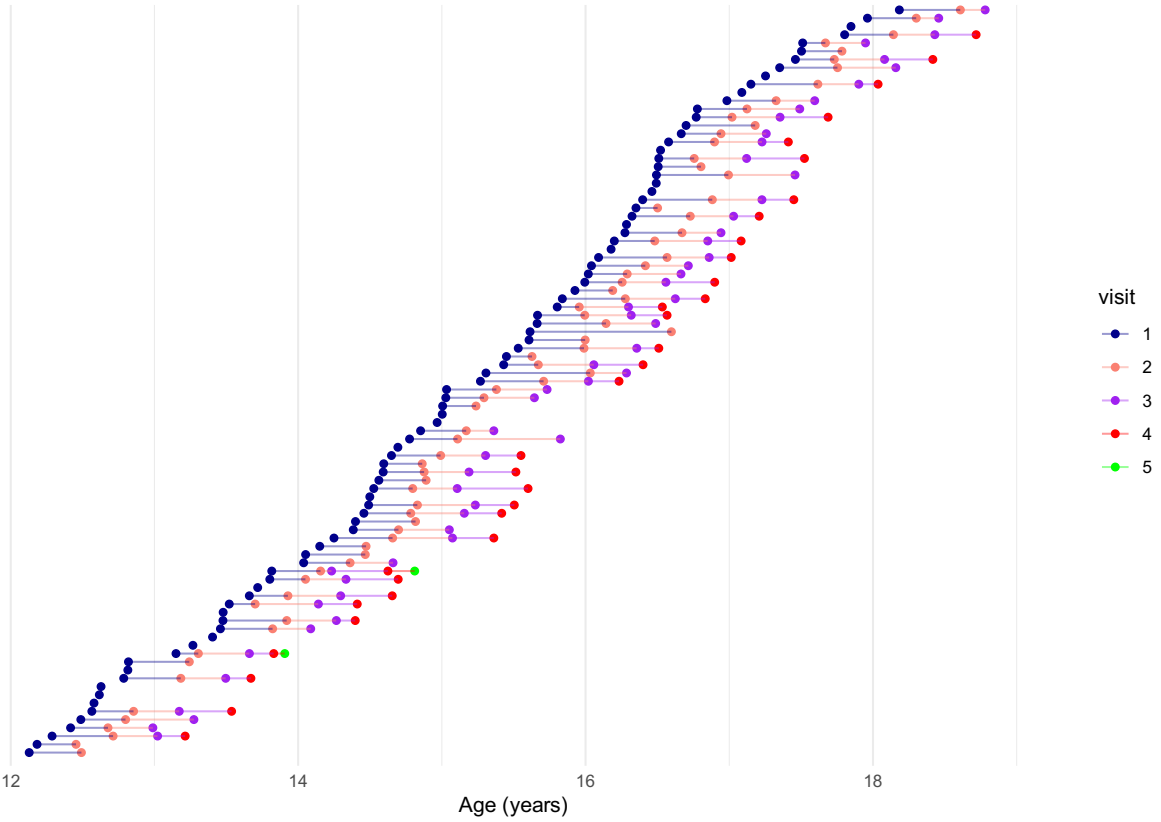


Figure 9. Retention of participant across age during the study period that completed the DOSPERT and SSC questionnaires at the same visit.

Table 2

Number of participants with 1, 2, 3, or 4 visits at which they completed both the Cups Task and SSC questionnaires

Number of Visits	Number of Participants
1	22
2	23
3	23
4	22

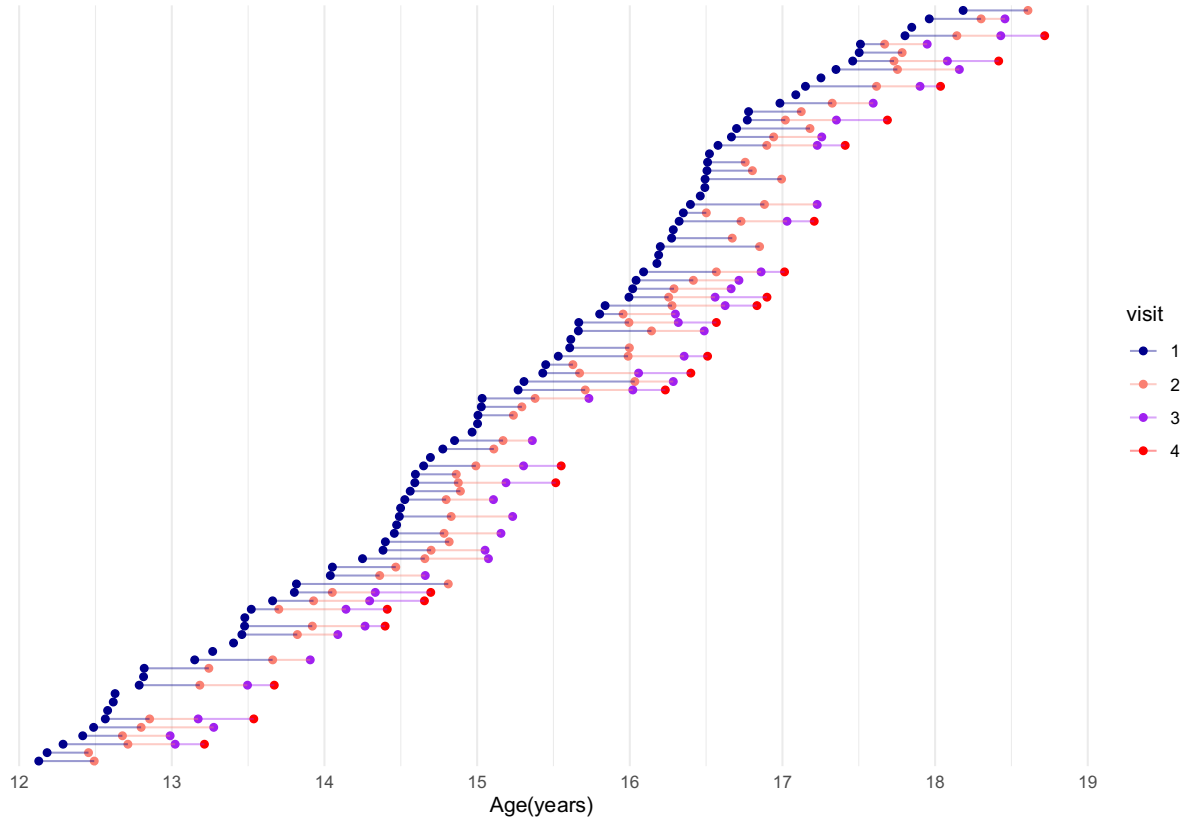


Figure 10. Retention of participants across age during the study period who completed the Cups Task and the SSC questionnaire at the same visit.

Measures

To measure risk preference as our Dependent Variable (DV), we use an experimental decision making task and a self-report survey:

1) Domain-Specific Risk-Taking Scale (DOSPERT, Blais & Weber, 2006): a questionnaire that measures real-life risk preferences by asking participants to rate the likelihood that they would engage in risky activities in domains including: financial decisions, health/safety decisions, recreational decisions, ethical decisions, and social decisions. In the present study, we focus on the social subscale for its relevance to our research questions on peer-relevant risk preference. This survey is administered every 3 to 4 months on average (Figure 9). Items from in this subscale can be found in the Appendix.

2) The Cups Task (Levin & Hart, 2003): a risky decision making task that is risk neutral (i.e., as advantageous to take risk vs. not in terms of expected values) and involves making sequential decisions between certain and uncertain financial outcomes. This task is administered every 3 to 4 months on average (Figure 10). Task procedure can be found in the "Risky Decision Making Task Procedure" section below.

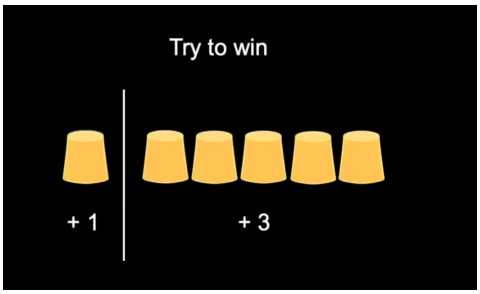
To measure perceived social support, we use the close friend support subscale from the Social Support Scale for Children (SSC, Harter, 2012) using a 4-point Likert Scale. Items in this subscale can be found in Appendix C.

The specific domains of the SSC and DOSPERT questionnaire were selected because they were the most relevant to the central research question on how friends and peers impact adolescent risk preference.

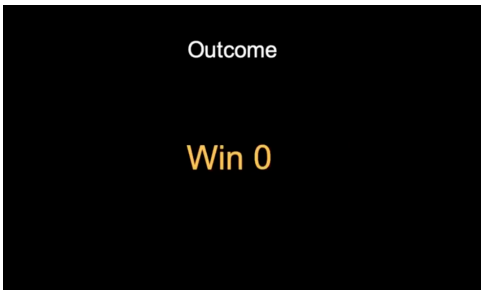
Risky Decision Making Task Procedure

The Cups Task (Levin & Hart, 2003) has been used in adult and developmental samples (e.g., Galván & McGlennen, 2012; Guassi Moreira et al., 2022; Uy & Galván, 2017a, 2017b; Weller et al., 2009; Xue et al., 2010) to measure decision making under uncertainty in gain and loss domains, where participants could gain or lose money respectively. Participants were instructed to choose between the left or the right side of the screen within 3.5 seconds; each side was randomized to contain a *safe* option that entailed gaining or losing one token, with certainty, under a flipped over cup, and a *risky* option that involved uncertainty: 2, 3, or 5 tokens were contained one of a set of 2, 3, or 5 cups, with the remaining cups containing zero tokens. If they chose the risky option, there was a probability (100% divided by the number of cups, P = {1/2, 1/3, 1/5}) that they would gain or lose the number of tokens hidden under that cup and 1-P probability they receive the zero outcome. Therefore, there were 18 unique decision scenarios across the two domains and an equal number of trials where the expected value (EV) of the *safe* and the *risky* options were the same, where the *safe* option had a higher EV, and where the *risky* option had a higher EV. This choice set was repeated three times in randomized orders. Participants were instructed to make decisions such that they earn as many tokens as possible, because at the end of the task the tokens would translate to a bonus. Typical bonus earnings for this task were up to $7. After participants made their decision on each trial, if they selected the risky option, the computer randomly selected a cup and displayed the tokens it contained; if they selected the safe option, the computer displayed the certain gain or loss amounts (Figure 11).

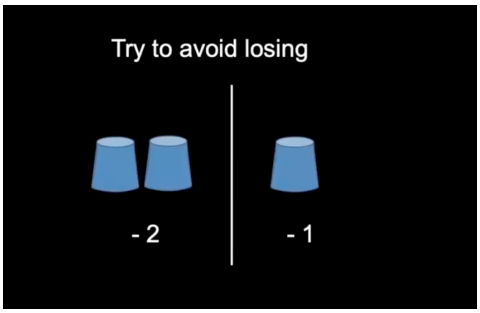
A



B



C



D



Figure 11. Example gain and loss trial in the Cups Task. (A) A gain trial with 1 token under 1 cup for the safe option on the left side of the screen, and 3 tokens with 5 cups for the risky option on the right side. (B) The feedback participants saw after they chose the *risky* option in (A) and task software randomly selected a cup that *did not* contain the 3 tokens (i.e., they lost 3 tokens). (C) A loss trial with -1 token with 1 cup for the safe option on the right side of the screen, and -2 tokens with 2 cups for the risky option on the left side. (D) The feedback participants saw after the they chose the *safe* option in (C), displaying that they lost 1 token.

Analysis

Scoring and Calculation of Dependent Variables

1. *Proportion of Risky Options Chosen*: the number of trials during which an individual chose the uncertain/risky option divided by the total number of trials in the Cups Task.

2. *DOSPERT Social score*: The average of participants' choices on a 7-point Likert scale (1- Extremely unlikely, 2 – Moderately unlikely, 3 – Somewhat unlikely, 4 – Not sure, 5 – Somewhat likely, 6 – Moderately likely, 7 – Extremely likely).

Separating Between- and Within-Person Effects of Close Friend Support

The separation of within- and between-person effects was achieved though predictor centering. The *between-person effect predictor* of close friend support was calculated as the mean of each participant's grand-mean-centered score (individual score minus the sample mean); this predictor is therefore stable across visits within an individual. The *within-participants effect predictor* was calculated as the grand-mean-centered score at each visit minus the between-person effect predictor and is therefore time-varying within an individua; it depicts, colloquially, an Individual's "usual" or "normal" level of a predictor. This approach has been used to disaggregate variations in predictors of interest into between- and within-person components, accounting for dependent nature of the data within-participants, as well as controlling for time-invariant characteristics of the predictors (Enders & Tofighi, 2007; e.g., Rodman et al., 2021; Vidal Bustamante et al., 2020)

Statistical Modeling

We fitted two linear mixed-effects models to evaluate how the within-person and between-person levels of close friend support are associated with risk preference over the course of participants' visits, and how age moderates the strength of their respective relationships, using the two DVs mentioned above. A random intercept associated with participant ID was included in both models.

For the model using *DOSPERT-Social score* as the DV, predictors included *age* (cross-sectional), two-way interactions between *age* and the *between-person* and *within-person* close

friend support scores, respectively, with *time* (at the month-level) included as a control. We note that controlling for time at the day-level, month-level, or visit number did not impact the model output. For the model using *proportion of risky options chosen* from the Cups Task as the DV, of the pair of two-way interaction terms were replaced by a pair of three-way interaction terms between *age*, *within-/between-person close friend support*, and *domain* (gain vs. loss); all other predictors remained the same.

Mixed-effects models were fitted using the *lmerTest* package (version 3.1.3; Kuznetsova et al., 2017), an extension of the *lme4* package (Bates et al., 2015), in R (version 4.4.1; R Core Team, 2024). Both DVs were reasonably normally distributed and fitted with a Gaussian distribution. These distributional assumptions of the models were appraised with qq-plots and posterior predictive check (using the posterior_predictive_check function from the *performance* package in R; version 0.12.4; Lüdecke et al., 2021) and deemed satisfactory.

For inferences, analyses of deviance (type II Wald $\chi 2$ tests with Satterthwaite approximations for degrees of freedom) using the Anova function from the *car* package in R (version 3.1.3; Fox & Weisberg, 2019) were performed on the mixed-effects models described above. Effect plots were produced using the *interactions* package (version 1.2.0; Long, 2024) and the *sjPlot* package in R (version 2.8.16; Lüdecke et al., 2024).

Post-hoc tests to help interpret interaction terms were conducted at illustrative age values using the emtrends function from the *emmeans* package (version 1.10.5; Lenth et al., 2025), with *p*-values corrected using the he multivariate *t*-distribution method (‘mvt’) method.

Results

Risk preferences measured by DOSPERT

To investigate how perceived close friend support impacted risk preference across age, we first characterized participants' attitude toward taking risks in their social life, as measured by the DOSPERT survey. We observed significant main effects of month ($\chi 2(1, N = 124) = 4.72$, $p = 0.030$, Figure 12A), age ($\chi 2(1, N = 124) = 10.76$, $p = .001$, Figure 12B), and a marginally significant main effect of the between-person levels of perceived close friend support ($\chi 2(1, N = 124) = 3.45$, $p = .063$). These findings indicate that as time went on during the study period, there was an overall increase in participants' average risk preference, and that overall, older participants and participants with lower levels of perceived close friend support, relative to those with higher levels, reported higher levels of risk preference. However, the main effects of age and between-person variations in perceived close friend support must be interpreted with more nuance, as elucidated by their interaction reported below. Within-person fluctuation of perceived close friend support was not significantly associated with participants' risk preference ($\chi 2(1, N = 124) = 0.02$, $p = .897$).

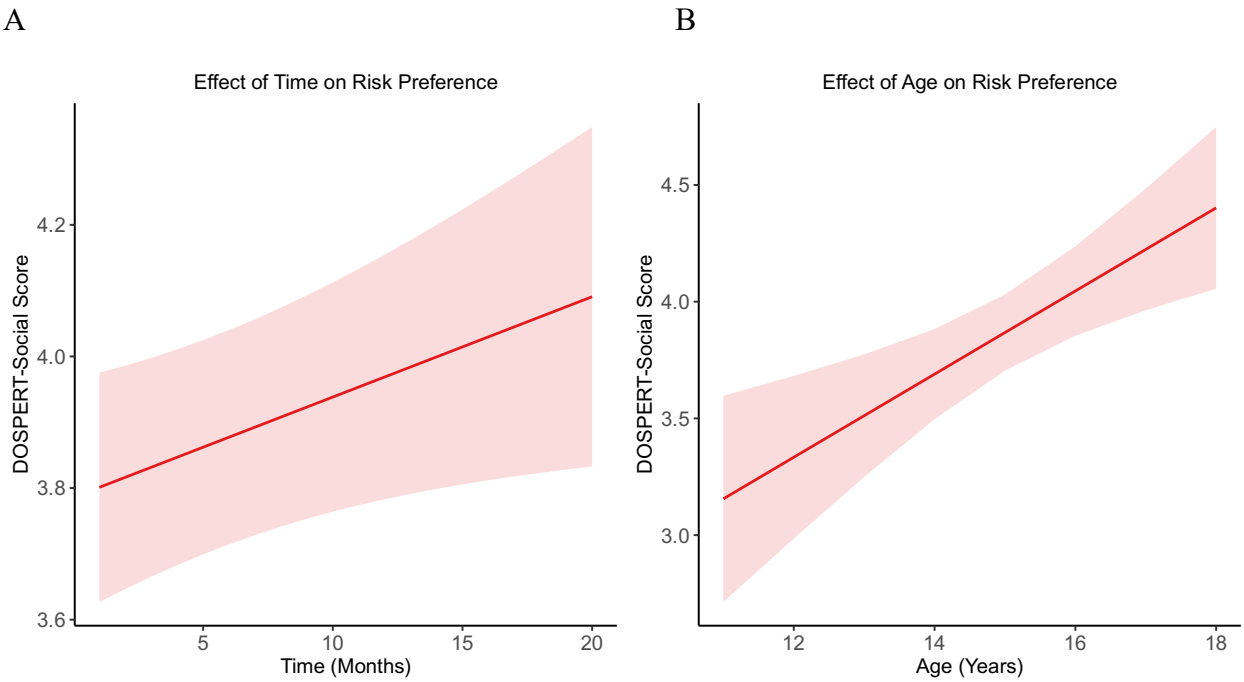


Figure 12. Effect plots of time and age. *Y*-axis denotes the participants DOSERT-Social scores. (A) *X*-axis denotes month of observation since participant's first visit (as opposed to calendar month) (B) *X*-axis denotes age in years.

We found a marginally significant interaction between age and between-person levels of close friend support ($\chi 2(1, N = 124) = 3.60$, $p = .058$, Figure 13). Participants with lower levels of perceived close friend support, relative to those with higher levels, reported greater risk preference in their social lives, and this trend diminished with age. Post-hoc tests indicated that perceived close friend support had a significant negative association with risk preference among younger participants (13 years: $B = -0.65$, $SE = 0.25$, $t(138) = -2.64$, $p = .019$), while the association was not statistically significant among older participants (17 years: $B = 0.009$, $SE = 0.22$, $t(118) = 0.04$, $p = .999$). This suggests that higher overall perceived close friend support was associated with lower levels of risk preference among younger participants, and that the strength of this association decreased with increasing age. The interaction between within-person fluctuation and age was not significant ($\chi 2(1, N = 124) = 0.01$, $p = .909$), indicating that the

observed lack of association between fluctuations from an individual's typical level of perceived friend support and risk preference was consistent across age.

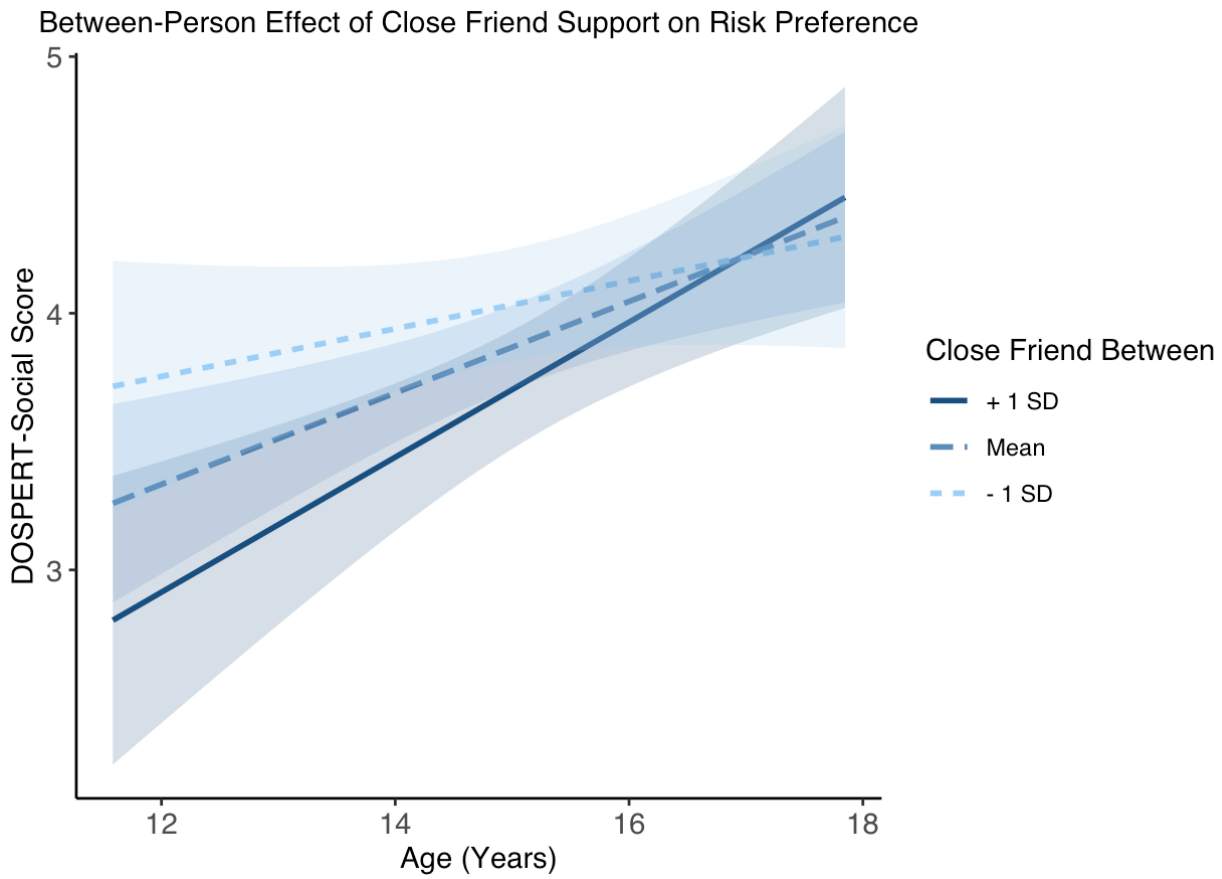


Figure 13. Effect plot of between-person levels of perceived close friend support on risk preference. *X*-axis denotes age in years. *Y*-axis denotes participants' DOSPERT-Social scores. The lines with shaded areas representing 95% CI represents show estimated values of DOSPERT-Social scores across the age range at different levels of perceived close friend support scores: the darkest blue line denotes one standard deviation above the mean score, the middle blue line denotes the mean score, and the lightest blue line denotes one standard deviation below the mean score.

Risk preference measured by the Cups Task

We also investigated the association between perceived close friend support and risk preference across age using the proportion of risky options participants selected in the Cups Task as a measure of risk, in both the gain and loss domains. The second linear mixed-effects model revealed significant main effects of month ($\chi 2(1, N = 90) = 16.97, p < .001$) and gain vs. loss domain ($\chi 2(1, N = 90) = 20.38, p < .001$). No other main effects were significant. These results suggest that on average, participants selected a greater proportion of risky options over time, and that they chose risky options more frequently in the gain domain than in the loss domain (Figure 14).

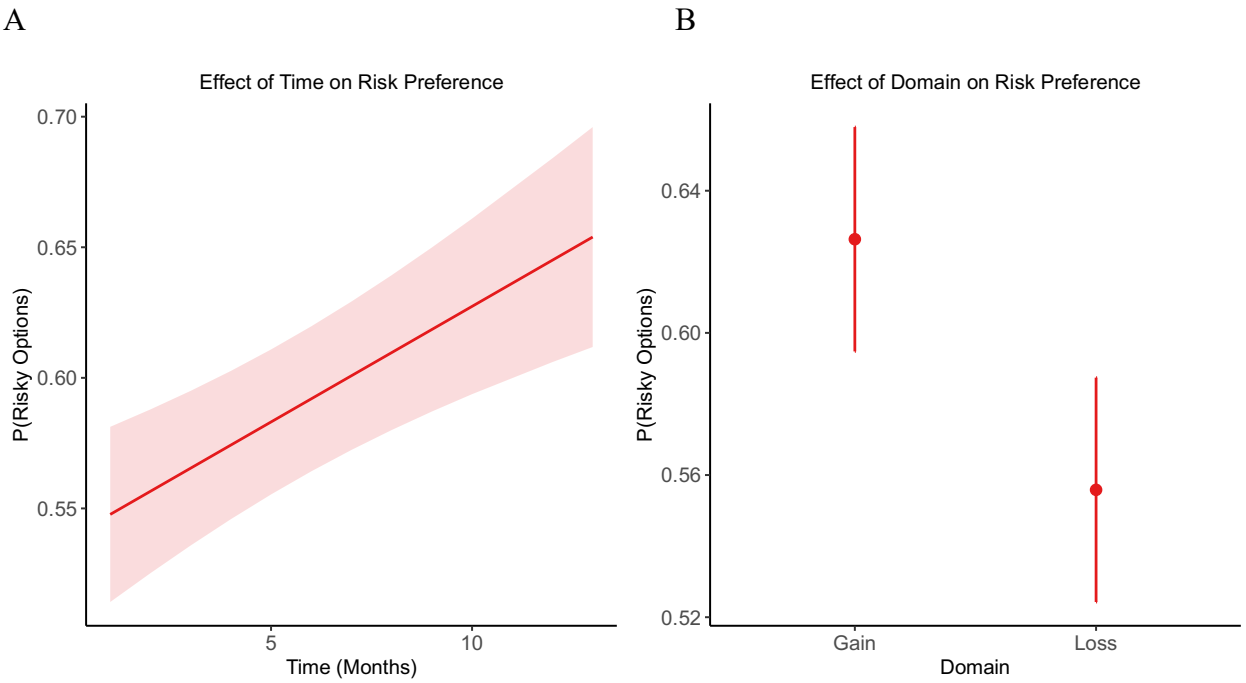


Figure 14. Effect plots of time and gain vs. loss domain. *Y*-axis in demotes the proportion of risky options participants selected during the task. (A) *X*-axis denotes month of observation since participant's first visit (as opposed to calendar month) (B) *X*-axis denotes whether participants made decisions on a potential gain or loss payout.

There was a significant two-way interaction between domain and month ($\chi 2(1, N = 90) = 10.84$, $p < .001$). As shown in Figure 15, participants selected more risky options in the loss domain over time but their risky choices in the gain domain remained relatively stable.

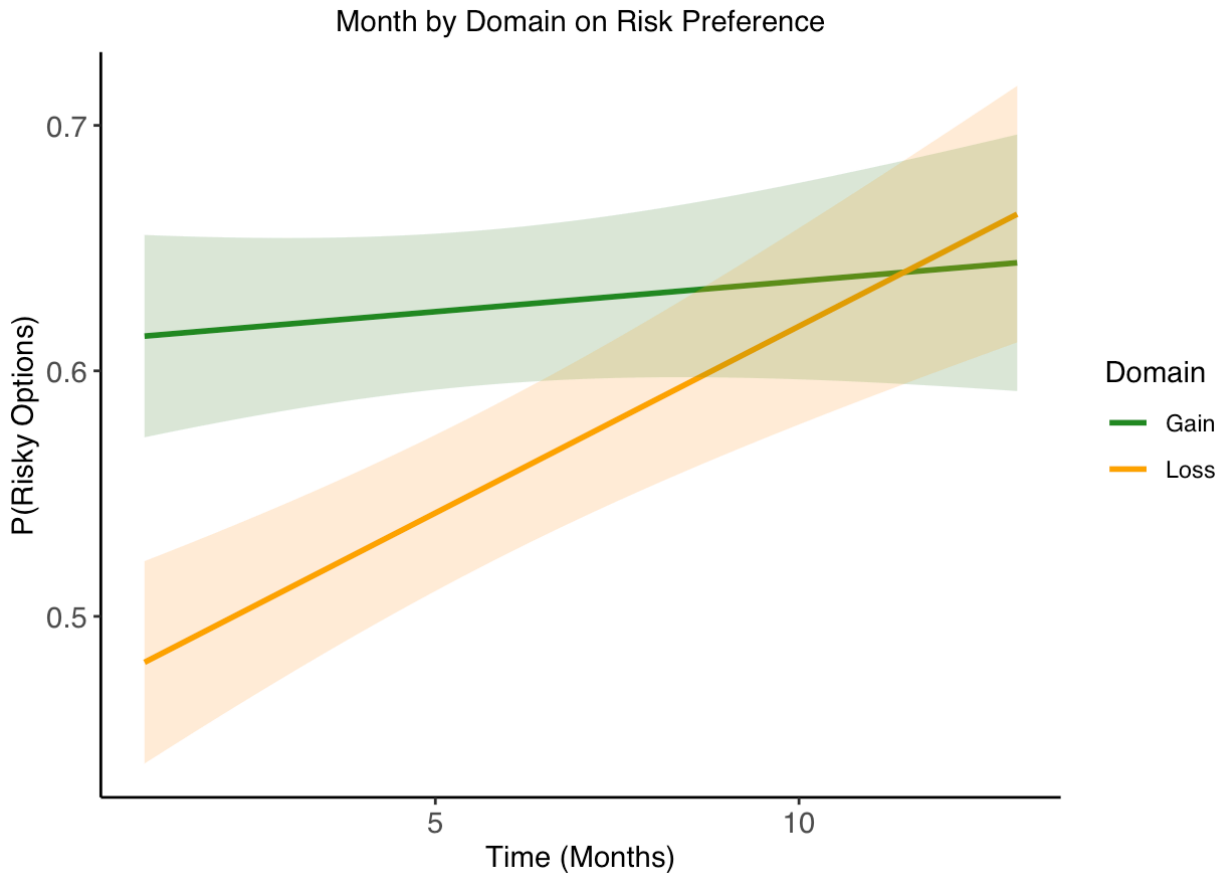


Figure 15. Effect plot of the interaction between time and domain (gain vs. loss) on risk preference. *X*-axis denotes month of observation since each participant's first visit (as opposed to calendar month). *Y*-axis denotes proportion of risky options participants selected during the task. The lines with shaded areas representing 95% CI represent estimated values of the proportion of risky options chosen in the gain and loss domains: green denotes the gain domain and orange the loss domain.

We also found a significant three-way interaction between domain, perceived close friend support, and age. Specifically, participants with higher levels of perceived close friend support relative to those with lower levels tended to select a higher proportion of risky options during the

task, and this trend diminished with increasing age; this pattern was observed in the loss domain but not in the gain domain (Figure 16). Post-hoc tests using the same approach as above were conducted at instructive age values and indicated that perceived close friend support had a marginally significant positive association among younger participants (13 years: $B = 0.11$, $SE = 0.05$, $t(194) = 2.06$, $p = .080$) while the association was not significant among older participants (17 years: $B = -0.02$, $SE = 0.04$, $t(136) = -0.529$, $p = .836$); in the gain domain, between-person differences in perceived close friend support were not significantly associated with the proportion of risky options selected at either age point tested (13 years: $B = -0.03$, $SE = 0.05$, $t(194) = -0.552$, $p = .824$; 17 years: $B = 0.01$, $SE = 0.04$, $t(136) = 0.376$, $p = .914$). This suggests that higher overall levels of perceived friend support are associated with higher risk preference among younger participants in the loss domain, but not in the gain domain, of the Cups Task. With increasing age, this domain-dependent between-person effect of perceived close friend support diminished.

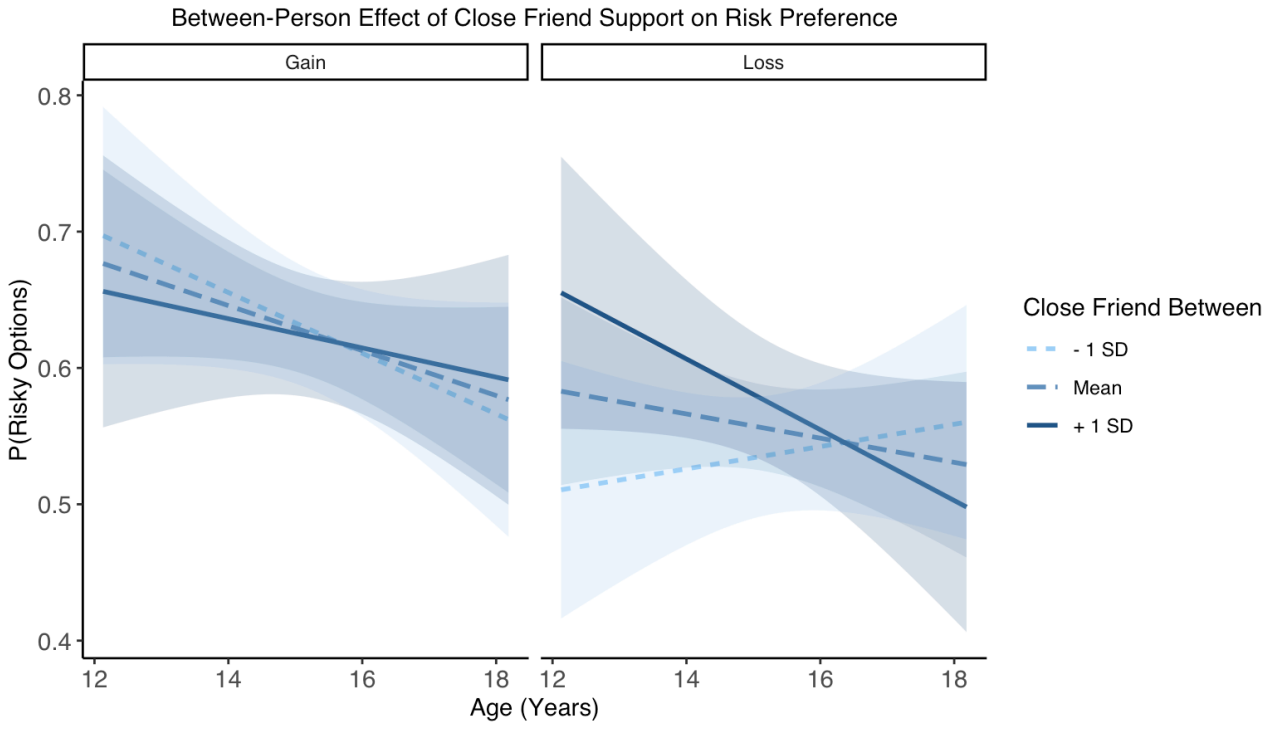


Figure 16. Effect plot of the interaction between age and between-person levels of perceived close friend support on risk preference in the gain (left panel) and loss (right panel) domains. *X*-axis denotes age in years. *Y*-axis denotes proportion of risky options participants selected during the task. The lines with shaded areas representing 95% CI represent estimated values of the proportion of risky options chosen across the age range at different levels of perceived close friend support: the darkest blue line denotes one standard deviation above the mean score, the middle blue line denotes the mean score, and the lightest blue line denotes one standard deviation below the mean score.

Discussion

The present study examined age-related changes in the association between individuals' perceived close friend support and their risk preference during adolescence, using an accelerated longitudinal cohort design. To assess this association with sensitivity to the individual differences and fluctuations across time, we chose an analytical approach that disaggregates within- and between-person effects of perceived close friend support on risk preference. We measured risk preference using both a self-report and an experimental measure to probe risk taking from two distinct angles, contributing to a more comprehensive account of peer support as a social context for adolescent risk preference. The Cups Task assessed risk preference through a series of choices between a certain and an uncertain option, presented in both gain and loss domains. The social subscale of the DOSPERT questionnaire investigates attitudes toward risky social activities that might alienate them from their peers. Both of these measures capture important facets of risk taking that are relevant to adolescents' social and cognitive development.

We found commonalities and divergences in the patterns of associations between perceived close friend support and risk preference with these two risk measures. Both self-reported risk preference and the task-based measure revealed a lack of observed association between within-person fluctuations of perceived close friend support across time on individuals'

risk preference. This pattern did not vary across age or the gain vs. loss framing of risky choices. The association between between-person variations in perceived close friend support and risk preference was more salient among younger participants as indicated by both measures, though in different directions and was specific to the loss domain in the task-based measure. Risk preference increased over time according to both measures, though only in the loss domain in the task-based measure.

Within-Person Effect of Perceived Close Friend Support

With both self-report and task-based measures, within-person variations were not associated with risk preference, and this pattern was consistent across age during adolescence. Not observing this association was surprising, and there is a possibility that the measurements were not frequent enough to observe this potential relationship. There is no objective way of determining whether the fluctuations in within-person levels of a variable are "sufficient" to justify longitudinal modeling approaches that employ effect separation, and commonly used benchmarks such as intraclass correlation coefficient (ICC) suggested there was a low to moderate amount of within-person variance relative to between-person variance in the DOSPERT-Social score (*ICC* = .697), and a more substantial amount in the Cups Task (*ICC* = .281). Thus, the null result could suggest that at the current cadence of visits where both risk preference and close friend support were measured, the variations within participants in their perceived close friend support from one time point to another did not appear to have an effect on their attitude toward social risk taking or decision making under uncertainty, indicating this relationship is relatively stable within individuals over time; alternatively, it is possible that more substantial amounts of within-person variation may occur in a shorter time frame, and that only

more frequent measurements may capture the potential association. Future studies might test these two possible interpretations by decreasing the time between visits where social support and risk preference are measured. If this present trend holds at increased frequencies of measurements, then our initial inference that the link between close friend support and risk preference seems stable within individuals over time is supported.

Age-Related Differences in Between-Person Effect of Perceived Close Friend Support

The between-person effect of perceived close friend support on self-reported risk taking in adolescents' social lives was moderated by age: younger participants who reported *higher* levels of perceived support, relative to those with lower levels, also reported *lower* levels of risk taking in their social life in the same month; this trend diminished with increasing age, controlling for time. Interestingly, this association also emerged in the task-based measure of risk preference, though in the opposite direction, and it is further moderated by the gain vs. loss framing of the decisions: younger participants who reported *higher* levels of perceived support, relative to those who reported lower levels, also selected the risky options *more* frequently during the task administered in the same month, indicating *higher* risk preference as measured by this task; this was only found when the risks were presented in the loss domain and not in the gain domain. Therefore, a higher risk preference in this case meant participants preferred probabilistic loss options with a chance of zero loss over certain losses, even though the certain loss might be smaller compared to the expected value of uncertain option. As with self-reported risk taking, this pattern diminished with increasing age. The convergence between these two sets of analyses – both showing more pronounced between-person effects among younger adolescents – suggests that feeling supported by friends may be especially influential in individuals' social

behavior and attitudes toward decisions involving potential losses during this stage of development, consistent with research showing early adolescence as a window of heightened sensitivity to social evaluation and peer influence (Rodman et al., 2017; Somerville et al., 2013; van den Bos et al., 2011).

Research has shown that feeling a lack of social support is associated with elevated risk for negative mental health outcomes such as anxiety and depression (Cacioppo & Hawkley, 2003; Coppersmith et al., 2019; Weeks et al., 1980) and states of stress and negative emotions can influence risk preferences (Cecchi et al., 2022). The age-dependent between-person effect of perceived close friend support on risk preference is in line with these findings, and suggests a potential mechanism behind findings that shows early adolescence to be a window of sensitivity to decision contexts that require adjudicating between self- and peer interest (Chen et al., in press): younger adolescents' susceptibility in comparison to older adolescents and young adults may be driven by a stronger need for close friend support. The fact that the between-person effect of close friend support had associations with risk preference in opposite directions depending on how the DV was operationalized does not indicate either risk measurement is invalid; rather, it points to the multidimensionality of risk taking as a concept (Highhouse et al., 2017) and the different cognitive and social processes it involves, and how it manifests in adolescent development.

Dependent variables from self-report surveys and behavioral experiments each have relative strengths with respect to the measurement of within- and between-person variations in the psychological construct they measure (Enkavi et al., 2019), and thereby provide a richer account of multifaceted phenomena. The two measures of risk preference in the present study gauge different aspects of adolescents' attitudes toward risk, and both forms are important in

their lives during this dynamic stage of development. The items in the DOSPERT-Social subscale (See Appendix) pertain to risky actions that call attention to oneself and may lead to potential social exclusion or rejection, which adolescents are particularly averse to (Rodman et al., 2017; Sebastian et al., 2010b; Silk et al., 2012). Therefore, a reduction in risk preference in the presence of elevated levels of close friend support aligns with views of risk taking as an attempt at social re-engagement (Tomova et al., 2021). If taking social risks is a bid for connection through drawing attention to oneself, and feeling more supported by friends can lessen the need for this behavior. On the other hand, the Cups Task measures risk preference as a tolerance of uncertainty. The loss domain, in which the association was observed, further constrains the type of risk preference involved as tolerance of potential losses. Higher close friend support is associated with "bolder" choices that aim to avoid sure losses despite the chance of a potentially larger loss. Situating this finding in adolescent development in real life, adolescent must take on challenges that sometimes involve possibilities of failures, and feeling supported by friends may encourage individuals to be more resilient in the face of potential negative outcomes.

Another commonality between the results using these two different measures of risk preference was that there was an increase in risk preference across time, controlling for cross-sectional age. This suggests a potential practice effect for the task: as participants returned for each visit, they were more familiar with it and more comfortable with the decisions. Here again we only observe this effect in the loss domain in the Cups Task. A previous study using the Cups Task, though not focused on age trends, also observed significant sensitivity to risk only in the loss domain (Guassi Moreira et al., 2022). Preferring the risky option in the loss domain reflected a greater value placed on avoiding sure losses, which is unsurprising since research has shown that losses loom larger than gains (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992).

The current choice set was too sparse to support further inference on how the larger or smaller probabilities might have differential impact on gain and loss trials. However, the gain vs. loss framing of these decisions evoked robustly different choice patterns, and only those in the loss domain varied over time, which might suggest that the loss trials were especially more challenging for participants during their initial experiences during the study. Future studies should consider using a choice set that covers a broader probability space to investigate additional factors that might have contributed to age-related changes in risk preference being observed in the loss domain only. Having contrasting experimental conditions with and without immediate feedback might also shed light on this question.

Age Trends in Risk Taking

Age trends in risk taking, as reviewed in Chapter One, are mixed as to whether there is an adolescent peak, an increase, a decrease, or stability in risk seeking as individuals transition from early adolescence to adulthood (e.g., Blankenstein et al., 2016; Gardner & Steinberg, 2005; Tymula et al., 2012; Van Leijenhorst et al., 2008; see Defoe et al., 2015 for a meta-analysis). Age trend detection can depend on experimental design as well as statistical modeling approaches. Task features that can influence the age-related patterns in risk seeking include, for example, whether peers were actively encouraging the participants to take risks (Powers et al., 2022) and whether the probability of the risky option was known or learned through trial-and-error (Rosenbaum et al., 2018). Risk preference as measured by the Cups Task, which is similar to the Baseline condition in the economic decision making task in Chen et al. (in press), except that the Cups Task included immediate feedback and a loss domain, similarly did not show a main effect of age. Prioritizing the interpretability of the higher-order interaction terms, which address key

research questions, we did not choose to use Generalized Additive Models as in previous chapters to detect potentially nonlinear age trends. However, the present sample consisted of a narrower age range, making the choice of a linear model more appropriate than it would be with a wider age range. The overall increase in participants' self-reported social risk taking with age should be interpreted in tandem with perceived close friend support. Taken together, these results underscore the value of combining behavioral experiments with questionnaires pertaining to real life scenarios to more a fully chart how attitudes toward risk and related cognitive processes unfold during adolescence.

Limitations

The Cups Task contained an equal number of trials where the risk was advantageous, disadvantageous, and equivalent to the certain option in terms of the expected value. However, the choice set was relatively small, and we did not deem the number of trials sufficient for testing how participants' choices with regard to the advantageousness of the risky option might have shifted in conjunction with fluctuations in close friend support. Future studies could enlarge the choice set and investigate this interesting question.

Though measurement frequency in the STAR study more broadly was ample for an intense longitudinal design with monthly measurements, the risk measures were only administered every three to four months. As mentioned in Discussion, an increased frequency of these measurements might reveal within-person effects of close friend support on risk preference that the current data cannot detect. As the STAR study is ongoing, the sample size reported in this chapter will increase at the conclusion of the study. A larger sample size will allow for more robust inferences in the observed patterns.

Future directions

Future studies with a larger data set might consider exploratory machine learning models with prediction as the primary goal, using measures included in the STAR study that tap into other areas of adolescents' social life, including parental support and self-esteem, to generate insights into other types of social influences on risk taking during adolescence. With more data available, these queries may extend to probe not only concurrent associations, but also lagged associations in time between social factors and risk preference.

General Discussion

Adolescent development has been a focus in psychological and public health research due to its uniquely dynamic nature as individuals transition from childhood to adulthood and navigate a more uncertain and complex social environment. Two of the characterizing features of this period are heightened rates of risk taking and the elevated importance of peer relationships. While adolescents' risky behaviors and susceptibility to peer influence are often viewed as negative and potentially harmful, the three papers in this dissertation examine risk taking as a neutral concept, adopting the definition of risk as outcome variability from the decision making literature. Papers 1 and 2 used statistical methods sensitive to nonlinearity to explore fine-grained age-related changes in how social contexts influence risky decision making from early adolescence to early adulthood. Computational approaches in these two papers quantified and elucidated cognitive processes that underlie risk decision making when peer outcomes are impacted. Paper 1 focused on the influence of distinct social contexts, while Paper 2 explored individuals' beliefs about peers' preferences and how they factor into decision processes. Project 3 aimed to tap into the multifaceted nature of adolescent risk taking by using two distinct measures of risk preference and longitudinal data to expand our understanding of how peer support in real life may impact risk preferences.

Paper 1 charted the changes in risky decision making evoked by different social-motivational contexts across adolescence by contrasting decisions that only impacted an individual's own outcome with those that also impacted their friend's outcome in two distinct ways: identical outcomes for oneself and one's friend and opposite outcomes for oneself and one's friend, such that the individual must consider whether to keep or give away their desired options. We found that the opposite outcome context elicited a robust shift in risk preference in

comparison to the solo outcome context, and younger adolescents shifted their original preferences to a greater extent and incurred more financial losses than older adolescents. The identical outcome context did not evoke overall or age-related changes in risk preference. Our computational model showed that the weight individuals assigned to their friend's outcome decreased with increasing age in this context, dovetailing with the age-related pattern in earnings. Taken together, these results suggest that when the decision context entails a conflict between the interests of a friend and oneself, early adolescence is a period in which individuals are particularly motivated to elevate outcomes for their friends, even if doing so is costly to themselves. We discussed the potential motives underlying this observed trend including an eagerness to maintain friendship bonds, as well as potential reputation concerns. Peer observation on Zoom did not evoke additional age-related changes in risk preference in either the identical or opposite outcome context.

Paper 2 used the same experimental paradigm and analytical approaches combining behavioral and computational measures to examine the accuracy of individuals' beliefs about their friends' risk preferences, how these are incorporated into their decisions, and whether there are age-related changes in willingness to accommodate friends' wishes that conflict with one's own. Paper 2 extends Paper 1 in that, whereas Paper 1 examines age-related changes in how differing outcomes for friends override inviduals' default (when only an individual's own outcome is concerned) risk preferences, Paper 2 explores, given explicit instructions to take the perspective of the friend and, in some conditions, information about the friend's preferences, whether individuals would alter their choices when considering the same decisions. In other words, the comparisons in Paper 2 examined, within the decision context that required adjudication between an individual's own outcome and their friend's, how individuals' risk

preferences shift when additional peer-relevant considerations are prompted. We found that individuals in general overestimated their friends' risk preferences, and during mid-late adolescence and early adulthood, they begin to express a wish for their friend to have the better option when asked to decide from their friend's perspective. Young adults additionally were more likely to give up their originally preferred options upon learning their friend wanted the same option. Taken together, these results suggest prosocial considerations that required utilization of multiple sources of information unfold as adolescents transition to becoming young adults.

Paper 3 expanded our investigation of risky decision making beyond the laboratory setting, examining the association between perceived close friend support and individuals' risk preference across age during adolescence. This association was assessed with an analytical approach that separates the intraindividual and interindividual differences, permitting the evaluation of how within- and between-person variations in perceived close friend support are distinctly linked with variations in risk preference. Risk preference was measured using self-reported risk taking in one's social life and a behavioral experiment that assessed risky decision making in both gain and loss domains, in order to probe risk taking from different angles that are relevant to adolescent development. Both the self-reported and the task-based measure revealed little association between within-person fluctuations of perceived close friend support and individuals' risk preferences. This pattern appears to be consistent across age and, for the task-based measure, across the gain and loss domain. The association of between-person differences in perceived close friend support and risk preference was moderated by age (and additionally domain, in the task-based measure), though in different directions depending on the risk preference measure. We discussed how the direction of influence aligned with the different facets

of risk taking the questionnaire and the experimental task capture respectively. Both measures reflected an increase in risk preference over time during the study period, though this was only observed in the loss domain in the task-based measure.

Synthesis and Implications

Novel Methodological Approaches

Our analytical approach for Papers 1 and 2 was data-driven and exploratory in nature, aiming to capture age-related shifts without imposing a presupposed shape for the age trends or using arbitrary age bins. Instead, we treated age continuously and used Generalized Additive Models, which are sensitive to nonlinear patterns and allow us to sidestep definitional issues related to categorical treatment of age data. We hope this approach will contribute to a fine-grained account of how risky decision making changes from early adolescence to early adulthood. Indeed, a challenge in synthesizing past research on adolescent risk taking stems from the heterogeneity of the definition of adolescence and its stages, and arbitrary assumptions of linearity or a quadratic shape. To have a unified developmental account of this phenomenon, it is important for the field to adopt statistical methods that are suited to study this dynamic period of development known for having accelerated and protracted windows of change in different processes, especially when the sample includes a wide age range. Overemphasis on confirmatory approaches is not conducive to capturing these changes with precision with regard to age-related differences.

Papers 1 and 2 also demonstrated how computational models may elucidate certain hypothesized processes regarding how individuals' beliefs about their friends' preferences were

incorporated into their computation of the expected utilities of the options presented to them. The successful application of the revised expected utility model to decisions in the opposite outcome context, which presents a conflict between self and friend-interest, was due to two additions to the original expected utility model: 1) a term that assigned weight to the friend's outcome relative to individuals' own outcome ($Weight_{friend}$), and 2) a risk preference parameter ($Alpha_{friend}$) derived from individuals' *prediction* of what their friend would choose used in calculating the friend's outcome term in the model. These two adjustments enabled this model to explain the behavior evoked by this context which the original model could not account for. The revised model also quantified changes in how much individuals valued their friend's outcome as a result of contextual shifts in the consequence of their choices for their friend (Paper 1) and in the perspective – their own or their friend's – from which they make these decisions (Paper 2). Using model-based measures to complement behavioral measures of risk preference, in combination with data-driven statistical approaches in these two studies provided a richer and more precise account of age-related changes in how adolescents integrate peer outcomes, their own preferences and their beliefs about peers' preferences to guide their decisions under uncertainty.

The adjustments to the original expected utility model were made possible by the collecting mutual (i.e., both member of a dyad took of the role of the primary decision maker and the role of the friend) data on risk preferences from real-life friends, as doing so permitted derivation of the predicted friend's preference parameter ($Alpha_{friend}$), a necessary component of the computation of the utility of an option in this model. This demonstrates that specific elements of experimental design, from the experimental manipulations to how the sample was collected, can directly inform the development of computational models; it is therefore important to

consider them jointly in designing future studies that aim to advance computational accounts of risky decision making in social contexts.

In contrast to Papers 1 and 2, Paper 3 did not employ a nonlinear approach to model age-related changes due of the trade-off between model complexity and interpretability. As the central aim of Paper 3 was to examine age-related differences in the effects of within- and between-person variations in perceived close friend support on risk preference, combining effect separation techniques and generalized additive models would have resulted in higher-order interaction terms that are difficult to interpret and draw useful inference from. Thematically, Paper 3 continued to explore the specific source of social influence that Papers 1 and 2 focused on – friends, a specific subgroup of "peers" – but instead of inviting one specific friend to co-participate in an experiment, we surveyed individuals' general feelings about close friends in their lives over time. With the evolving social landscape during adolescence, friendship dynamics are an important factor to consider in building a more comprehensive account of how peers shape adolescents' risky decisions. Though we did not observe a substantial association between deviations from individuals' typical levels of perceived close friend support and their attitudes toward risk, we demonstrated an analytical framework and initial findings that future studies can build on in this relatively new area of research (see the "Outstanding Questions and Limitations" section below for further discussion on the observed lack of within-person effect).

Age Windows of Sensitivity to Distinct Aspects of Risky Decisions: Shifting Contexts, Incorporating Perspectives, and Feeling Supported

These three papers revealed social-cognitive mechanisms relevant to risky decision making that develop across different stages of adolescence. The results from Papers 1 and 2 point to early and late adolescence as two distinct periods of sensitivity to different types of social-motivational contexts. Early adolescents are more susceptible to contexts pitting self- and friend-interest against one another, and more likely to override their original risk preferences; older adolescents' and young adults' preferences, in contrast, were less impacted. However, within this decision context, mid-late adolescence to early adulthood is an age range in which individuals are more likely to alter their choices when asked to take a friend's perspective. Only young adults in our sample were observed to show willingness to accommodate their friend's wishes that conflicted with their own, holding the expected values of the risky and safe options equivalent, though this last finding used a smaller set of trials in which conflicts of preferences actually occurred. This set of findings indicate that, holding decision context constant, decision processes that incorporate multiple perspectives and sources of social information may experience protracted development well into emerging adulthood.

Paper 3 revealed age-dependent associations between feeling supported by friends and risk preference. The direction of the interacting effects of age and between-person levels of close friend support was different depending on the risk measurement used in the analyses, which captures different facets of risk taking: younger adolescents feeling more supported by friends, relative to those who felt less supported, tolerated a higher degree of uncertainty about a potential loss in an economic decision task; when it comes to actions that might lead to rejections in one's social group, younger adolescents who reported higher levels of close friend support, compared to those with lower levels, preferred such actions less. These results highlight the

multifaceted nature of risk taking as a concept in adolescent social and cognitive development, and the need for specificity and context for the conclusions we draw in this line of research.

Taking on challenges involved in becoming independent adults comes with possibilities of success and failure, and feeling supported by friends may encourage individuals to be more resilient to the latter. At the same time, it can be a bid for connection through drawing attention to oneself, and feeling supported by friends may lessen the need for this behavior. Findings from Papers 1 and 3 dovetail in that older individuals' preferences are less impacted by their social environment. In light of results from Paper 2, this decreased susceptibility may be a downstream consequence of individuals being more adept at perspective taking in decision making later in adolescence. Thus, taken together, the findings from these papers reveal distinct stages during adolescence in which individuals are more sensitive to different types of social-contextual information surrounding risky decisions, including the adjudication between self- and friend-interests, incorporating others' perspectives, and a sense of support from friends.

Outstanding Questions and Limitations

Studies included in this dissertation were limited by investigating age-related changes in risky decision making cross-sectionally, and therefore definitive causal conclusions cannot be made regarding the social factors and developmental changes in risk preferences. Paper 3 used a longitudinal dataset but due to the nature of the accelerated cohort design, age was modeled cross-sectionally.

As remarked in Paper 3, more frequent visits where relevant constructs were measured would have allowed for clearer inferences. A more densely sampled dataset would additionally

permit examination of lagged associations between close friend support and risk preference. Furthermore, among the social measures included in the study, aside from close friend support, there are other constructs such as parental support, that could be used to answers different but relevant research questions on how social forces shape adolescent risk taking.

As discussed in Papers 1 and 2, we did not explore the degree of intimacy or stability of friendship between the dyads in our sample. However, these may be potentially influential moderators of the relationship between social context and risk preference that we observed. Incorporating variables indexing the strength of social bonds can reveal more insight into why the opposite outcome context evoked a shift in risky choice. For example, would the effect be stronger for a closer friend than a more distant peer in one's social circle? Paper 3 investigated a relevant but different construct, as the social measure in that study did not query feelings about a specific friendship. Future work may specifically investigate the interacting influences of these variables and social-motivational contexts on risky decisions.

Furthermore, choice sets that cover a wider range of probabilities and outcomes, and ideally induce more conflicting preferences between participants and their friends would be useful to confirm the early adulthood age window in which individuals were shown to be more willing to accommodate friends' preferences that conflicted with their own. We constrained our analysis to trials with equivalent expected values for the risky and safe options because for this question, the choice set did not allow for the disentanglement of the advantageousness of the accommodating behavior from shifts in risk preference, as the limited number of trials where actual conflicting preferences were observed were insufficient for us to fit computational models that can decompose these two factors. A larger choice set may permit examination of these factors in individuals' decisions to accommodate their friend's wishes.

Conclusion

Taking risks is a necessary developmental task, especially during adolescence, as individuals experience a changing social landscape and begin to assume adult roles and responsibilities. The results from these three studies shed light on different ways adolescents' social environment might shape their risk preference. Insight from this dissertation may help educators, developmental scientists, and parents better understand adolescents' behavioral tendencies and peer dynamics. Knowledge of age-related patterns of social-contextual influence on risky decision making, with risk being viewed in its multidimensionality, may inform us when adolescents might be especially susceptible to reckless impulses driven by peer influence, as well as how to best support them through challenges they encounter, taking the social and cognitive development that unfold at difference stages across adolescence into account.

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Appendices

Appendix A: Paper 1 Supplemental Materials

Supplementary Materials

To support

Social contexts requiring adjudication between self- and peer-interest differentially alter risk preferences across adolescence

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I. Supplementary Methods

A. Original expected utility (EU) model

$$EU = pv^{\alpha} \qquad original\ expected\ utility\ model$$

1. Simulation and recovery

To verify that our parameter of interest (Alpha) is recoverable, we simulated choice data of 10,000 subjects each with 35 trials, with values of each parameter in the model drawn randomly and uniformly from the range of possible parameter values. We chose a range sufficient to explain the range of risk preferences that can be captured by our task for our parameters during simulation (0.02 < Alpha < 3.32, 1e-06 < Beta <10). In particular, we calculated the lower bound (0.035) for α by solving the following equation:

$$0.9 \times 100^{\alpha} = 5^{\alpha}$$

The reasoning is as follows: given our choice set, the most risk averse individual would prefer the safe option ($5 with certainty) to the risky option with the highest expected value in our choice set, which is winning $100 with 0.90 probability. Under the same logic, the most risk seeking individual would prefer the risky option with the lowest expected value in our choice set ($10 with 0.1 probability) to the certain option ($5). We therefore calculated the upper bound (3.32) for α by solving the following equation:

$$0.1 \times 10^{\alpha} = 5^{\alpha}$$

An individual who would not select the lowest EV risky option over the safe option but would select the second lowest ($10 with 0.25 probability) from our choice set would solve the following equation:

$$0.25 \times 10^{\alpha} = 5^{\alpha}$$

The resulting Alpha is 2. The choice set could have limited the model's precision in distinguishing between Alpha values ranging from 2 to 3.32, as the difference between these two values lies in one choice.

We fit computational decision models at the subject level and used the mfit toolbox (Gershman, 2016) for MATLAB, which uses *fmincon* (*MATLAB 2018b; Mathworks*). For parameter recovery, we fit the simulated data using the abovementioned bounds for Beta (1e-06 < Beta <10) and slightly wider range for Alpha (0 < Alpha < 3.5). By slightly widening the search space, we are able to determine if a person's Alpha is truly unrecoverable by seeing whether their value lies between 3.32 and 3.5; if we had capped fitted Alpha at 3.32 and the fitted Alpha is 3.32, we wouldn't know whether that is really within the bounds or whether the model does not have the option to put it out of bounds.

We fitted the simulated data using the same EU model that generated it. Recoverability of model parameters is defined as the correlation between the parameter that generated the data and the parameter produced through model fitting (Wilson & Collins, 2019). We ran correlations between parameters used to simulate the data ("input parameters") and parameters fit by *fmincon* ("fitted parameters"). Although Beta recovery was mediocre (r = .400; Alpha <= 2: r = .594; Alpha > 2: r = .057), recovery for Alpha was quite reliable (r = .922) with a drop after Alpha exceeds 2 (Alpha <= 2: r = .935; Alpha > 2: r = .049). As mentioned above, Alpha = 2 is the value at which one would be indifferent between the risky and safe options for the second riskiest choice in our choice set. The fact that values of Alpha were indistinguishable between 2 and 3.5, is in line with the notion that such values (mostly) do not yield different choices. Within this range, there was not a difference in recoverability above vs. below the Alpha necessary to explain the range of risk preferences in the task (3.32). Together, these results suggest that the model is limited in its ability to distinguish small differences among the most risk-seeking participants, likely due to the choice set. Reassuringly, input values of Alpha above 2 did not yield recovered values below 2, so participants who are in this maximally risk seeking range are nearly always identified as such based on their Alpha (except where Beta was very low, such that participants frequently do not choose the option with higher EU) (Figure S1).

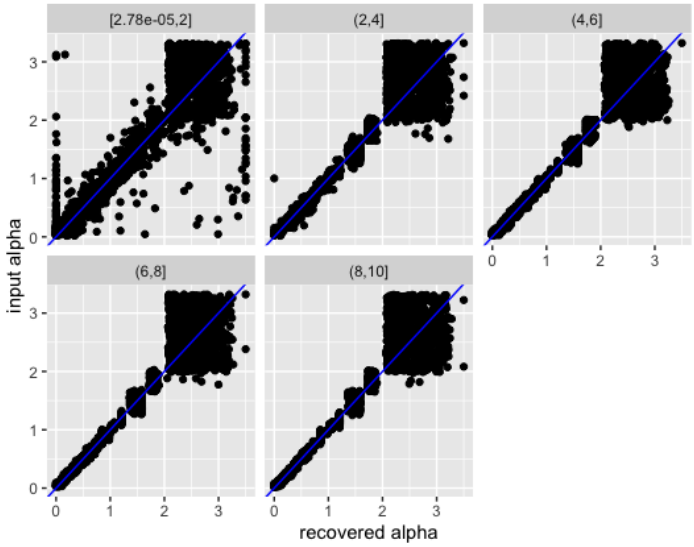


Figure S1. Recovery of Alpha based on different thresholds of input (simulated) Beta. *x*-axes denote recovered (fitted) Alpha. *y*-axes denote input (simulated) Alpha. The range on top of each panel denotes the range of input Beta that was used to generate the simulated data.

2. Preliminary model comparison: Expected utility versus prospect theory models

According to prospect theory and past research (Tversky & Kahneman, 1992; e.g., Gonzalez & Wu, 1999; Hsu et al., 2009;) nonlinear weighting of probabilities is an important bias in decision making. Our choice set was designed according to an expected utility framework (Levy & Glimcher, 2011; Levy et al., 2012; Tymula et al., 2012) and not a prospect theory framework, and we did not expect that prospect theory based models would fit the data well. Nevertheless, for completeness and as a preliminary analysis step, we fit two additional models in the latter framework to determine whether incorporating a probability weighting function could improve the model fit. The first prospect theory model is constructed by combining the expected utility function and the following single-parameter weighting function:

$$w(p) = \frac{p^{\gamma}}{(p^{\gamma} + (1-p)^{\gamma})^{\frac{1}{\gamma}}} \qquad prospect\ theory\ model$$

Therefore, this prospect theory model includes three free parameters: Alpha, Beta, and Gamma, where Gamma (γ) controls the weighting of probabilities (p). The second prospect theory model we fitted included only Beta and Gamma, i.e., assuming the decision-maker is risk neutral. We examined the parameter recoverability of the two prospect theory models before fitting them to real data using the aforementioned procedure. These correlations between input and fitted parameters are displayed in Table S1, indicating poor parameter recovery for the prospect theory models. We conclude that it is not feasible to incorporate prospect theory into our computational approach and which is likely due to limitations of the choice set.

Table S1. Parameter recoverability for expected utility and two prospect theory models

	Alpha, Beta (EU model)	Alpha, Beta, Gamma (prospect theory model)	Beta, Gamma (prospect theory model)
Alpha correlation (fitted, simulated input)	0.922 (when Alpha<=2: 0.935; when Alpha>2: 0.049)	0.206 (when Alpha<=2: 0.204; alpha > 2: 0.024)	
Beta correlation (fitted, simulated input)	0.400 (when Alpha<=2: 0.594; when Alpha>2: 0.057)	0.138 (when Alpha<=2: 0.222; when Alpha>2: 0.006)	0.52
Gamma correlation (fitted, simulated input)		0.003 (when Alpha<=2: 0.005; when Alpha> 2: -0.0004)	0.028

3. <u>Decisions on model usability by condition</u>

We decided we would not use the original model if a given condition had more than 30 participants with a negative log likelihood (LL) that exceeded the value of negative LL for an agent who chose randomly for all 35 trials:

$$-ln\,(0.5)\ \times 35 = 24.26$$

According to the criterion, which translates to an AIC of 52.52, we decided not to use the original model for the Opposite condition, Observed Opposite, and Unobserved Opposite conditions (Table S2).

Table S2. Number of unusable participants by condition

Conditions	*N* with negative LL > 52.52
Baseline	0
Friend Predicted	0
Opposite	39
Identical	0
Unobserved Opposite	31
Observed Opposite	37
Unobserved Identical	4
Observed Identical	6

4. Model-based exclusions

The criteria described in the Methods - Model-based exclusion section resulted in the following exclusions (Table S3). We conducted sensitivity analyses including and excluding participants whose Alpha is theoretically possible but exceeds 2, due to simulations showing poor recovery of Alpha in this range. See Sensitivity Analyses

Table S3. Model exclusions by condition

Conditions	Number of participants excluded	Number of analyzed participants	percentage of participants excluded
Baseline	1	127	0.78%
Opposite	10	118	7.81%
Identical	0	128	0.00%
Unobserved Identical	12	111	9.76%
Observed Identical	10	113	8.13%
Unobserved Opposite	5	118	4.07%
Observed Opposite	8	115	6.50%

These exclusions apply to analyses of Alpha and $Weight_{friend}$ as dependent variables only, as they were derived from computational models. No participant was excluded for analyses using simulated earnings or proportion of risky choices.

5. Posterior predictive check

We ran a posterior predictive check on the Expected Utility model. For each real participant in each condition, we simulated 100 participants with the same parameter estimates. As a model-free measure, we calculated that participant's proportion of risky choices and the proportion of risky choices across the corresponding 100 simulated participants for a given condition. The correlation between the proportion of risky choices for each real and simulated participant was high for all conditions ($r > .8$).

Table S4. Results of posterior predictive check

Conditions	Correlation between real and simulated choices
Baseline	*r*=.98
Friend Predicted	*r*=.98
Identical	*r*=.98
Unobserved Identical	*r*=.84
Observed Identical	*r*=.83

B. Revised model for Opposite context conditions

$$EU = (1 - w)p_{self}{v_{self}}^{\alpha} + w\left(\, p_{friend}{v_{friend}}^{\alpha_{friend}}\right) \qquad \text{revised model}$$

Through the same process outlined for our original model, we determined that our revised model was recoverable in its parameter of interest within the following bounds: Alpha ([0,2]).

1. Parameter recovery

Table S5. Parameter recovery for revised model.

	$\text{Weight}_{\text{friend}}$	Alpha
Correlation between simulated input and fitted value	*r*=.73	*r*=.78

Beta (*r* =.35) is not a parameter of interest but rather a nuisance parameter that is meant to absorb noise in the data. Generally, the fit of noise parameters is not germane unless the overall model fit is poor, which we have shown to be *not* true in our case. Otherwise, model recovery focuses on parameters carried forward for inference, which in our case, is Alpha and $\text{Weight}_{\text{friend}}$, and both recovered well (*r* >.7).

As Ballard & McClure (2019) presented in detail, the tradeoff between parameters of interest (i.e., the underlying psychological process we are interested in) and decision noise is a general problem for models that attempt to describe noisy psychological processes. Low correlations between decision noise and parameters of interest provide evidence indicating that there is little trade-off of parameters against one another, bolstering confidence that they are individually identifiable (Wilson & Collins, 2019). In our study, correlations between fitted values of Beta and $\text{Weight}_{\text{friend}}$ (*r* = .09) and Beta and Alpha (*r* = -.03) are extremely low. The fact that Alpha / $\text{Weight}_{\text{friend}}$ and Beta are not highly correlated (i.e., they are identifiable), paired

with the fact that Alpha (the parameter of interest) is recoverable, builds confidence that the Alpha parameter is indeed robust and suitable for inference.

2. Model Recovery with the revised vs. the original model

Like the process outlined for the original model, we simulated data using the original and revised model respectively, and fitted the resulting simulated data with both models respectively. Our new model outperformed the original model for the following bounds for $Weight_{friend}$ [1e-06,1].

Table S6. Given what the generating model is (row), percentage of times that AIC suggests (column) is a better model.

Fit model / Data generating model	Original	Revised
original	88.7%	11.3%
revised	37.7%	62.3%

Additionally, we explored the possibility that individuals use their own alpha as a proxy of their friend's risk preference as well. To this end, we compared the median AIC resulting from using $Alpha_{friend}$ vs. participant's own Alpha for the second term in our revised model. Using $Alpha_{friend}$ resulted in a better fit of the data (median AIC using $Alpha_{friend}$ vs. one's own Alpha: 30.056 vs. 30.593), indicating that using an estimated friend preferences better fit individual's' choices in the Opposite context, compared to using their own risk preference as a proxy for their friend's preference. This means that participants tended to represent their friend's risk preferences as distinct from their own.

II. Supplementary Results

A. Results using proportion of risky choices as dependent variable

1. Baseline Risky Choices

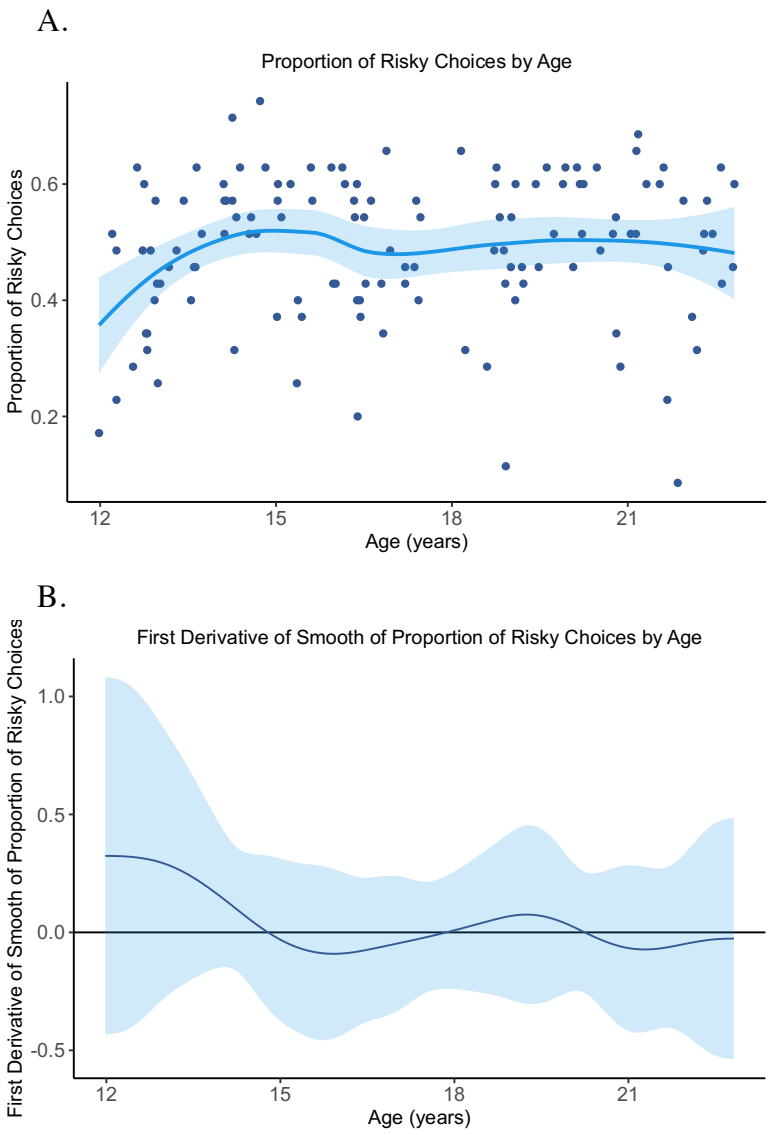


Figure S2. Age-related patterns of risk seeking (proportion of risky choices). (A) Scatter plot of raw data. *x*-axis denotes age in years. *y*-axis indicates proportion of risky choices (number of risky choices divided by total number of trials in a condition). The blue line is a smoothing line over the data points to visualize age trend in the data. Shaded regions represent 95% CIs around the trend line. (B) First derivative of the GAM model. Shaded area represents 95% simultaneous CIs.

This analysis evaluated the relationship between proportion of risky choices and age in the Baseline condition. On average, participants chose risky choices 49% for the time (*SD*=0.13). The simultaneous CI of the first derivative of the spline included 0 at all ages (Fig. S2B). This indicates that in the age range of our sample, participants' risk aversion remained constant as age increased.

2. Age-related shifts in risky choices evoked by identical friend outcome

Comparing the Identical condition to Baseline, we examined whether joint outcomes (risky choice identically impacting oneself and one's friend) influence one's baseline risk preferences. There were no differences between the Identical condition and Baseline overall, or age-related changes on the proportion of risky choices (Mean of Identical vs. Baseline: .51 vs. .49; B=0.05, t=0.99, SE=0.05, p=.323). This indicates that individuals did not proportionally take a different amount of risks when the choice stood to benefit oneself only, or oneself and one's friend.

3. Age-related shifts in risky choices evoked by opposite friend outcome

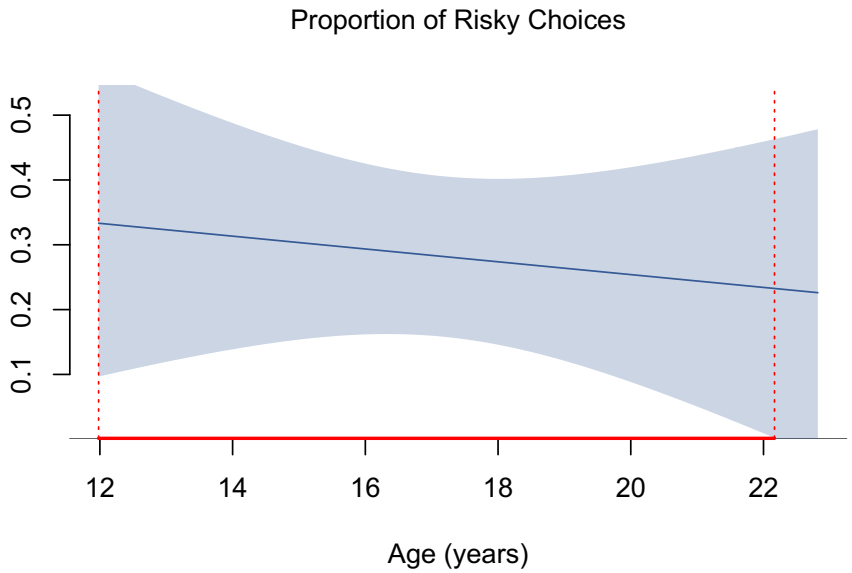


Figure S3. Age-related patterns of proportion of risky choices: difference of fit estimates of the GAM model. Positive values indicate greater proportion of risky choices at Opposite than Baseline, negative values indicate the reverse, and 0 indicates proportions of risky choices are not significantly different across the conditions. Shaded area represents 95% simultaneous CIs of the difference between fit estimates at each age points. Dotted red lines show that between ages 12.0-22.2 years, the 95% simultaneous CIs do not include 0, indicating significant age-related changes.

In the Opposite condition, participants' choices caused their friends to receive their unchosen option. Analyses determined the extent to which participants changed the proportion of risky options they chose compared to Baseline when the decision only concerned themselves. On average, participants chose risky options more often for themselves when it meant that their friend would otherwise have to accept the risky option (Mean of Opposite vs. Baseline: .56 vs. .49; B=0.28, t=5.50, SE=0.05, p<.001). This trend was significant in ages 12.0 to 22.2 years (Figure S3*)*. Thus, participants from almost the entire age range of our sample chose proportionally more risky options when they had to decide whether to keep their preferred option or assign it to their friend instead.

4. Age-related shifts in risky choices evoked by friend observation by context

In the Identical context, participants chose proportionally more risky options when their friends watched them make decisions that yielded the same outcomes for them both, compared to when unwatched (Mean of Observed Identical vs. Unobserved Identical: .71 vs. .69; B= 0.13, t=2.47, SE= 0.05, p=.014).

In the Opposite context, there were no significant differences by observation (Mean of Observed Opposite vs. Unobserved Opposite: .55 vs. .55; B=0.006, t=0.13, SE=0.05, p=0.900).

There were no significant age-related differences by observation in either Identical or Opposite contexts.

B. Distributions of actual and simulated random earnings

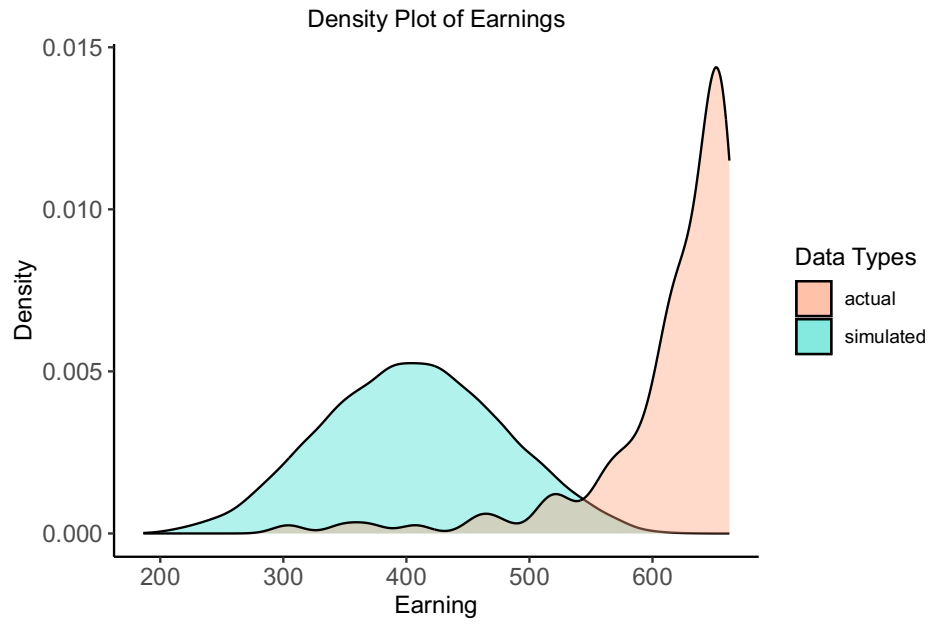


Figure S4. Distributions of actual and simulated random earnings: the blue area represents simulated earnings, and the red area represents actual data. We simulated 10,000 participants choosing at chance (50%) with 35 trials each in the Baseline condition, and compared this distribution to that of the actual data from the Baseline condition (Mean of simulated random earnings vs. actual data: $406.06 vs. $614.52; Standard deviation of simulated random earnings vs. actual data: 72.14 vs. 63.75).

C. Distributions of Alpha values by condition

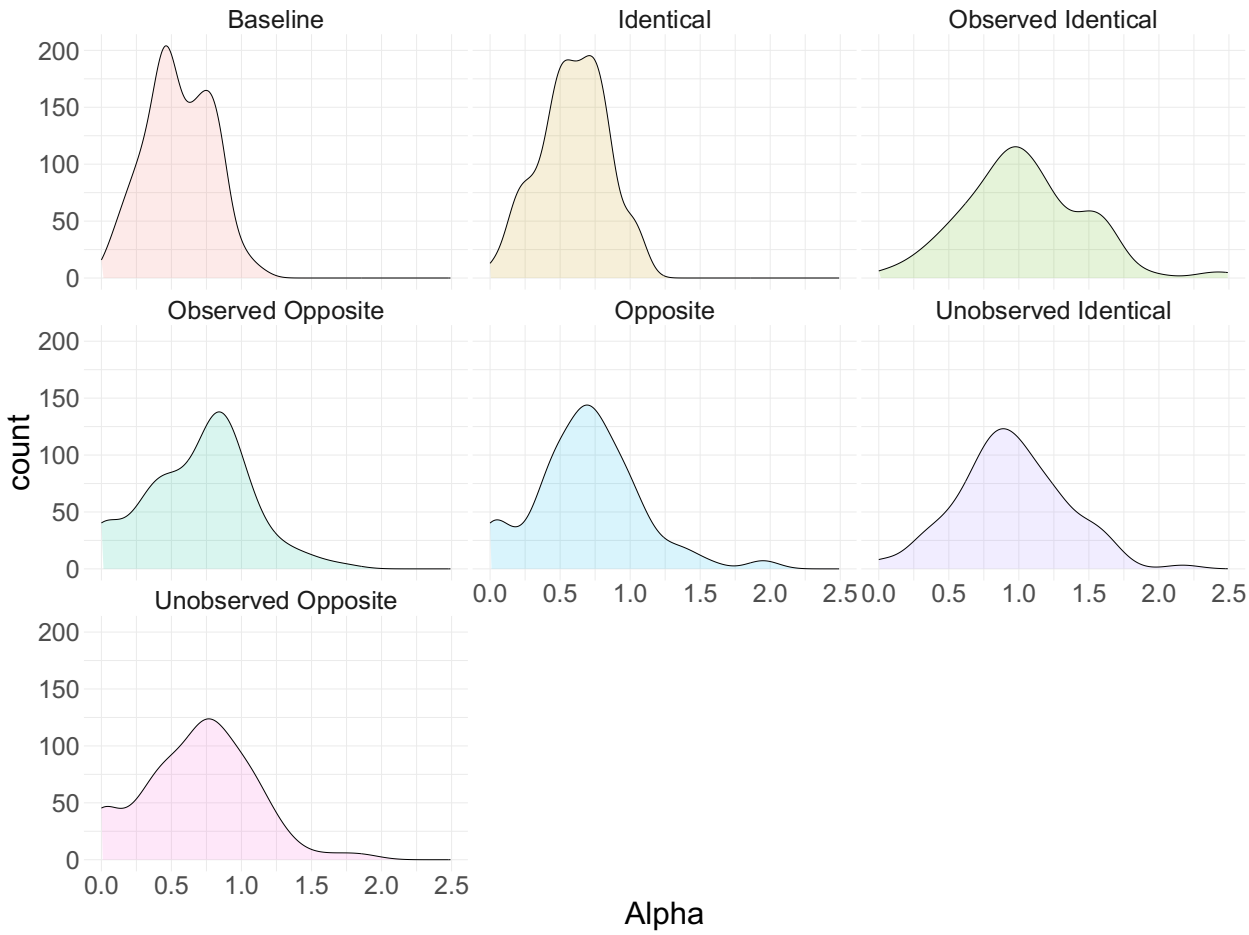


Figure S5. Distributions of Alpha in each condition of the study. *x*-axis indicates Alpha value, *y*-axis (count) indicates the frequency of Alpha taking on a specific value.

D. Results of friend predicted Alpha

We evaluated the degree of consistency between participants' own risk preferences and what they envisioned the risky choices to be if their friend was choosing for themselves (i.e., the Friend Predicted condition). By comparing the Friend Predicted condition to participants' own Baseline condition, we can evaluate whether participants thought their friend's choice would be the same, or riskier, than their own. This analysis follows the same logic as section "Treatment of age" paragraph 2 in the main paper.

The overall mean risk preference (Alpha) derived from participants' predicted choices for their friend is 0.63 (SD = 0.34) and does not change with age, as demonstrated by the fact that the first derivative of the spline for Predicted Friend Alpha includes 0 at all ages. We used a factor smooth interaction described in Analysis section "Treatment of age" paragraph 3 of main text to ascertain whether there are age-related changes between one's own Baseline Alpha (for solo decisions) vs. their predicted Friend Alpha (their prediction of their friend's solo decisions). There was a main effect of Condition (Mean of Baseline vs. Predicted Friend Alpha: 0.55 vs. 0.63, B=-0.08, *SE*=0.03, *t*=-2.96, *p*=.003), indicating that on average, participants predicted their friend to be relatively more risk seeking than they themselves are. There are no age-related changes, indicated by the fact that the Simultaneous CIs included 0 for all ages. In all, participants across the age range consistently thought their peer was more risk seeking than they themselves were.

E. Why the revised model is not used for conditions using the Identical context

Although our revised model was designed with the Opposite context in mind, we checked whether we should consider using it for the Identical, Observed Identical, and Unobserved Identical condition, since they involved friend outcome in the decision as well, though in a different dynamic. Across all three Identical context conditions, the median AIC of the original model is smaller than that of the revised model, suggesting that the original model, which did not treat friend outcome as a competing source of utility to one's own, provides a better model fit for these conditions (Table S7).

Table S7. Model comparison for Identical conditions

Condition	Median AIC, Original Model	Median AIC, Revised Model
Identical	15.159	17.159
Observed Identical	27.325	28.966
Unobserved Identical	25.278	26.687

III. Sensitivity Analysis

Our primary analysis excluded participants based on the model-based exclusion section in the main text. As pre-registered, we conducted two sets of sensitivity analyses using different exclusion criteria on Alpha fitted by the original model, which was used for the Baseline condition and all Identical context conditions. The first set of analyses exclude participants with fitted Alpha > 2, i.e., excluding participants whose Alpha is theoretically possible but exceeds 2, due to simulations showing poor recovery of Alpha within the range of 2-3.32 despite the recovery over the entire range of Alpha being robust. The second set of analysis had no exclusions, i.e., all participants' data were used, including those with a theoretically impossible Alpha value based on our choice set (Alpha > 3.32). We did not conduct similar sensitivity analyses for Alpha fitted by the revised model by including data excluded in the primary analysis because when Alpha was not recoverable outside of the range [0,2] (see section I.B). In contrast, Alpha in the original model was still recoverable over the whole range used for recovery [0,3.5], though Alpha exceeding 3.32 was theoretically implausible given our choice set (see section I.A.1).

A. Baseline risky choices

Table S8. Number of participants in the Baseline condition under different exclusion criteria based on Alpha

Exclusion based on Alpha	Number of participants in Baseline
No exclusions	128
Exclude Alpha > 3.32 (Primary Analysis)	*127*
Exclude Alpha > 2	127

Excluding Alpha > 2 resulted in the same usable data as the analysis reported in the main text (Table S8), see the corresponding section in the Results.

No exclusions: we fit our statistical model with no exclusions based on Alpha. The simultaneous CI of the first derivative of the spline included 0 at all ages (Figure S6B), which is

the same as the primary finding that in the age range of our sample, participants' risk aversion remained constant as age increased.

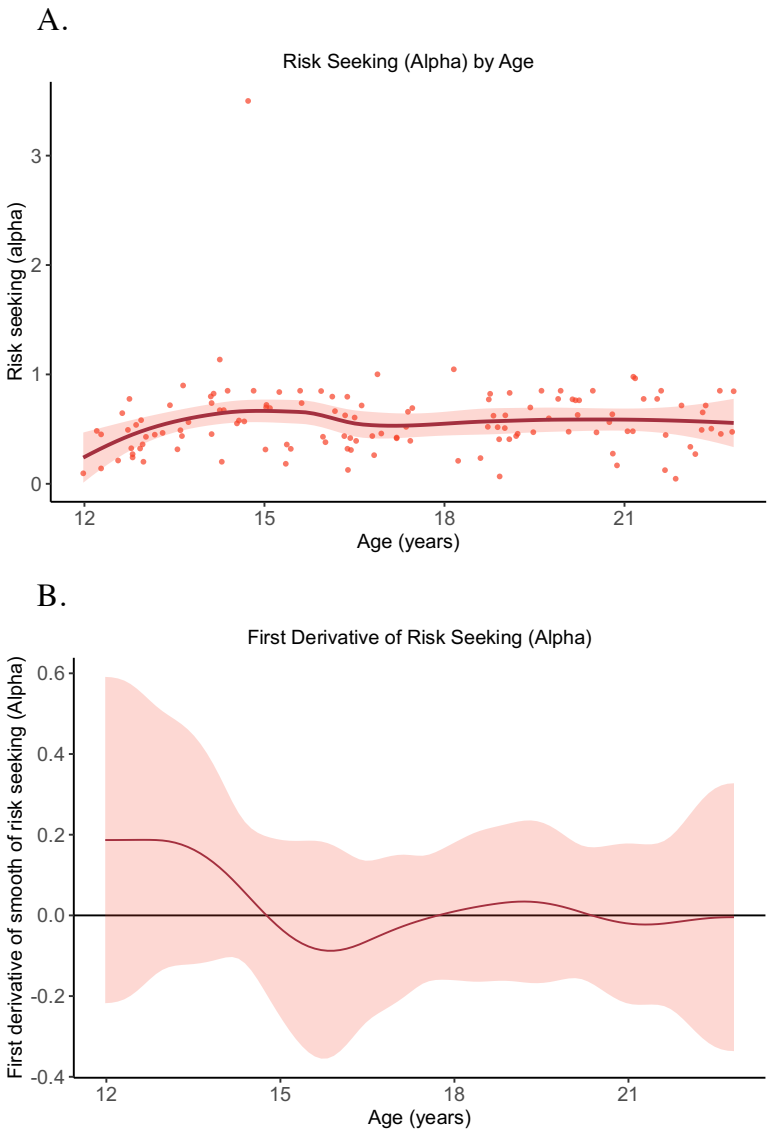


Figure S6. Age-related patterns of risk seeking (Alpha) with no exclusions. A. Scatterplot of raw data (Alpha values). The red line is a smoothing line over the data points to visualize the age trend in the data. Shaded region represents 95% simultaneous CIs around the trend line. B. First derivative of the GAM model. Shaded area represents 95% simultaneous CIs.

B. Age-related shifts in risky choices evoked by friend outcome

Table S9. Number of participants for Baseline and Identical conditions under different exclusion criteria based on Alpha.

Exclusion based on Alpha	Number of participants in Baseline	Number of participants in Identical
No exclusion	128	128
Exclude Alpha > 3.32 (Primary Analysis)	*127*	*128*
Exclude Alpha > 2	127	128

Excluding Alpha > 2, similar to the section above, resulted in the same usable data as the analysis reported in the main text (Table S9), see corresponding section in Results.

No exclusions:

1) Identical condition vs. Baseline

There was no significant difference between Baseline and Identical condition overall or age-related differences in (Mean of Identical vs. Baseline: 0.59 vs. 0.57; $B = 0.02, t = 0.61, SE = 0.03, p = .543$), which is similar to the main text (Mean of Identical vs. Baseline: 0.59 vs. 0.55; $B = 0.04, t = 1.61, SE = 0.03, p = .108$). This analysis confirms that the exclusion criteria did not have an undue influence on the primary findings, which is that individuals judge risk similarly when it stands to benefit oneself only, and oneself and one's friend.

2) Opposite condition vs. Baseline

Overall, participants were more risk seeking for themselves in the Opposite condition (Mean of Opposite vs. Baseline: 0.69 vs. 0.57; $B = 0.12, t = 3.53, SE = 0.03, p < .001$), leading to the same inference as the primary analysis (Mean of Opposite vs. Baseline: 0.69 vs. 0.55; $B = 0.14, t = 5.25, SE = 0.03, p <. 001$). Unlike our primary analysis where we found significant age-related differences between age 12.3-15.1 years, we only found significant age-related difference between age 13.7-14.1 years with no exclusions (Figure S7). However, visualizing the raw data (Figure S8) revealed that the one participant that was excluded in the primary analysis but

included here is an outlier with a theoretically impossible Alpha. Therefore, this result does not warrant alterations to our primary inferences drawn from our primary analysis.

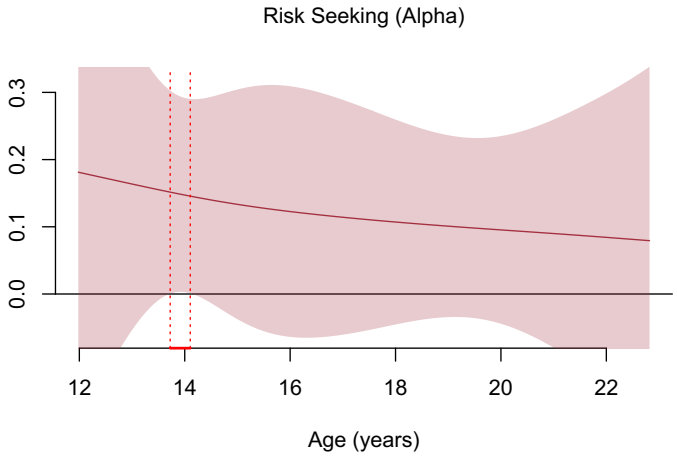
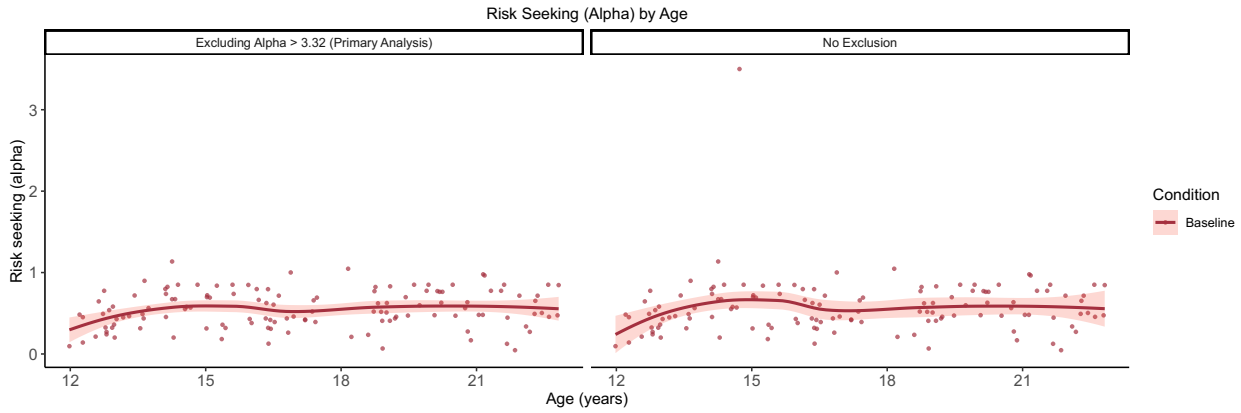


Figure S7. Age-related patterns of risk seeking: Difference of fit estimates of the GAM model. Positive values indicate risk seeking is greater at Opposite than Baseline, negative values indicate the reverse, and 0 indicates risk seeking is equivalent across the conditions. Shaded area represents 95% simultaneous Cis. Dotted red lines show that between ages 13.7-14.1 years, the 95% simultaneous CIs do not include 0, indicating significant age-related changes.

A.



B.

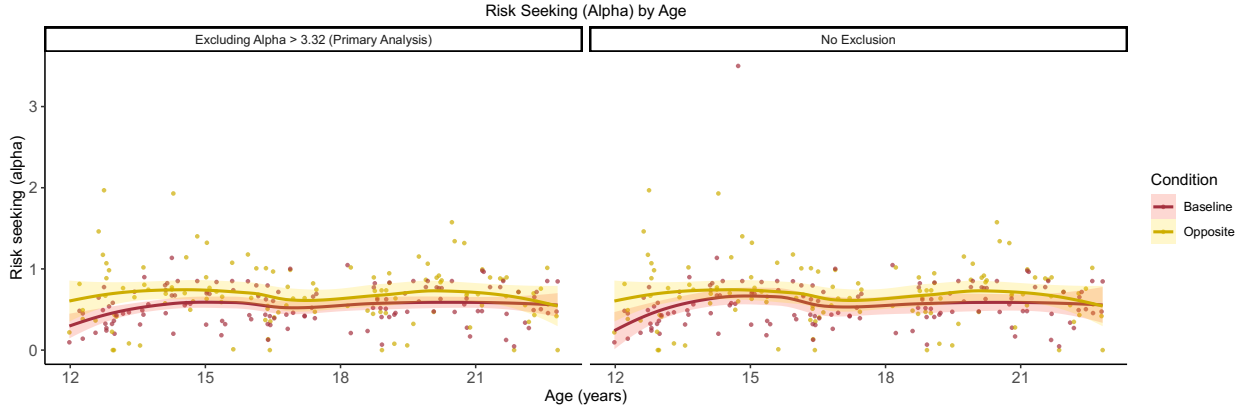


Figure S8. (A) scatterplot of raw data in Baseline in primary analysis vs. with no exclusion. (B) scatterplot of raw data in Baseline and Opposite in primary analysis vs. with no exclusion.

C. Age-Related shifts in risky choices evoked by friend observation in Identical and Opposite contexts

Table S10. Number of participants for Observed and Unobserved Identical conditions under different exclusion criteria based on Alpha.

Exclusion based on Alpha	Identical	
	Observed	Unobserved
No exclusion	114	114
Exclude Alpha > 3.32 (Primary Analysis)	*113*	*111*
Exclude Alpha > 2	111	110

Because all three exclusion criteria resulted in different datasets (Table S10), we fit our statistical models with two preregistered thresholds for model-based exclusion on Alpha: one with no exclusion, and the other excluding participants with Alpha > 2.

1) No exclusions

Unlike our primary analysis where we found participants more risk seeking in the Observed Identical condition than in the Unobserved Identical condition (Mean of Observed Identical vs. Unobserved Identical: 1.04 vs. 0.94; $B = 0.10$, $t = 2.65$, $SE = 0.04$, $p = .008$), we did not find this effect with no exclusions (Mean of Observed Identical vs. Unobserved Identical: 1.06 vs. 1.01; $B = 0.05$, $t = 0.97$, $SE = 0.05$, $p = .331$). However, visualizing the raw data (Figure S9) revealed that the 4 participants that were excluded in the primary analysis but included here are outliers with theoretically impossible values at the upper bound of the aforementioned slightly widened range for Alpha recovery, making these data points unreliable. Therefore, this result does not warrant alternations for our primary inferences drawn from our primary analysis.

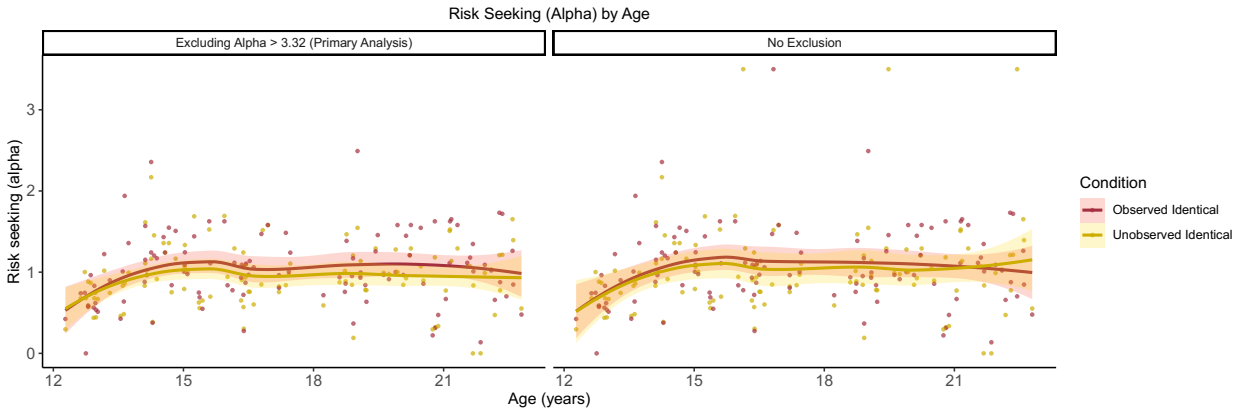


Figure S9. Scatterplot of raw data in Observed Identical and Unobserved Identical in primary analysis vs. with no exclusions.

There was no difference between Observed Opposite condition and Unobserved Opposite condition (Mean of Observed Opposite vs. Unobserved Opposite: 0.69 vs. 0.69; B = -0.001, t = -0.023, SE = 0.05, p = .982), leading to the same inference as the primary analysis (Mean of Observed Opposite vs. Unobserved Opposite: 0.69 vs. 0.69; B = -0.001, t = -0.04, SE = 0.04, p = .971). There were no age-related differences between Observed and Unobserved in both Identical and Opposite conditions, as was the case in the primary analysis.

2) Excluding Alpha > 2

Overall, participants were more risk seeking in the Observed Identical condition than in the Unobserved Identical condition (Mean of Observed Identical vs. Unobserved Identical: 1.01 vs. 0.93; B = 0.08, t = 2.31, SE = 0.03, p = .022), leading to the same inference as the primary analysis (Mean of Observed Identical vs. Unobserved Identical: 1.04 vs. 0.94; B = 0.10, t = 2.65, SE = 0.04, p = .008). There was no difference between Observed Opposite condition and Unobserved Opposite condition (Mean of Observed Opposite vs. Unobserved Opposite: 0.69 vs. 0.69; B = 0.002, t = 0.062, SE = 0.03, p = .951), leading to the same inference as the primary analysis (Mean of Observed Opposite vs. Unobserved Opposite: 0.69 vs. 0.69; B = -0.001, t = -0.04, SE = 0.04, p = .971). There were no age-related differences between Observed and Unobserved in both Identical and Opposite conditions, as was the case in the primary analysis.

Conclusion

These sensitivity analyses confirm that our exclusion criteria did not have undue influence on the primary findings.

IV. References

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Appendix B: Paper 2 Supplemental Materials

Supplementary Materials

To support

Developmental emergence of complex prosocial motives and their influence on risky decision making

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I. Supplementary Methods

A. Original expected utility (EU) model

$$EU = pv^{\alpha} \qquad original\ model\ (1)$$

$$P(choose\ risky) = \frac{1}{1 + \exp\left(\beta\left(EU_{safe} - EU_{risky}\right)\right)} \qquad decision\ rule\ (2)$$

1. Simulation and recovery

To verify that our parameter of interest (Alpha) is recoverable, we simulated choice data of 10,000 subjects each with 35 trials, with values of each parameter in the model drawn randomly and uniformly from the range of possible parameter values. We chose a range sufficient to explain the range of risk preferences that can be captured by our task for our parameters during simulation (0.02 < Alpha < 3.32, 1e-06 < Beta <10). In particular, we calculated the lower bound (0.035) for α by solving the following equation:

$$0.9 \times 100^{\alpha} = 5^{\alpha}$$

The reasoning is as follows: given our choice set, the most risk averse individual would prefer the safe option ($5 with certainty) to the risky option with the highest expected value (EV) in our choice set, which is winning $100 with 0.90 probability. Under the same logic, the most risk seeking individual would prefer the risky option with the lowest expected value in our choice set ($10 with 0.1 probability) to the certain option ($5). We therefore calculated the upper bound (3.32) for Alpha by solving the following equation:

$$0.1 \times 10^{\alpha} = 5^{\alpha}$$

Alpha for an individual who would not select the lowest EV risky option over the safe option but would select the second lowest from this choice set would solve the following equation:

$$0.25 \times 10^{\alpha} = 5^{\alpha}$$

The resulting Alpha is 2. The choice set could have limited the model's ability to distinguish between Alpha values ranging from 2 to 3.32, as the difference between these two values lies in one choice.

We fit computational decision models at the subject level and used the mfit toolbox (Gershman, 2016) for MATLAB, which uses *fmincon* (*MATLAB 2018b; Mathworks*). For parameter recovery, we fit the simulated data using the abovementioned bounds for Beta (1e-06 < Beta <10) and slightly wider range for Alpha (0 < Alpha < 3.5). By slightly widening the search space, we are able to determine if a person's Alpha is truly unrecoverable by seeing whether their value lies between 3.32 and 3.5; if we had capped fitted Alpha at 3.32 and the fitted Alpha is 3.32, we wouldn't know whether that is really within the bounds or whether the model does not have the option to put it out of bounds. Using similar logic, we tested whether Alpha was less recoverable above vs. below 2, the value at which participants would be indifferent between risky and safe options for the second lowest EV risky choice (as described above).

We fitted the simulated data using the same EU model that generated it. Recoverability of model parameters is defined as the correlation between the parameter that generated the data and the parameter produced through model fitting (Wilson & Collins, 2019). We ran correlations between parameters used to simulate the data ("input parameters") and parameters fit by *fmincon* ("fitted parameters"). Although Beta recovery was mediocre (r = .400; Alpha <= 2: r = .594; Alpha > 2: r = .057), recovery for Alpha was quite reliable (r = .922) with a drop after Alpha exceeds 2 (Alpha <= 2: r = .935; Alpha > 2: r = .049). Values of Alpha were indistinguishable between 2 and 3.5, in line with the notion that such values (mostly) do not yield different choices. Within this range, there was not a difference in recoverability above vs. below the Alpha necessary to explain the range of risk preferences in the task (3.32). Together, these results suggest that the model is limited in its ability to distinguish small differences among the most risky-seeking participants, likely due to the limited choice set. Reassuringly, input values of Alpha above 2 did not yield recovered values below 2, so participants who are in this more risk seeking range are nearly always identified as such based on their Alpha (except where Beta was very low, such that participants frequently do not choose the option with higher EU) (Figure S1).

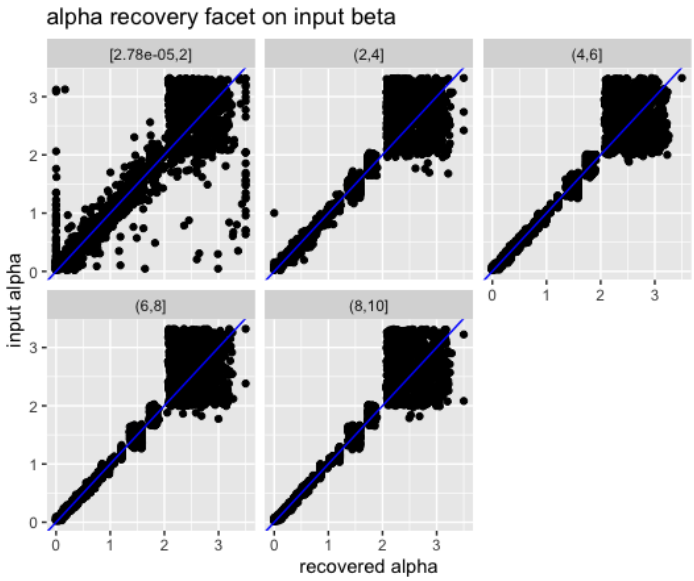


Figure S1. Recovery of Alpha based on different thresholds of input (simulated) Beta. *x*-axes denote recovered (fitted) Alpha. *y*-axes denote input (simulated) Alpha. The range on top of each panel denotes the range of input Beta that was used to generate the simulated data.

2. Comparing EU model with prospect theory models

According to prospect theory and past research (Tversky & Kahneman, 1992; e.g., Gonzalez & Wu, 1999; Hsu et al., 2009) nonlinear weighting of probabilities is an important bias in decision making. Although our choice set was designed according to an expected utility framework (Tymula et al., 2012) and not a prospect theory framework, we nevertheless fit two additional models in the latter framework to determine whether incorporating a probability weighting function could improve the model fit. The first prospect theory model is constructed by combining the expected utility function and the following single-parameter weighting function:

$$w(p) = \frac{p^{\gamma}}{(p^{\gamma} + (1-p)^{\gamma})^{\frac{1}{\gamma}}} \qquad first\ prospect\ theory\ model\ (3)$$

Therefore, this prospect theory model includes three free parameters: Alpha, Beta, and Gamma, where Gamma (γ) controls the weighting of probabilities (p). The second prospect theory model we fitted included only Beta and Gamma, i.e., where EU = pv, implying that the decision maker is risk neutral. We examined the parameter recoverability of the two prospect theory models before fitting them to real data using the aforementioned procedure. These correlations between input and fitted parameters are displayed in Table S1, indicating poor parameter recovery for the prospect theory models. We conclude that it is not feasible to incorporate prospect theory into our computational approach and which is likely due to limitations of the choice set.

Table S1. Parameter recovery for competing models.

	Alpha, Beta (EU model)	Alpha, Beta, Gamma (prospect theory model)	Beta, Gamma (prospect theory model)
Alpha correlation (fitted, simulated input)	0.922 (when Alpha<=2: 0.935; when Alpha>2: 0.049)	0.206 (when Alpha<=2: 0.204; alpha > 2: 0.024)	
Beta correlation (fitted, simulated input)	0.400 (when Alpha<=2: 0.594; when Alpha>2: 0.057)	0.138 (when Alpha<=2: 0.222; when Alpha>2: 0.006)	0.52
Gamma correlation (fitted, simulated input)		0.003 (when Alpha<=2: 0.005; when Alpha> 2: -0.0004)	0.028

3. Decisions on model usability by condition

We decided we would not use the original model if a given condition had more than 30 participants with a negative log likelihood (LL) that exceeded the value of negative LL for an agent who chose randomly for all 35 trials:

$$-ln\,(0.5)\ \times 35 = 24.26$$

According to the criterion, which translates to an AIC of 52.52, we decided not to use the original model for the Opposite context conditions (Table S2).

Table S2. Number of participants that the original model failed to predict better than random choices according to AIC values.

Conditions	*N*
Baseline	0
Friend Predicted	0
Opposite	39
Desired Opposite	57

4. Model-based exclusions

The criteria described in the "Methods - Model-based exclusion" section resulted in the following exclusions (Table S3). We conducted sensitivity analyses including and excluding participants whose Alpha is theoretically possible but exceeds 2, due to simulations showing poor recovery of Alpha in this range. See Sensitivity Analyses.

Table S3. Percentage of participants excluded by condition.

Conditions	Number of participants excluded	Number of analyzed participants	Percentage of participants excluded
Baseline	1	127	0.78%
Friend Predicted	0	128	0.00%
Opposite	10	118	7.81%
Desired Opposite	5	120	4.00%

These exclusions apply to analyses of Alpha and $Weight_{friend}$ as dependent variables only, as they were derived from computational models. No participant was excluded for analyses using simulated earnings or proportion of risky choices.

B. Revised model for Opposite context conditions

$$EU = (1 - w)p_{self}{v_{self}}^{\alpha} + w\left(p_{friend}{v_{friend}}^{\alpha_{friend}}\right) \qquad revised\ model\ (4)$$

Through the same process outlined for our original model, we determined that our revised model was recoverable in its parameter of interest within the following bounds: Alpha ([0,2]).

1. Parameter recovery

Table S4. Parameter recovery for $Weight_{friend}$ and Alpha from Revised model (equation 4).

	$Weight_{friend}$	Alpha
correlation between simulated input and fitted value	*r*=.73	*r*=.78

2. Model Recovery with the revised (equation 4) vs. the original model (equation 1)

Like the process outlined for the original model, we simulated data using the original and revised model respectively, and fitted the resulting simulated data with both models respectively. Our revised model outperformed the original model for the following bounds for $Weight_{friend}$ [1e-06,1].

Table S5. Given what the generating model is (row), percentage of times that AIC suggests (column) is a better model.

Fit model / Data generating model	original	revised
original	88.7%	11.3%
revised	37.7%	62.3%

II. Supplementary Results

A. Distributions of actual and simulated random earnings

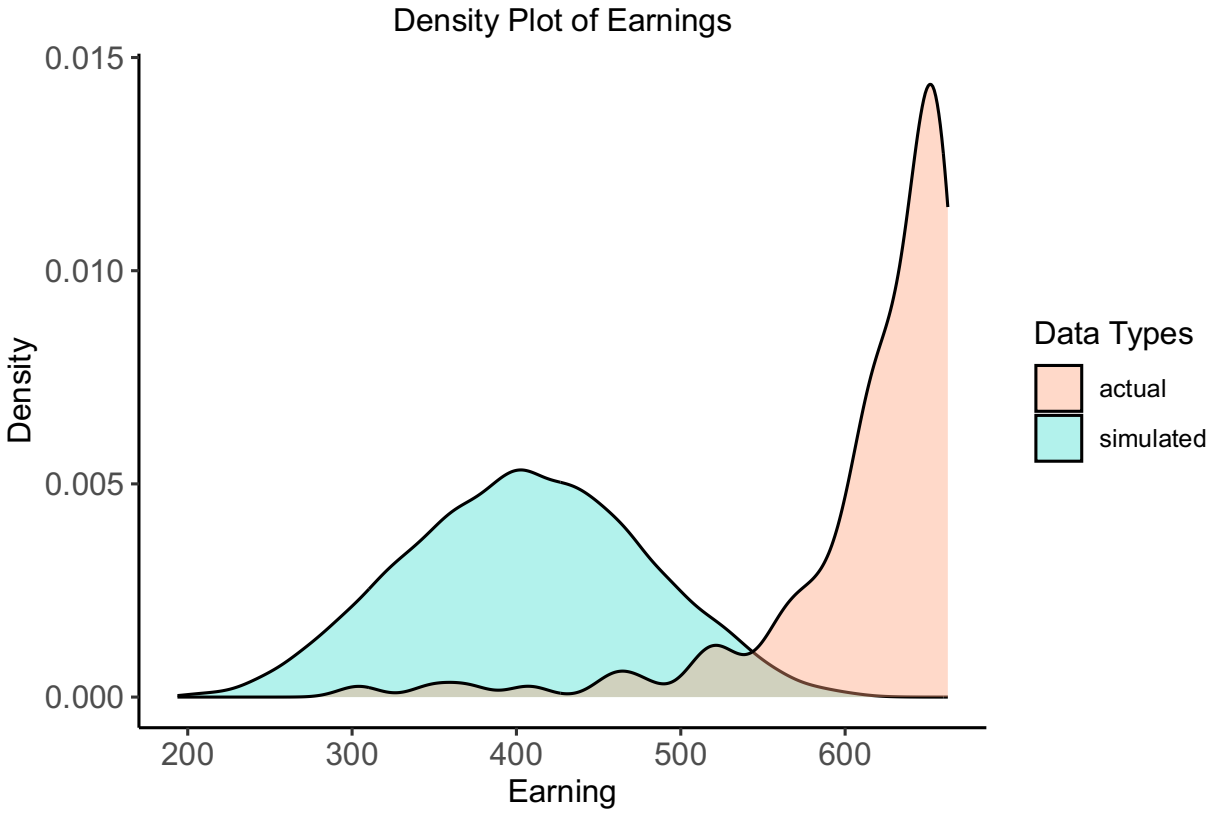


Figure S1. Distributions of actual and simulated random earnings. The blue area represents simulated earnings, and the red area represents actual data. We simulated 10,000 participants choosing at chance (50%) with 35 trials each in the Baseline condition, and compared this distribution to that of the actual data from the Baseline condition (Mean of simulated random earnings vs. actual data: $406.06 vs. $614.52; Standard deviation of simulated random earnings vs. actual data: 72.14 vs. 63.75.

B. Distribution of trials and participants across age for analyses on relinquishing preferred option

1. Distribution of all trials with conflicting self- and friend-preference

A. B.

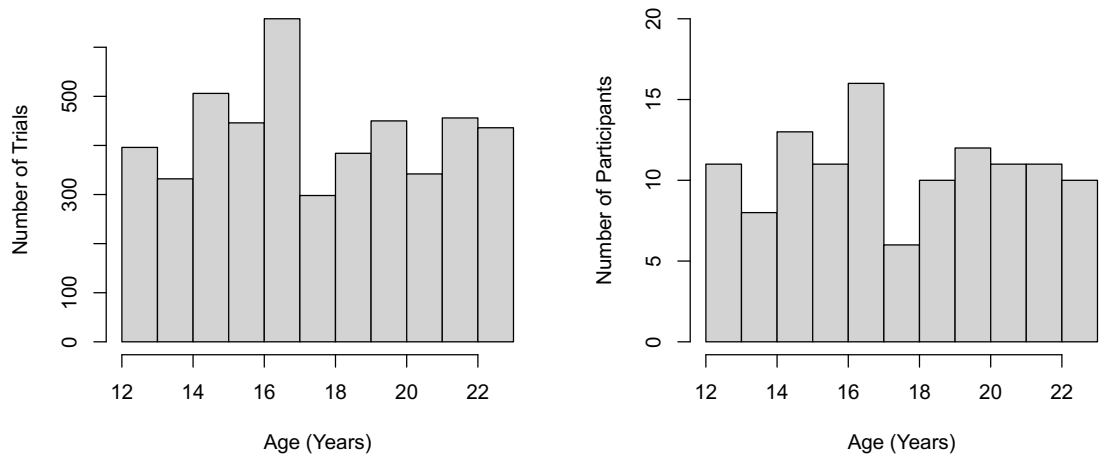


Figure S2. Histograms of the distribution of trials with conflicting self- and friend- preferences across the age range. *X*-axis: age in years. A. Distribution of 4730 trials included. *Y*-axis: number of trials. B. Distribution of 120 participants included. *Y*-axis: number of participants.

2. Distribution of the subset of conflicting trials with equal expected value (EV) of risky and safe options across age

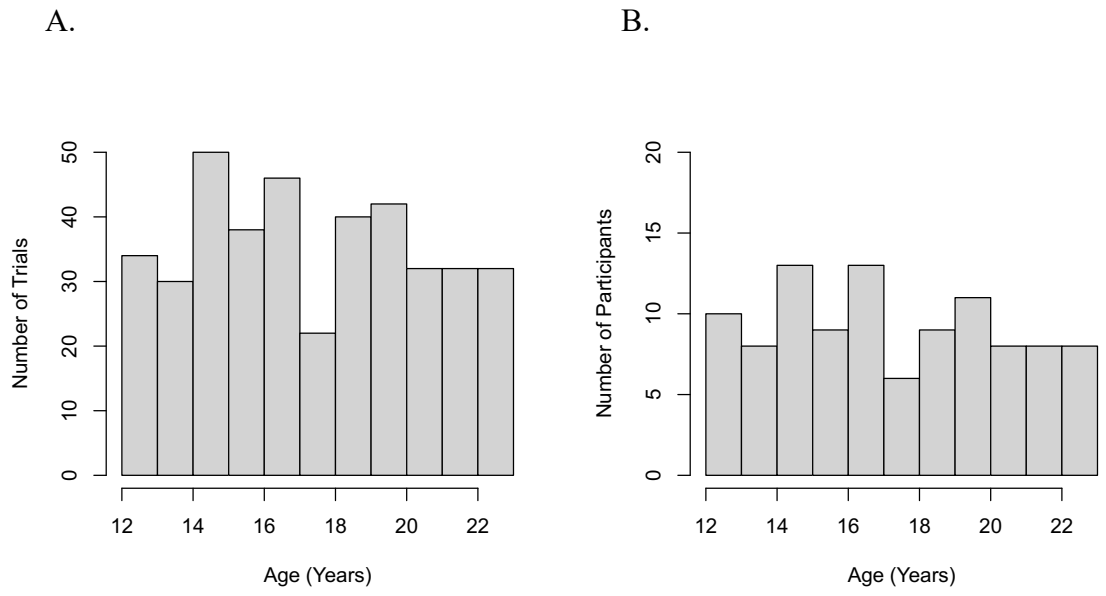


Figure S3. Histogram of the distribution of trials in which the expected value (EV) of the safe and risky options are equivalent across the age range. *X*-axis: age in years. A. Distribution of 398 trials included in this set of analysis: y-axis: number of trials. B. Distribution of 103 participants included in this set of analysis: y-axis: number of participants.

C. Supplementary results for relinquishing preferred options on trials with different EV for risky and safe options

In the main manuscript, we report findings charting age related differences in the tendency to relinquish an originally preferred option to peers, when the risky and safe choice options have an equal EV. Here, we explore more complex scenarios: when the risky options were advantageous ($EV_{risky\ option} > EV_{safe\ option}$ on a given trial) and disadvantageous ($EV_{risky\ option} < EV_{safe\ option}$ on a given trial). See section C.1 for distribution of trials and participants included for these analyses across age.

1. Distributions of trials and participants across age

1) When risky options were advantageous ($EV_{risky} > EV_{safe}$)

A. B.

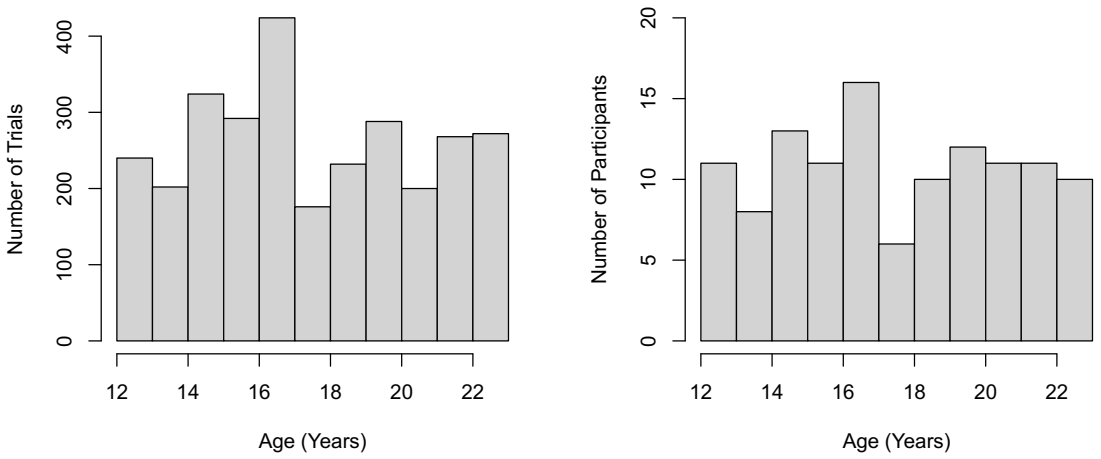


Figure S5. Histogram of the distribution of trials in which the expected value (EV) of the safe and risky options are equivalent across age. *x*-axis: age in years. A. Distribution of 2918 trials included in this set of analysis: y-axis: number of trials. B. Distribution of 119 participants included in this set of analysis: y-axis: number of participants.

2) When risky options were disadvantageous ($EV_{risky} < EV_{safe}$)

A. B.

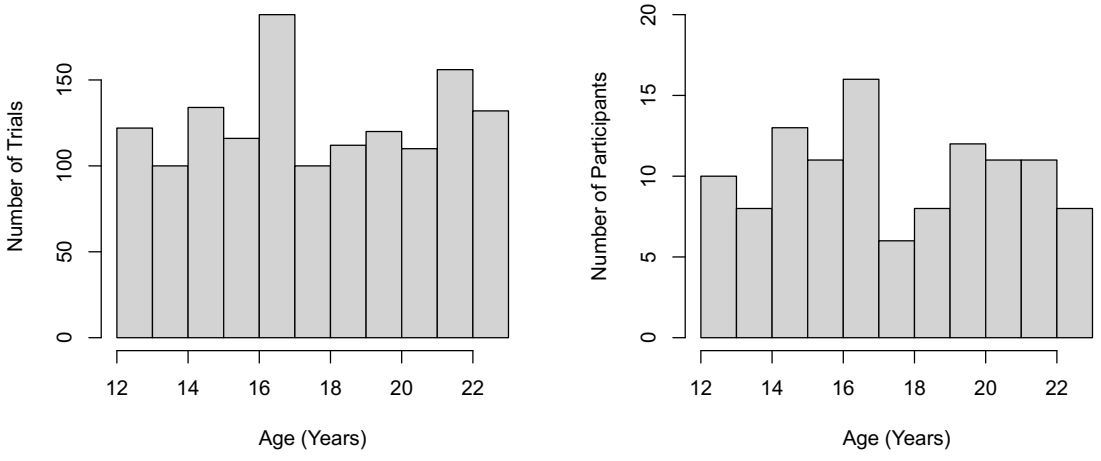


Figure S6. Histogram of the distribution among trials in which the expected value (EV) of the safe and risky options are equivalent across age. *x*-axis: age in years. A. Distribution of 1390

trials included in this set of analysis: y-axis: number of trials. B. Distribution of 114 participants included in this set of analysis: y-axis: number of participants.

2. Results

When the risky options were advantageous, giving up an originally preferred safe option would maximize payout but would require the individual to overcome their initial preferred level of risk aversion. If maximizing payout were a weaker motive than risk aversion, they would refuse to change their preference. Note that here, being motivated by shielding a friend from undesired risks and payout maximization would yield the same behavior. The analogous analysis to the one in the Equal-EV section in the manuscript revealed that on average, participants were more likely to relinquish their preference if it entailed giving up their originally preferred safe option (Mean proportion of total choices relinquished when originally preferring safe options vs, originally preferring risky options: .456 vs. .234, B=0.99, SE=0.13, Z=7.41, p<.001). This trend was significant in ages 13.5-17.3 and 19.7-22.8 years (Figure 4), We speculate that payout maximization (and/or prosocial motives) were stronger than risk aversion in these individuals and drove them to relinquish their original preferences.

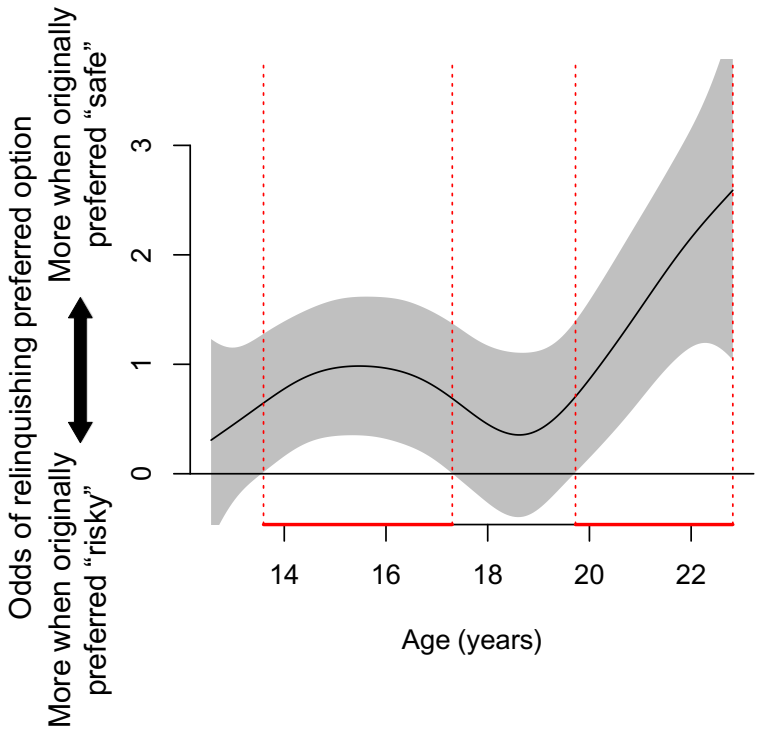


Figure S4. Age-related patterns of odds of relinquishing preferred option on trials where the EV of the risky options exceeded that of the safe options AND there was a conflict between self- and friend preferences. Shaded area represents 95% simultaneous CIs of the difference between fit estimates at each age point. Dotted red lines indicate ages and 13.5-17.3 and 19.7-22.8 years, the 95% simultaneous CIs do not include 0, indicating significant age-related changes. Positive difference indicates participants were more likely to relinquish if they originally preferred the safe option than if they originally preferred the risky option. Negative difference indicates the opposite. Zero indicated there is no difference between the odds of switching in either direction.

When risky options were disadvantageous, relinquishing an originally preferred safe option would be detrimental to payout maximation and contrary to risk aversion. Thus, it could only plausibly be driven by prosocial motives of accommodating one's friend. Analogous analysis to the ones above revealed that on average, participants were more reluctant/unwilling to relinquish their preferred safe option in exchange for a disadvantageous risky option (Mean proportion of total choices relinquished when originally preferring safe options vs. when originally preferring risky options: .167 vs. .395, B=-0.39, SE=0.19, Z=-2.11, p=.035). We speculate that prosocial motives were not strong enough to overcome either payout maximization or risk aversion (or both) and motivate behavioral change. There was no age-related difference, as the model did not

detect significant difference in the odds of switching in either direction (i.e., the simultaneous CI included 0 at all ages).

3. Discussion

When relinquishing the safe option was advantageous in terms of EV, this trend was observed in early-to-mid adolescence and young adulthood but not during mid-to-late adolescence. At a glance, this suggests they were not more likely to relinquish preferred risky or safe options, setting them apart from the clear directional switch of the other ages. This finding was not hypothesized and would benefit from future replications. When the risky option was disadvantageous, participants from all ages were not more likely to switch from originally preferred safe option to receive risky options, or the other way around. This indicates that the prosocial motive was as strong in this scenario to motive behavioral change as in the previous two, where it clearly motivated individuals from certain ages to relinquish their preferred safe options.

D. Effect of observation on risky choice and peer effects

In addition to the choices varying over experimental conditions, we also had a manipulation of whether active observation by peers (real-time monitoring of performance over zoom) moderated the reported peer effects. We ran two preliminary analyses to explore potential impact observation had on the odds of relinquishing one's preferred options on trials with conflicting self- and friend-preference. A GAM model with a factor smooth interaction for age and categorical variable observation while controlling the probability and amount of money on each trial revealed no main effect of observation (Mean proportion of total choices relinquished when observed vs. unobserved: .302 vs. .294, B=0.04, SE=0.08, Z=0.52, p=.602) or age-related difference. A second GAM model with age as the only smoothed term and observation as a categorical predictor of interest, controlling for the probability and amount of money on each trial also revealed no main effect of observation (Mean proportion of total choices relinquished when observed vs. unobserved: .302 vs. .294, B=0.05, SE=0.08, Z=-0.70, p=.483) or age effect (edf=1.00, $chisq$=0.64, p=0.424). Although previous research has demonstrated that adolescents engage in greater risk seeking under the active observation of peers (Gardner & Steinberg, 2005;

Powers et al., 2022) no such effects emerged in the present study. We discuss this further in Chen et al., (under review).

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Appendix C: Paper 3 Supplemental Materials

SSC – Close Friend Support Items

1. I had a close friend I can tell problems to.

2. I had a close friend who really understands me.

3. I had a close friend who I can talk to about things that bother me.

4. I didn't have a close friend who I like to spend time with.

5. I didn't have a close friend who really listens to what I say.

6. I didn't have a close friend who cares about my feelings.

DOSPERT – Social Subscale items

1. Admitting that your tastes are different from those of a friend

2. Disagreeing with an authority figure (such as your boss or teacher) on a major issue

3. Dropping out of school to pursue your dream

4. Choosing a job you enjoy over going to school

5. Speaking out against a popular opinion at school

6. Spending a semester somewhere far away from your extended family

7. Choosing to spend more time on a hobby than studying for school