Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-023-02347-w OPEN

# Risk tolerance in youth with emerging mood disorders

Angé Weinrabe [1], James Tran[2] & Ian B. Hickie [1]✉

Reward-seeking behavior drives adolescents toward risky decision-making. As compared to their older and younger peers, adolescents experience higher rates of anxiety and depressive disorders, leading to impaired decision-making with negative consequences. At two time points, separated by 6–8 weeks, we measured risky and ambiguous choices concurrently with levels of dysregulated emotion for youth aged 16–25 ($N = 30$, mean age 19.22 years, 19 males) attending a youth mental health clinic. The Kessler Psychological Distress Scale (10 items) (K10), the Quick Inventory of Depressive Symptomatology Adolescent (17 items) (QIDS-A17) specifically designed for youth, and the Somatic and Psychological Health Report (12 items) (SPHERE-12) questionnaires were used to evaluate participant's self-reported anxiety and depression scores. Risk and ambiguity tolerance was calculated at the individual and group level. At baseline, 25 (83%) participants were rated as experiencing a mental health condition, and 15 (50%) rated high on all three psychological questionnaires combined, scoring "severely" depressed and "severely" anxious. At follow-up, 25 returning participants, 80% ($N = 20$) remained distressed, with 11 continuing to rate high on all psychological scores. In Session 1, participants had a mean of approximately 14 risky choices (SD = 4.6), and 11 ambiguous choices (SD = 7.6), whilst in Session 2, participants' mean equated to approximately 13 ambiguous choices (SD = 8.5), but their risk increased to 15 choices (SD = 6.5). Applying a multiple regression analysis at the group level, the data suggests that participants were risk averse ($\alpha = 0.55$, SE = 0.05), and preferred making ambiguous choices ($\beta = 0.25$, SE = 0.04). These results suggest that high trait-like anxiety in youth is associated with risk intolerance. These findings may have implications for screening young people with emerging mood disorders.

[1] Youth Mental Health Research, Brain and Mind Centre, Faculty of Medicine, The University of Sydney, Sydney, Australia. [2] School of Banking and Finance, University of NSW, Kensington, Australia. ✉email: ian.hickie@sydney.edu.au

## Introduction

Adolescents have a differential tolerance to risk and ambiguity than both children and adults simply because this is their way of learning (Levy et al., 2012). Scientists have predicted that risk-taking behavior is necessary to help facilitate the adolescent's social move toward independence, this evolutionary phenomenon occurring in young persons around the age of puberty (Steinberg et al., 2008). Increased reward-seeking behavior renders adolescents more prone to risky decision-making relative to their younger peers, with engagement in higher-risk activities where the outcomes are often negative (Albert et al., 2013; Mulye et al., 2009; Pharo et al., 2011). Extensive research on social (Guyer et al., 2016; Tomé et al., 2012), emotional, and cognitive factors (Steinberg, 2005) associated with risky decision-making in young people suggest that these individuals make suboptimal choices because of critical neurodevelopmental changes taking place, specifically the prefrontal cortex and its interconnections which are slow to mature (Luciana, 2013). Furthermore, young people are also extremely vulnerable to mood disorders such as anxiety and depression during adolescence, factors which further influence their attitudes towards risk, sensation seeking, and impulsivity (Hickie et al., 2013; Steinberg, 2008, 2010, 2004; Steinberg and Cauffman, 1996; Steinberg and Morris, 2001; Steinberg et al., 2008, 2009). Contemporary research demonstrates that prolonged mood states, such as anxiety, have been shown to correlate with impaired decision-making (Alvares et al., 2014; Caplin and Leahy, 2001; Charpentier et al., 2017; Harle et al., 2017; Larquet et al., 2010; Mukherjee and Kable, 2014; Scott et al., 2014; Weinrabe et al., 2020; Weinrabe and Hickie, 2021; Wu, 1999). Young individuals with severe mood disorders have even greater neuropsychological impairment, impacting brain regions that in turn affect decision-making (Hermens et al., 2015, 2013).

To better understand youth decision-making, it is critical to evaluate subjective attitudes toward risk and ambiguity. Many studies have evaluated risk in healthy adolescents (Blankenstein et al., 2016; Tymula et al., 2012; Van Den Bos and Hertwig, 2017; Van Duijvenvoorde et al., 2016), but few studies have evaluated risk and ambiguity using economic decision-making tasks in clinical populations—especially youth with emerging mood disorders. Research comparing healthy adults to healthy adolescents under fMRI whilst completing a monetary task that evaluated responses to gains and losses revealed that an adolescents' brain activation patterns showed a reduction in the mesolimbic circuitry (right ventral striatum and right amygdala) when compared to adults in response to anticipating gains but found no difference between adult brains during reward notification (Blakemore, 2018). From this and other clinical research we know that the adolescent's ability to navigate the complexity of the decision-making process itself is problematic (Steinberg, 2010). When evaluating specifically risk and ambiguity in the context of severe mental disorders, it was found that decision-making was severely impaired, (Cisler et al., 2019, 2023; Fujino et al., 2016, 2017; Sonuga-Barke et al., 2016) and anxiety-disordered patients were more risk averse than non-clinical controls (Charpentier et al., 2017).

In the current study, to evaluate risk and ambiguity attitudes in young people with emerging mood disorders, we used decision-making tasks widely applied in economics research (Andersen et al., 2008, 2014; Andersen and Teicher, 2008; Cox and Harrison, 2008; Ellsberg, 1961; Holt and Laury, 2002; Tymula et al., 2012; Weger and Sandi, 2018). Risk is defined as the willingness to accept offers and gambles when the person knows the precise odds of each outcome (Knight, 2012). The difference between risk and ambiguity stems from how much information is available at the time the decision occurs (Glimcher, 2011; Levy et al., 2012). We hypothesize that participants experiencing anxiety, especially heightened trait-like anxiety, would avoid risky decision-making, making our anxious participants more risk averse; and those who rated high on depression scores, would be more risk tolerant as compared to those experiencing anxiety. In light of recent studies, there is a need to understand more clearly other impact factors (beyond mainly age) that influence the young decision-maker.

## Method

**Participants**. This study had a total of 30 participants (19 males, 11 females, mean age = 19.2 years, age range = 16–25 years, standard deviation = 2.23 years), recruited from Youth Services Clinics across two regions in New South Wales (NSW), Australia. These clinics were selected to ensure an accurate representation of youth in the region's varied socio-economic and cross-cultural population. Recruitable subjects were evaluated by the on-site clinician at the Youth Services Clinics to qualify and participate in the experiment. Criteria for inclusion in this study were: (i) aged between 16 and 25 years, (ii) seeking professional help primarily for a depressive (unipolar or bipolar) syndrome, (iii) sufficient fluency in the English language to complete the decision-task, (iv) no history of the neurobiological disease (e.g., head trauma), (v) lack of any intellectual and/or developmental disability, (vi) no allergies or dietary sensitivities, (vii) abstaining from drug and alcohol use for 48 h prior to the appointment, and (viii) willingness to participate in two experimental sessions: on the day they signed up for the study and approximately 6–8 weeks later. Excluded from the study were those participants insufficiently fluent in the English language to be able to partake in the economic tasks or psychological assessment, had a known history of neurobiological disease (e.g., head trauma), disability (intellectual and/or developmental), or those with allergies or dietary sensitivities. Study investigators received clinician-referred potential participant information using the research study's University's Human Research Ethics Committee approved referral letter, which contained de-identified personal information, no information on proposed treatment for each person, and their mood scores for this visit to the clinic. Investigators then issued potential participants with a Participants Information Statement providing clear information about the study content, its aims, and objectives. Upon agreeing to participate in the Youth Choice Study, a Participant's Consent Form was issued, and consent was obtained from each study participant. The University of Sydney's Human Research Ethics Committee approved the study, and the methods and data confidentiality were carried out in accordance with the relevant guidelines and regulations. All data was de-identified during statistical analysis. Due to the strict medical privacy policy held by the clinics where the study was conducted (as determined by the Australian Government), study investigators were not kept informed whether patients received treatment, or what kind of interventions were being used (pharmacological or otherwise).

Table 1 presents the demographic information of the study participants. 30 participants completed Session 1 and 25 completed both sessions. The attrition rate ($N = 5$ at Session 2) is expected for the study because patients visiting the clinic may be too ill to return for their subsequent visit to the mental healthcare clinic. Unreported analysis indicates that subjects did not vary significantly from the rest of the group completing Session 2 (available upon request).

**Procedure**. Clinical factors. Three well-known questionnaires were applied: Kessler's Psychological Distress Scale (10-item) (K10) (Kessler et al., 2003), Quick Inventory of Depressive

**Table 1 Demographic information.**

| | Group *N* | Sex ratio (M:F) | Age (year) | Education (participant) | Education (mother) | Education (father) | Income[a] |
|---|---|---|---|---|---|---|---|
| Session 1 | 30 | 19:11 | 19.22[b] 2.23[c] | 3.23 (1.01) | 3.73 (1.11) | 3.69 (1.23) | 6.33 (1.79) |
| Session 2 | 25 | 16:9 | 19.09 (2.15) | 3.24 (1.01) | 3.80 (1.12) | 3.75 (1.26) | 6.52 (1.76) |

Education (participant), 1 Primary, 2 Year 10, 3 Year 12, 4 TAFE College, 5 Undergraduate, 6 Postgraduate; Education (Mother/Father) 1 Primary, 2 Secondary, 3 TAFE, 4 University Undergraduate, 5 University Postgraduate; Income, 1 very poor, 10 very rich; Attrition rate: 5 subjects did not complete the study.
*F* female, *M* male.
[a]Self-rated household income.
[b]Mean values reported.
[c]Standard deviation reported in parentheses.

Symptomatology Adolescent (17-item) (QIDS-A17) (Rush et al., 2003) specifically designed for youth (Bernstein et al., 2010), and The Somatic and Psychological Health Report (12-item) (SPHERE-12) questionnaire (Hickie et al., 2001). At Session 1, and before the decision-making component of the study started, participants met with their clinicians. At Session 2, 6–8 weeks later, participants met directly with the researcher, who was uninformed whether participants were receiving clinical treatment on the day.

K10 assessed participants' severity of distress on the day of the study. Scores were between 0–50, where 10–19 means 'Likely to be well', 20–24 'Likely to have a mild disorder', 25–29 'Likely to have a moderate disorder', and 30–35 'Likely to have a severe disorder'. When rated >30 a severe mental disorder is present (Scott et al., 2013)

QIDS-A17 evaluated how severe the study participant's depressive symptoms were on the day they arrived for testing and included symptoms present for the previous seven days. The QIDS-A17 total score can vary between 0–27, where 0–5 means 'Not Depressed', 6–10 'Mild', 11–15 'Moderate', 16–20' Severe', and >21 'Very Severe'.

SPHERE-12 measuring physiological and psychological distress was divided into two parts: 6 PSYCH items and 6 SOMA items and participants scored themselves on how distressed they felt across those two primary areas in the past weeks. PSYCH refers to psychological distress, and SOMA refers to physiological distress. When scoring positive on PSYCH and/or SOMA, it will be rated as being either Level 1 (Type 1), reflecting participants with the most symptoms present; Level 2 (Type 2) where participants report on the PSYCH subscale or psychological symptoms only; or Level 2 (Type 3) where participants report on the SOMA subscale or somatic symptoms only; and lastly, "No Symptoms", where participants score neither a psychosocial nor somatic symptomatology and is not rated as having any symptoms to support a diagnosis.

Decision-making. We assessed each person's attitude towards risk and ambiguity using a robust and widely used experimental task, well-known to evaluate subjective risk preferences in economic studies. At both time points in the study, participants accessed a computer where they received written instructions and practical training for the task, prior to the researcher starting the task.

The overall decision task consisted of 60 choices that tested the participant's preference for risk and ambiguity. The choices that made up the overall task consisted of thirty separate questions and involved the participant making a choice between one of two monetary options: an immediate payout amount of $5, or a lottery option that might pay more than $5, but potentially no payout. This experiment using the Ellsberg Paradox ensured probabilities were always clear in the risky task (using two distinct colors), whereas for the ambiguous task, an occluder purposefully covered the outcome of probabilities making the choices obscured (Ellsberg, 1961). For each choice, participants were presented with purposefully randomized options to evaluate probabilities and payoffs for the chances of winning (between $5 and $41). The ambiguity of choices factored in a 50% probability of winning for each of the three different chances of winning, but this was occluded and not known by the participants. The choices were randomized by the software each time presented online.

After the tasks were completed the software program randomly picked a trial from the 60 questions in total. The subject was instructed to request that the researcher determine whether the payout was to be paid on the day of a lottery trial. If the payout was a for sure amount, participants received the payout on the day. If the subject picked a lottery, the participant chose from an actual container with two colored props, using the color of the prop to be allocated that amount. Importantly, it is known that if payments are hypothetical and not realized on the day of the study, people will not make authentic choices (Holt and Laury, 2002). If the software detected that a participant kept making the same choices, their decision-making data would not be included as these are known by economists to not be an accurate representation (Konovalov and Krajbich, 2019; Tymula et al., 2012). The tasks were repeated 6–8 weeks later, with final layouts realized at the end of the session.

Participants each took home approximately AU$17–AU$18 on average for the whole experiment. The experiment took no more than 45 min to complete at each time point (90 min in total). The study used E. prime2 Professional (Schneider and Zuccolotto, 2012) computer software to capture all decision-making tasks.

Analytic Approach Measuring Economic Preferences. We applied a well-known economic model that is used to calculate risk and ambiguity tolerances (Levy et al., 2012). We use the choices from the participants, with approaches from previous economic studies (Levy et al., 2010; Tymula et al., 2012), to show how the utility function is effectively applied to evaluate risk and ambiguity tolerances within subjects:

$$U(p, A, v) = \left(p - \beta * \frac{A}{2}\right) * v^{\alpha}$$

"where $v$ is the dollar amount, $p$ is the winning probability, $A$ is the ambiguity level, $\alpha$ is a measure of the risk attitude, and $\beta$ is a measure of ambiguity attitude" (Tymula et al., 2012). Practically, this expected utility prediction experiment measures risk and ambiguity by using a count of the number of risky and ambiguous choices each participant made in the experiment. To estimate these choices accurately, we first calculated the times each person decided on the lottery amount instead of the "for certain" amount available at each risk level in our experiment. We then estimated the effect of ambiguity on perceived winning probability on each person's mood score.

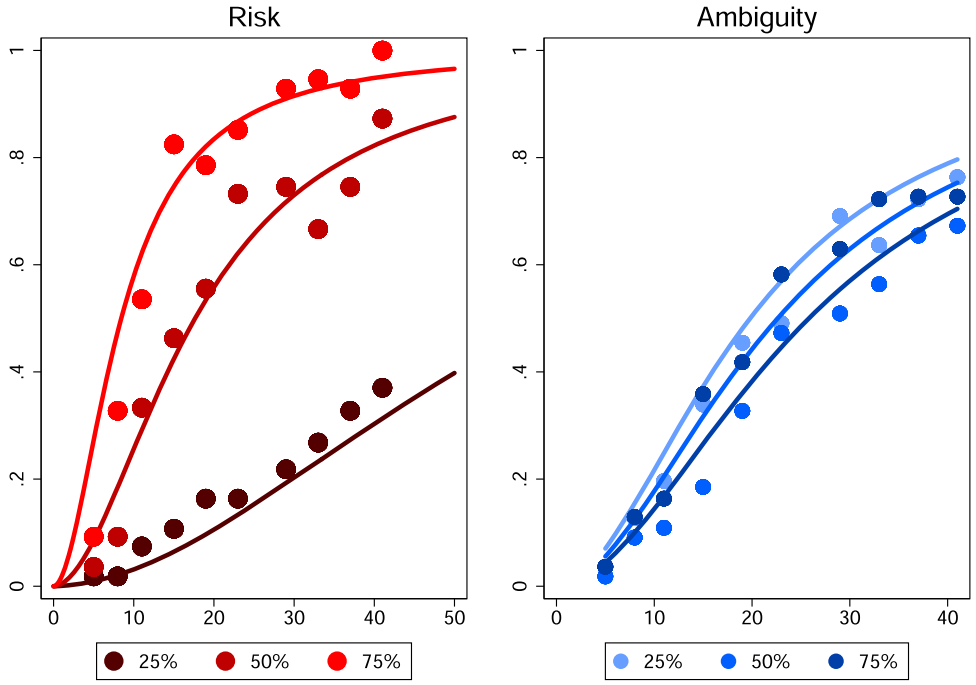


**Fig. 1 Economic preference curves.** Graphs display within subject choice behavior for risk and ambiguity options. Both choices display the pooled sample's preference for choosing the lottery option over the for sure amount, and the exact amount of reward they prefer (various % probability options).

For our statistical analyses, we then had to approximate how risk or ambiguity-tolerant each person was during the study. When calculating risk, an individual can range between the following: risk neutral ($\alpha = 1$); preferred a risky choice to a safe one ($\alpha > 1$); preferred to avoid risk ($\alpha < 1$). When calculating ambiguity ($\beta$) those who avoid ambiguity would show $\beta > 0$, those preferring ambiguity ($\beta < 0$), and those who neither preferred nor avoided ambiguity ($\beta = 0$) Fig. 1.

**Statistical analysis**. We then used multiple regression analysis, across both Session 1 and Session 2. The outcome of the preference proxy (e.g., risk or ambiguity tolerance) is standardized to a mean of 0 and a standard deviation of 1. The mood states are either the continuous proxy of prolonged mood states (e.g., K10, QIDS-A17, or SPHERE-12) or as a binary measure (0,1), which indicates clinically relevant health problems. The control variables are age and gender. For study replication purposes, a well-known economic model (Schurer, 2015) was applied:

$$y_i = \alpha_1 + \alpha_2 \text{Mood State}_i + \alpha_3 \text{Age}_i + \alpha_4 \text{Female}_i + \epsilon_i$$

Here, $y_i$ is the outcome of interest: either "risk tolerance" or "ambiguity tolerance." The subscript i refers to each individual participant; $\text{Mood}_i$ is a proxy for the mood state of interest (K10, or QIDS-A17 or SPHERE-12); $\text{Age}_i$ is a continuous measure of age, $\text{Female}_i$ is a binary indicator for whether the participant is female; and $\epsilon_i$ is the error term. Standard errors are estimated using the Huber/White method which is robust to non-constant variance. Parameters that need an estimation are defined by the Greek letters: $\alpha_1$ measures the mean outcome, if all other values of mood state, age, and female, were to be set to zero. Therefore, $\alpha_2$ measures the difference in $Y$ for a unit increase in the mood measures, $\alpha_3$ measures the difference in $Y$ for each additional year of age or "age gradient" in preferences, and $\alpha_4$ is the difference in outcomes between females and males, or "sex gradient" in preferences. $\alpha_2$ is the main parameter of interest in this model. Statistical analyses were performed using STATA/MP Version 14.2. All tests evaluated groups at both sessions.

**Experiment timeline and demographics**. Participants first completed their psychological questionnaires and decision-making tasks and then the demographic questionnaire. All this information was captured before they received their payment. Participants also filled out demographic questionnaires to evaluate any correlations to age, gender, education level, father's, mother's/guardian's education (used as a proxy for this group), postcode, and self-assessed wealth (ratings will determine where the participants state they sit on a scale from rich to very poor). Participants filled in psychological questionnaires upon arrival and thereafter completed the experiment's decision-making component. Participants were asked to participate in two sessions, Session 1 (after meeting with their clinician) and the same Session 2 again around six to eight weeks later. At no time, due to strict ethics protocol, were the investigators informed whether participants were receiving clinical treatment, and if so, what kind of treatment was being applied, even though study participants had been recruited for this 6–8-week period.

## Results

**Clinical profile**. We conducted data analyses of 30 patients in Session 1 and calculated that 25 participants were rated as experiencing a mental health condition. In total, 15 (50%) participants scored high across all three psychological questionnaires combined: "severely" anxious (K10 ≥ 30), "severely" depressed (QIDS-A17 ≥ 16), and "Level 1 (Type 1)" for SPHERE-12 (PSYCH ≥ 2 and SOMA ≥ 3). Based on psychological scores, we estimated that 5 (17%) participants self-rated as having no condition.

In Session 2, taking attrition into account ($n = 25$), results showed that 20 participants rated as having a mental health condition, with 5 (20%) self-rated as having no condition. Across all three mood questionnaires, 11 (44%) participants rated: "severely" depressed (QIDS-A17 ≥ 16), severely" anxious (K10 ≥ 30), and "Level 1 (Type 1)" for SPHERE-12 (see Table 2).

When analyzing the battery of psychological scores separately for K10, QIDS-A17, and SPHERE-12 it was estimated that at

baseline, 1 participant was rated highly on K10 only, no others were scored high on QIDS-A17 only and 2 participants rated as "Level 1 (Type 1)" for SPHERE-12 only. When evaluating scores 6–8 weeks later, one change occurred on the QIDS-A17 only scores, with the addition of 1 participant who rated as "severely" depressed (QIDS-A17 ≥ 16). However, no changes occurred on the K10 and SPHERE-12 scores (see Table 2). These results suggest that in general, most participants experienced dysregulated emotion for the duration of our study.

### Decision-making

*Individual level*. We found a positive correlation between risk ($\rho = 0.68$) and ambiguity ($\rho = 0.64$) scores across sessions. In other words, if someone makes an ambiguous choice, they are more likely to make a riskier choice as well. In Session 1, participants had a mean of approximately 14 risky choices (SD 4.6), and a mean of approximately 11 ambiguous choices (SD = 7.6). In Session 2, participants' mean increased to approximately 13 ambiguous choices (SD = 8.5), but risk increased by 1–15 choices (SD = 6.5). This correlation implies that the measure has stability and validity as it indicates that decision-making remained consistent over the 6–8 weeks study period.

**Table 2 Mood scores at Sessions 1 and 2.**

| | Session 1 | Session 2 |
|---|---|---|
| *Condition* | | |
| K10 only | 1 | 1 |
| QIDS-A17 only | 0 | 1 |
| Sphere-12 only | 2 | 2 |
| No condition | 5 | 5 |
| *Combination of mood scores* | | |
| High K10 × High QIDS | 0 | 1 |
| High K10 × High Sphere | 4 | 4 |
| High QIDS × High Sphere | 3 | 0 |
| High K10 × High QIDS × High Sphere | 15 | 11 |
| *N* | 30 | 25 |

Table presenting study participant numbers ($N = 30$) at baseline, and ($N = 25$) 6–8 weeks later that self-rated as "severely" depressed (QIDS-A17 ≥ 16), "severely" anxious (K10 ≥ 30), "Level 1 (Type 1)" for SPHERE-12 (PSYCH ≥ 2 and SOMA ≥ 3), and those rated "severe" on mood scores combined. Those who rated "No condition" did not mean a participant was healthy. Results are participants' self-reported scores on the different days of the study. Participants may also be visiting the clinic for treatment which was deliberately not made known to the researchers.

*Group-level*. In Fig. 2, we illustrate the percentage of times that this group of young people chose risky and ambiguous lottery choices over the two-time points. Figure 2 shows that overall, this population chose riskier, and specifically more ambiguous lotteries during Session 2, than when first arriving for mental health care and participating in this study. In other words, most participants avoided taking any kind of risk the first time they completed the experiment compared to the second time. We also found that on average, when making risky choices, the group chose the higher winning probability (75%) more often than the lower winning probabilities. This suggests that the participants distinguished between riskier choices in a consistent and monotonic sense, where they chose more risky bets that had a higher probability of success. However, this does not appear to be the case for ambiguous choices, where participants had similar ambiguity attitudes for lotteries that were the highest and lowest probabilities.

Fitting the expected utility model to the choices from participants, we estimated the pooled risk ($\alpha = 0.55$, SE = 0.05) and ambiguity ($\beta = 0.25$, SE = 0.04) parameters of the model, suggesting that our participants were overall risk-averse and preferred ambiguity (see Supplementary Material for modeled choices for each individual).

*Group-level regression analysis: risk tolerance and mood*. Table 3 presents our estimation of results applying a multiple regression analysis for observations across both Session 1 ($N = 30$) and Session 2 ($N = 25$). Panels A1 and A2 report the results for risk tolerance using a continuous measure for each mood score in Sessions 1 and 2, respectively. Presented are estimated coefficients, obtained from the model described above. Although the estimated coefficients are like zero in a statistical sense, interesting qualitative patterns emerge, mainly that this economic model at a group level suggests that participants behaved averse to risk. To evaluate this more closely, we first test the association between risky choices and mood state applying a regression analysis. Qualitatively, we found the group's K10 results maintain their sign across Sessions 1 and 2, which suggests that anxiety lowers risky decision-making. In other words, the group's scores

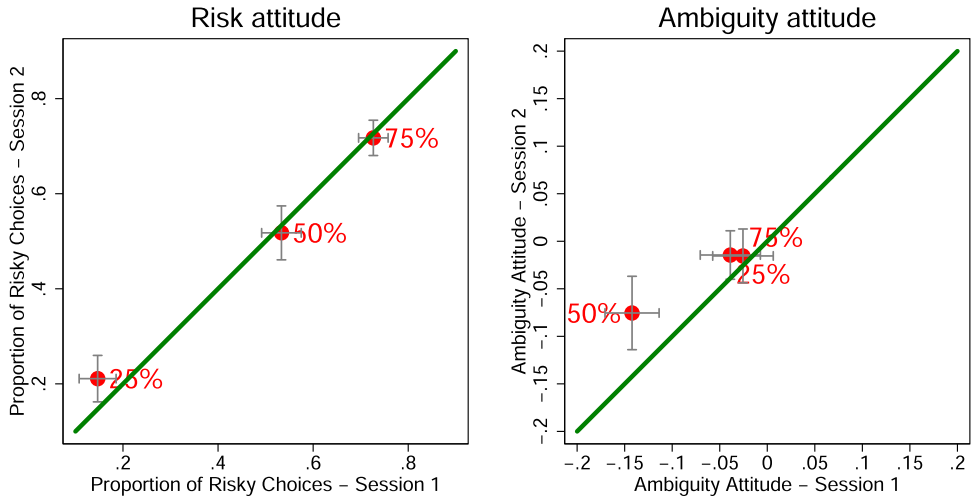


**Fig. 2 Risk and ambiguity attitudes in Sessions 1 and 2.** In the left figure, we show the percentage of times the clinical group chose a lottery, reflected by its winning probability (25%, 50%, or 75%), preferred to a for sure offer ($5) in Session 1 (horizontal axis) and Session 2 (vertical axis). In the right figure, the group's average ambiguity attitude is compared at the same three winning probabilities between sessions. Group differences between risk and ambiguity attitudes for $N = 30$ at Session 1 and $N = 25$ at Session 2.

**Table 3 Predictors of risk tolerance, for different proxies of mood states.**

| | K10 | | | QIDS-A17 | | | SPHERE-12 | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Coefficient** | **Std error** | ***P*-value** | **Coefficient** | **Std error** | ***P*-value** | **Coefficient** | **Std error** | ***P*-value** |
| *Panel A1: Continuous measure of mood state, Session 1* | | | | | | | | | |
| Mood state | −0.02 | 0.02 | 0.51 | 0.02 | 0.02 | 0.40 | −0.65 | 0.24 | 0.01 |
| Age | 0.01 | 0.07 | 0.86 | 0.03 | 0.07 | 0.63 | 0.00 | 0.06 | 0.98 |
| Female | −0.32 | 0.33 | 0.33 | −0.39 | 0.33 | 0.25 | −0.61 | 0.36 | 0.10 |
| Constant | 0.30 | 1.56 | 0.85 | −0.82 | 1.43 | 0.57 | 0.88 | 1.30 | 0.50 |
| *N* | 30 | | | 30 | | | 30 | | |
| *Panel A2: Continuous measure of mood state, Session 2* | | | | | | | | | |
| Mood state | −0.03 | 0.03 | 0.38 | −0.01 | 0.03 | 0.73 | 0.39 | 0.19 | 0.06 |
| Age | 0.06 | 0.12 | 0.61 | 0.08 | 0.12 | 0.51 | 0.04 | 0.11 | 0.73 |
| Female | −0.32 | 0.54 | 0.56 | −0.38 | 0.54 | 0.49 | −0.41 | 0.54 | 0.46 |
| Constant | −0.30 | 3.01 | 0.92 | −1.17 | 2.59 | 0.66 | −0.98 | 2.12 | 0.65 |
| *N* | 25 | | | 25 | | | 25 | | |
| *Panel B1: Binary measure of mood state, Session 1* | | | | | | | | | |
| Mood state | −0.43 | 0.30 | 0.16 | 0.14 | 0.35 | 0.70 | 0.48 | 0.30 | 0.12 |
| Age | 0.01 | 0.07 | 0.89 | 0.03 | 0.07 | 0.66 | 0.03 | 0.07 | 0.70 |
| Female | −0.30 | 0.32 | 0.36 | −0.41 | 0.34 | 0.24 | −0.45 | 0.34 | 0.20 |
| Constant | 0.08 | 1.30 | 0.95 | −0.54 | 1.35 | 0.69 | −0.79 | 1.34 | 0.56 |
| *N* | 30 | | | 30 | | | 30 | | |
| *Panel B2: Binary measure of mood state, Session 2* | | | | | | | | | |
| Mood state | −0.76 | 0.49 | 0.14 | −0.63 | 0.50 | 0.22 | 0.01 | 0.57 | 0.99 |
| Age | 0.08 | 0.11 | 0.48 | 0.07 | 0.11 | 0.55 | 0.09 | 0.12 | 0.46 |
| Female | −0.29 | 0.54 | 0.60 | −0.38 | 0.53 | 0.48 | −0.38 | 0.58 | 0.51 |
| Constant | −1.06 | 2.28 | 0.65 | −0.92 | 2.37 | 0.70 | −1.48 | 2.55 | 0.57 |
| *N* | 25 | | | 25 | | | 25 | | |

Outcome measure is risk tolerance, which measures the total number of risky choices (out of 30). Outcome measure is standardized to mean 0 and standard deviation 1; Binary measures for mood are constructed with the following clinically relevant thresholds: "severely" depressed (QIDS-A17 ≥ 16), "severely" anxious (K10 ≥ 30), and "Level 1 (Type 1)" for SPHERE-12 (PSYCH ≥ 2 and SOMA ≥ 3). Coefficients are obtained from a regression of risk tolerance on age, gender, mood state, and Session 2. Standard errors are calculated using the Huber/White method.

demonstrate that when anxiety is present, there is risk-avoidant behavior. This result is presented in the data when evaluating a pooled sample, results that are directionally consistent with the economic model of risk aversion (see Supplementary Material).

*Group-level regression analysis: evaluating ambiguity tolerance (see Supplementary Material).* We applied the same multiple regression analysis as above, using a sample of observations across both Session 1 ($N = 30$) and Session 2 ($N = 25$), evaluating ambiguity and mood for our sample of study participants. Overall, we find no statistically significant relationship between mood and ambiguity tolerance when using conventional levels of significance ($\alpha = 0.05$) across both Sessions 1 and 2. However, we find some evidence in Session 1 of a direct association between depression scores and ambiguous choices, but they are not statistically significant in Session 2. Furthermore, we note that overall, there is more ambiguous decision-making in Session 2, yet not visible in the regressions. This suggests that either some learning process emerges, or other factors influence how people choose during the experiment that increases ambiguous choices, whilst making it independent of depression (see the "Discussion" section).

## Discussion

Youth research suggests that healthy adolescents, more so than healthy young adults, are risk-seeking (Gullone et al., 2000) and that a range of factors directly contribute to this behavior (Pfeifer et al., 2011). Economic decision-making studies, not controlling for mood, demonstrate an alternative finding, that adolescents are more averse to risk than adults, when ambiguity is present, making them more risk-tolerant in these situations (Tymula et al., 2012) Nevertheless, it is the negative consequences of risky decisions, that are problematic for the young person (Eaton et al., 2006). For ill populations experiencing psychopathologies, negative decision-making is due to alternations in fear, learning, and alternation neurocircuitry (Harle et al., 2017; Hartley and Phelps, 2012). Research studies reporting on the correlation between dysregulated emotions (anxiety and depression), and impaired economic decision-making found that a positive relationship existed between these key variables (Weinrabe and Hickie, 2021). For example, when working with a clinically depressed population this study found that patients accepted more unfair offers more of the time than did healthy control groups (Harle et al., 2010). Another more recent economic study, although not reporting on the causes of the symptoms of mood disorders, claims that adolescents who suffer from severe anxiety symptoms systematically violate principles of normative decision-making (Weinrabe et al., 2020).

Few empirical studies address emotional dysregulation in a natural setting, depending on mood-changing laboratory experiments to bring about certain emotional states. Importantly, negative emotional states do not impact decision-making in the same way as prolonged mood states—such as trait anxiety and depression. Trait anxiety, a serious influencer of stress-induced depression is known to negatively influence a person, leading to behavioral and physiological changes (Weger and Sandi, 2018). Our study addressed how risk tolerant a within-subject level group that was experiencing prolonged mood, as validated by a referring clinician and according to self-report mood scores. Study participants were also seeking professional care for an emerging mood disorder. Our sample's risk attitudes are like studies in the economic decision literature that suggest—unhealthy youth populations are averse to risk as measured by the same or similar experiments used in this study (Hartley and Phelps, 2012; Maner et al., 2007). Although taken from a small sample size, our results suggest that overall, those young people self-rated as experiencing an emerging mood disorder, specifically

trait anxiety, were overall more risk averse in their decision-making. Our results also show that young people in this age group who take risks are more prone to making ambiguous choices, or ambiguity tolerant. We consider that our results show no statistically significant relationship between our other key variables, for example, depression scores and risk. This highlights that other factors influencing the young person, either on the day of the study or overall, are affecting our results. Authors suggest that although there is tremendous value in this type of research (the clinical setting), there are multiple challenges to rigorously evaluate mood disorders, specifically anxiety and its impact on decision-making, using economic paradigms (Murphy et al., 2001; Paulus and Yu, 2012). These authors suggest that multiple external factors impact the patients before or during treatment, confounding the effect on the study results (Paulus and Yu, 2012). We consider that these and other factors are playing a role, making it more challenging to answer the question in this specific study. Are these findings generalizable beyond monetary gambles? Are economic tasks sensitive to people not only with mood disorders but especially so for youth at a certain stage of brain development?

It could be argued that in addition to a young person experiencing anxiety leading to negative psychological bias, another factor has a major impact on the person's capacity to make well-informed decisions (Murphy et al., 2001, 1999), i.e., task comprehension. Each young person decides based on their subjective value or utility function, and how they estimate risk and uncertainty depends on these processes at work (Harbaugh et al., 2002). Does this play a significant role, especially so in youth, in relation to calculating the probability of gains versus losses? For example, our experimental setup gave participants three choices: picking a for-sure amount, predicting a risky amount where the probability was clear, or predicting the probability of winning a lottery amount where the probability was ambiguous. Thus, the option available to choose a certain amount was always clearer than the risky (and ambiguous) choices. Is it possible that the young person had difficulty estimating the probability of winning because of their IQ score, limited experience, and/or because ambiguous choices are challenging at this age anyway? Was this especially so when trying to differentiate the outcome of each gamble, therefore making less risky choices during the experiment?

Probability weighting function in youth is a recognized limitation of other decision-making studies, where studies claim the results vary considerably (Lang and Betsch, 2018). A more comprehensive behavioral economic study, evaluating risk and ambiguity attitudes in healthy youth aged 10–25, included a choice experiment that assessed participants' understanding of the overall economic task (Blankenstein et al., 2016). This study did not control mood using any psychological questionnaires, but when evaluating choice violations, it found that most participants were economically rational—unrelated to age. In other words, when given the chance at a lottery offering a higher amount, participants choose a certain amount (avoided risky choices) and consistently do so, over the course of the experimental task. Healthy adolescents in Blankenstein's study, like participants in our study who self-rated as severely anxious, were also risk averse. Another famous study reporting on risk attitudes across different age groups, specifically evaluating probability weighting of the choices in children, young adults, and adults, makes the bold claim that "younger participants' behavior over both losses and gains appear consistent with a tendency to underweight low-probability events and overweight high-probability ones" (Harbaugh et al., 2002, p. 63). In other words, the authors found that a lean towards adulthood, made the individual more risk neutral, and the younger they were more risk-taking, the latter especially so when the perceived yield of the choice was a high-probability prospect over gains (Harbaugh et al., 2002, p. 53). Overall, what their study demonstrates is the change in attitudes towards risk over the healthy person's lifetime (Harbaugh et al., 2002),

What these mixed results reinforce is the importance of the context in which the decisions are being made. In a large review studying the impact of stress on decision-making in multiple contexts, these findings are further validated (Starcke and Brand, 2012). Young people may therefore struggle with the decision process itself (Berns et al., 2008), and when having to make them in a variety of uncertain situations that often present themselves in day-to-day life. Decision-making of any kind, but especially ambiguous decision-making, requires that affective and cognitive processing work in sync, and economic scholars have long suggested that people in general struggle with decisions where the probability of a choice outcome cannot be estimated (Ellsberg, 1961; Knight, 2012). One recent scientific study using Magnetic resonance imaging (MRI), exploring social decision-making in 61 adolescents with trauma who were experiencing internalizing symptoms, found that individuals suffered a diminished prospective of mental simulation of reward because the mechanism associated with learning is impacted (Cisler et al., 2023, pp. 6910–6920). This had a major influence on their capacity to make more rewarding decisions. Trauma in this context refers to one or multiple factors associated with psychological, emotional, and/or physical abuse and neglect experienced in developmental years (Cisler et al., 2019).

Furthermore, decision-making continually changes because of multiple variables that need to be in place for the decision process to occur effectively. Regulated mood is not the only factor that impacts the person's decision outcomes, other factors have a major influence—such as the biologically developing neural mechanisms. Whether choice offerings are real versus hypothetical is another example that demonstrates the subtle biases associated with the process (Holt and Laury, 2002); and for example money itself, as compared to food items as payment outcomes for individuals (Chung et al., 2019).

**Limitations**. Our study has a few limitations. We did not compare our findings to healthy controls, run the study longer than the 6–8-week period, nor did we collect longitudinal data over a long-term period. Due to mental health privacy laws, we were not allowed to include an analysis in this study of whether or not our study participants were in treatment, what kind of treatment they were receiving, and for how long. Future studies could compare risk and ambiguity attitudes during this crucial neurodevelopmental stage and evaluate whether or not the young person experiencing dysregulated emotions outgrew their risky attitudes and/or their mood scores improved over the course of this time frame. This is due to multiple factors, but the influence of receiving clinical treatment. Future studies could separate the possible conflation between 'mood disordered' and 'healthy adolescent' behavior using indirect measures, such as those used in economic paradigms. Our current study only included economic tasks to evaluate behavior. Future studies could include a more age-sensitive and comprehensive battery of tasks, such as cognitive tasks used in contemporary and clinical neuropsychological studies[24] that could aim to better understand whether other issues are presenting, either related to or unrelated to an emerging mood disorder.

Another limitation of this experiment was our small sample size and that we used psychological self-reporting to evaluate dysregulated mood. The sample size was estimated this size for three reasons: firstly, this was a pilot study testing economic methodologies in a clinical population in an Australian youth clinic for the first time; secondly, our aim was to precisely

duplicate the Harbaugh economic experiment (Harbaugh et al., 2002) with a similar sample size for young adults, and compare these results, before moving to a much larger trial; and thirdly, due to constraints associated with recruitment of clinical youth study participants arriving for mental health support, it was challenging to have a bigger sample size participate. Future studies could target larger cohorts of young people with clinical diagnoses in larger clinical facilities and longitudinally, to allow for generalizability of our results. We could apply the Mental Health Clinical Staging Model (Scott et al., 2013), where earlier signs and symptoms of mood disorders can be identified in young help-seekers and evaluate risk and ambiguity attitudes at each of the staging levels. Furthermore, our study did not screen out those participants who were prescribed anti-depressive medication and/or who were receiving other forms of treatment, or for how long, and whether some or all participants were in fact receiving treatment during our study's research period—all factors that could further confound our results.

Where our study differs from other research using the same economic tasks to capture risk and ambiguity preferences, especially in youth decision-making, is that our focus was on the impact of prolonged mood states—anxiety (trait) and depression in a clinical setting, as opposed to a laboratory setting. There has been much research conducted using economic methodologies in healthy youth populations—such as university student populations, in the United States of America and in Europe, giving our pilot study a foundation to build on. When reviewing the literature, we identified that even when conducting studies in these healthy populations, or populations where the study was not screening for mental health disorders, few mentioned biological factors that could be influencing their findings, such as youth in this age group are biologically still developing. In conclusion, this pilot study forms part of a growing number of empirical studies that aim to investigate how the decision-making of young people experiencing dysregulated emotion is affected when exposed to risk. The impact of mood disorders on decision-making in general is complicated—even with technological advances in science shedding light on this topic. Anxiety and depression, especially during adolescence, have become more prevalent in our society with negative decision-making consequences, in some cases tragically leading to suicide (Twenge et al., 2018). Our empirical findings emphasize the relevance of investigating youth risk attitudes, not in opposition to other fields, but in conjunction with a broader research schema. This interdisciplinary research may have clinical implications as well as support policymakers.

## Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author.

Received: 11 April 2023; Accepted: 6 November 2023;
Published online: 28 November 2023

## References

Albert D, Chein J, Steinberg L (2013) The teenage brain: peer influences on adolescent decision making. Current Dir Psychol Sci 22(2):114–120

Alvares GA, Balleine BW, Guastella AJ (2014) Impairments in goal-directed actions predict treatment response to cognitive-behavioral therapy in social anxiety disorder PLoS ONE 9(4):e94778

Andersen S, Harrison GW, Lau MI, Rutström EE (2008) Eliciting risk and time preferences. Econometrica 76(3):583–618. https://doi.org/10.1111/j.1468-0262.2008.00848.x

Andersen S, Harrison GW, Lau MI, Rutström EE (2014) Discounting behavior: a reconsideration. Eur Econ Rev 71:15–33. https://doi.org/10.1016/j.euroecorev.2014.06.009

Andersen SL, Teicher MH (2008) Stress, sensitive periods and maturational events in adolescent depression. Trends Neurosci 31(4):183–191. https://doi.org/10.1016/j.tins.2008.01.004

Berns GS, Capra CM, Moore S, Noussair C (2008) Three studies on the neuroeconomics of decision-making when payoffs are real and negative. Adv Health Econ Health Serv Res 20:1–29

Bernstein IH, Rush AJ, Trivedi MH, Hughes CW, Macleod L, Witte BP, Jain S, Mayes TL, Emslie GJ (2010) Psychometric properties of the Quick Inventory of Depressive Symptomatology in adolescents. Int J Methods Psychiatr Res 19(4):185–194. https://doi.org/10.1002/mpr.321

Blakemore SJ (2018) Development of the adolescent brain: implications for executive function and social cognition. Eur Neuropsychopharmacol 28:S1. https://doi.org/10.1016/j.euroneuro.2017.12.017

Blankenstein NE, Crone EA, van den Bos W, van Duijvenvoorde ACK (2016) Dealing with uncertainty: testing risk-and ambiguity-attitude across adolescence. Dev Neuropsychol 41(1–2):77–92

Caplin A, Leahy J (2001) Psychological expected utility theory and anticipatory feelings. Q J Econ 116(1):55–79. https://doi.org/10.1162/003355301556347

Charpentier CJ, Aylward J, Roiser JP, Robinson OJ (2017) Enhanced risk aversion, but not loss aversion, in unmedicated pathological anxiety. Biol Psychiatry 81(12):1014–1022

Chung H-K, Glimcher P, Tymula A (2019) An experimental comparison of risky and riskless choice—limitations of prospect theory and expected utility theory. Am Econ J: Microecon 11(3):34–67

Cisler JM, Esbensen K, Sellnow K, Ross M, Weaver S, Sartin-Tarm A, Herringa RJ, Kilts CD (2019) Differential roles of the salience network during prediction error encoding and facial emotion processing among female adolescent assault victims. Biol Psychiatry 4(4):371–380

Cisler JM, Tamman AJF, Fonzo GA (2023) Diminished prospective mental representations of reward mediate reward learning strategies among youth with internalizing symptoms. Psychol Med 53(14):6910–6920. https://doi.org/10.1017/S0033291723000478

Cox JC, Harrison GW (2008) Risk aversion in experiments: an introduction. In: Harrison GW (ed) Risk aversion in experiments. Emerald Group Publishing Limited, p 1–7

Eaton DK, Kann L, Kinchen S, Ross J, Hawkins J, Harris WA, Lowry R, McManus T, Chyen D, Shanklin S, Lim C, Grunbaum JA, Wechsler H (2006) Youth risk behavior surveillance—United States, 2005. J School Health 76(7):353–372. https://doi.org/10.1111/j.1746-1561.2006.00127.x

Ellsberg D (1961) Risk, ambiguity, and the savage axioms. Q J Econ 75(4):643–669

Fujino J, Hirose K, Tei S, Kawada R, Tsurumi K, Matsukawa N, Miyata J, Sugihara G, Yoshihara Y, Ideno T (2016) Ambiguity aversion in schizophrenia: an fMRI study of decision-making under risk and ambiguity. Schizophr Res 178(1–3):94–101

Fujino J, Tei S, Hashimoto R-I, Itahashi T, Ohta H, Kanai C, Okada R, Kubota M, Nakamura M, Kato N (2017) Attitudes toward risk and ambiguity in patients with autism spectrum disorder. Mol Autism 8(1):45

Glimcher PW (2011) Foundations of neuroeconomic analysis. Oxford University Press

Gullone E, Moore S, Moss S, Boyd C (2000) The adolescent risk-taking questionnaire: development and psychometric evaluation. J Adolesc Res 15(2):231–250. https://doi.org/10.1177/0743558400152003

Guyer AE, Silk JS, Nelson EE (2016) The neurobiology of the emotional adolescent: from the inside out. Neurosci Biobehav Rev 70:74–85. https://doi.org/10.1016/j.neubiorev.2016.07.037

Harbaugh WT, Krause K, Vesterlund L (2002) Risk attitudes of children and adults: choices over small and large probability gains and losses. Exp Econ 5(1):53–84

Harle, Guo DL, Zhang SA, Paulus MP, Yu AJ (2017) Anhedonia and anxiety underlying depressive symptomatology have distinct effects on reward-based decision-making. PLoS ONE 12(10):e0186473. https://doi.org/10.1371/journal.pone.0186473

Harle KM, Allen JJ, Sanfey AG (2010) The impact of depression on social economic decision making. [Article]. J Abnormal Psychol 119(2):440–446. May 2010

Hartley CA, Phelps EA (2012) Anxiety and decision-making. Biol Psychiatry 72(2):113. https://doi.org/10.1016/j.biopsych.2011.12.027

Hermens DF, Naismith SL, Chitty KM, Lee RS, Tickell A, Duffy SL, Paquola C, White D, Hickie IB, Lagopoulos J (2015) Cluster analysis reveals abnormal hippocampal neurometabolic profiles in young people with mood disorders. Eur Neuropsychopharmacol 25(6):836–845. https://doi.org/10.1016/j.euroneuro.2015.02.009

Hermens DF, Naismith SL, Lagopoulos J, Lee RSC, Guastella AJ, Scott EM, Hickie IB (2013) Neuropsychological profile according to the clinical stage of young persons presenting for mental health care. BMC Psychol 1(1):8–8. https://doi.org/10.1186/2050-7283-1-8

Hickie IB, Davenport TA, Hadzi-Pavlovic D, Koschera A, Naismith SL, Scott EM, Wilhelm KA (2001) Development of a simple screening tool for common mental disorders in general practice. Med J Aust 175:S10

Hickie IB, Hermens DF, Naismith SL, Guastella AJ, Glozier N, Scott J, Scott EM (2013) Evaluating differential developmental trajectories to adolescent-onset mood and psychotic disorders. BMC Psychiatry 13(1):303–303. https://doi.org/10.1186/1471-244X-13-303
Holt CA, Laury SK (2002) Risk aversion and incentive effects. Am Econ Rev 92(5):1644–1655. https://doi.org/10.1257/000282802762024700
Kessler RC, Howes MJ, Walters EE, Hiripi E, Normand S-LT, Colpe LJ, Zaslavsky AM, Manderscheid RW, Epstein JF, Gfroerer JC, Barker PR (2003) Screening for serious mental illness in the general population. Arch Gen Psychiatry 60(2):184–189. https://doi.org/10.1001/archpsyc.60.2.184
Knight FH (2012) Risk, uncertainty and profit. Courier Corporation
Konovalov A, Krajbich I (2019) Revealed strength of preference: inference from response times. Judgm Decision Mak 14(4):381–394
Lang A, Betsch T (2018) Children's neglect of probabilities in decision making with and without feedback. Front Psychol 9:191
Larquet M, Coricelli G, Opolczynski G, Thibaut F (2010) Impaired decision making in schizophrenia and orbitofrontal cortex lesion patients [research support, non-U.S. Gov't] Schizophr Res 116(2-3):266–273. https://doi.org/10.1016/j.schres.2009.11.010
Levy I, Rosenberg Belmaker L, Manson K, Tymula A, Glimcher PW (2012) Measuring the subjective value of risky and ambiguous options using experimental economics and functional MRI methods. J Vis Exp (67):e3724. https://doi.org/10.3791/3724
Levy, Snell J, Nelson AJ, Rustichini A, Glimcher PW (2010) Neural representation of subjective value under risk and ambiguity. J Neurophysiol 103(2):1036–1047. https://doi.org/10.1152/jn.00853.2009
Luciana M (2013) Adolescent brain development in normality and psychopathology. Dev Psychopathol 25(4):1325–1345. https://doi.org/10.1017/S0954579413000643
Maner JK, Richey JA, Cromer K, Mallott M, Lejuez CW, Joiner TE, Schmidt NB (2007) Dispositional anxiety and risk-avoidant decision-making. Personal Individ Differ 42(4):665–675
Mukherjee D, Kable JW (2014) Value-based decision making in mental illness: a meta-analysis. Clin Psychol Sci 2(6):767–782. https://doi.org/10.1177/2167702614531580
Mulye TP, Park MJ, Nelson CD, Adams SH, Irwin Jr CE, Brindis CD (2009) Trends in adolescent and young adult health in the United States. J Adolesc Health 45(1):8–24. https://doi.org/10.1016/j.jadohealth.2009.03.013
Murphy FC, Rubinsztein JS, Michael A, Rogers RD, Robbins TW, Paykel ES, Sahakian BJ (2001) Decision-making cognition in mania and depression. Psychol Med 31(4):679–693. https://doi.org/10.1017/S0033291701003804
Murphy FC, Sahakian BJ, Rubinsztein JS, Michael A, Rogers RD, Robbins TW, Paykel ES (1999) Emotional bias and inhibitory control processes in mania and depression. Psychol Med 29(6):1307–1321. https://doi.org/10.1017/S0033291799001233
Paulus MP, Yu AJ (2012) Emotion and decision-making: affect-driven belief systems in anxiety and depression. Trends Cogn Sci 16(9):476–483. https://doi.org/10.1016/j.tics.2012.07.009
Pfeifer JH, Masten CL, Moore WE, Oswald TM, Mazziotta JC, Iacoboni M, Dapretto M (2011) Entering adolescence: resistance to peer influence, risky behavior, and neural changes in emotion reactivity. Neuron 69(5):1029–1036. https://doi.org/10.1016/j.neuron.2011.02.019
Pharo H, Sim C, Graham M, Gross J, Hayne H (2011) Risky business: executive function, personality, and reckless behavior during adolescence and emerging adulthood. Behav Neurosci 125(6):970–978. https://doi.org/10.1037/a0025768
Rush AJ, Trivedi MH, Ibrahim HM, Carmody TJ, Arnow B, Klein DN, Markowitz JC, Ninan PT, Kornstein S, Manber R, Thase ME, Kocsis JH, Keller MB (2003) The 16-Item quick inventory of depressive symptomatology (QIDS), clinician rating (QIDS-C), and self-report (QIDS-SR): a psychometric evaluation in patients with chronic major depression. Biol Psychiatry 54(5):573–583. https://doi.org/10.1016/S0006-3223(02)01866-8
Schneider WEA, Zuccolotto A (2012) Psychology software tools, Inc. [E-Prime 2.0] [Webpage]. Retrieved from http://www.pstnet.com
Schurer S (2015) Lifecycle patterns in the socioeconomic gradient of risk preferences. J Econ Behav Organ 119:482–495
Scott J, Leboyer M, Hickie I, Berk M, Kapczinski F, Frank E, Kupfer D, McGorry P (2013) Clinical staging in psychiatry: a cross-cutting model of diagnosis with heuristic and practical value. Br J Psychiatry 202(4):243–245
Scott J, Scott EM, Hermens DF, Naismith SL, Guastella AJ, White D, Whitwell B, Lagopoulos J, Hickie IB (2014) Functional impairment in adolescents and young adults with emerging mood disorders. Br J Psychiatry 205(5):362–368. https://doi.org/10.1192/bjp.bp.113.134262
Sonuga-Barke EJS, Cortese S, Fairchild G, Stringaris A (2016) Annual Research Review: transdiagnostic neuroscience of child and adolescent mental disorders–differentiating decision making in attention-deficit/hyperactivity disorder, conduct disorder, depression, and anxiety. J Child Psychol Psychiatry 57(3):321–349
Starcke K, Brand M (2012) Decision making under stress: a selective review. Neurosci Biobehav Rev 36(4):1228–1248. https://doi.org/10.1016/j.neubiorev.2012.02.003
Steinberg L (2005) Cognitive and affective development in adolescence. Trends Cogn Sci 9(2):69–74. https://doi.org/10.1016/j.tics.2004.12.005
Steinberg L (2008) A social neuroscience perspective on adolescent risk-taking. Dev Rev 28(1):78–106
Steinberg L (2010) A dual systems model of adolescent risk-taking. Dev Psychobiol 52(3):216–224
Steinberg L, Cauffman E (1996) Maturity of judgment in adolescence: psychosocial factors in adolescent decision making. Law Hum Behav 20(3):249–272
Steinberg L, Morris AS (2001) Adolescent development. Annu Rev Psychol 52(1):83–110
Steinberg L (2004) Risk taking in adolescence: what changes, and why? Ann N Y Acad Sci 1021(1):51–58
Steinberg L, Albert D, Cauffman E, Banich M, Graham S, Woolard J (2008) Age differences in sensation seeking and impulsivity as indexed by behavior and self-report: evidence for a dual systems model. Dev Psychol 44(6):1764
Steinberg L, Graham S, O'Brien L, Woolard J, Cauffman E, Banich M (2009) Age differences in future orientation and delay discounting. Child Dev 80(1):28–44. https://doi.org/10.1111/j.1467-8624.2008.01244.x
Tomé G, Matos M, Simões C, Diniz JA, Camacho I (2012) How can peer group influence the behavior of adolescents: explanatory model. Global J Health Sci 4(2):26–35. https://doi.org/10.5539/gjhs.v4n2p26
Twenge JM, Joiner TE, Rogers ML, Martin GN (2018) Increases in depressive symptoms, suicide-related outcomes, and suicide rates among US adolescents after 2010 and links to increased new media screen time. Clin Psychol Sci 6(1):3–17
Tymula A, Belmaker LAR, Roy AK, Ruderman L, Manson K, Glimcher PW, Levy I (2012) Adolescents' risk-taking behavior is driven by tolerance to ambiguity. Proc Natl Acad Sci USA 109(42):17135–17140. https://doi.org/10.1073/pnas.1207144109
Van Den Bos W, Hertwig R (2017) Adolescents display distinctive tolerance to ambiguity and to uncertainty during risky decision making. Sci Rep 7:40962
Van Duijvenvoorde ACK, Peters S, Braams BR, Crone EA (2016) What motivates adolescents? Neural responses to rewards and their influence on adolescents' risk taking, learning, and cognitive control. Neurosci Biobehav Rev 70:135–147
Weger M, Sandi C (2018) High anxiety trait: a vulnerable phenotype for stress-induced depression. Neurosci Biobehav Rev 87:27–37. https://doi.org/10.1016/j.neubiorev.2018.01.012
Weinrabe A, Chung H-K, Tymula A, Tran J, Hickie IB (2020) Economic rationality in youth with emerging mood disorders. J Neurosci Psychol Econ 1701:164–177
Weinrabe A, Hickie IB (2021) A multidisciplinary approach to evaluate the impact of emotional dysregulation on adolescent decision making Humanit Soc Sci Commun 8(1):332. https://doi.org/10.1057/s41599-021-01013-3
Wu G (1999) Anxiety and decision making with delayed resolution of uncertainty. Theory Decision 46(2):159–199. https://doi.org/10.1023/A:1004990410083

## Acknowledgements

We thank the participants attending Headspace clinics for being part of the Youth Choice Study, as well as the clinicians and administration team at the clinics in Camperdown and Campbelltown, New South Wales, Australia. A special thanks goes to Agnieszka Tymula, for her supervision and support with this study. This research was funded by the National Health and Medical Research Council (NHMRC) Centres of Research Excellence grant (application identifier 1171910).

## Author contributions

AW initiated and coordinated research, implemented software of study design, wrote original draft and prepared manuscript, revising it critically for important intellectual content. JT curated data and ran formal analysis. IH conceptualized, led and funded research study, reviewed and edited manuscript. All authors read and approved the final manuscript.

## Funding

This research was funded by the National Health and Medical Research Council (NHMRC) Centres of Research Excellence grant (application identifier 1171910).

## Competing interests

AW holds 100% shares in and is the Founder and Director of My Sound Wellbeing Pty Ltd, a health software company offering personalized music as sleep intervention to the public; she is also the Founder of Non-Profit, Giving Education Meaning Ltd. (GEM), a registered Australian charity supporting youth and community development in Australia. AW does not receive a salary from either companies or the Charity. At the time of print, AW is a Ph.D. student at the University of Sydney and receives a Research Training

Program (RTP) Scholarship through the University of Sydney. AW is a sessional academic at the University of Sydney. JT declares no conflict and has no financial interests in AW organizations. IBH declares no financial interests in AW's organizations. Author B has completed his PhD at The University of NSW, Australia, and is a full-time employee of the Australian Government. IBH is the Co-Director of Health and Policy at the Brain and Mind Centre (BMC) University of Sydney, Australia. The BMC operates early-intervention youth services at Camperdown under contract to Headspace. IBH has previously led community-based and pharmaceutical industry-supported (Wyeth, Eli Lily, Servier, Pfizer, AstraZeneca, Janssen Cilag) projects focused on the identification and better management of anxiety and depression. He is the Chief Scientific Advisor to, and a 3.2% equity shareholder in, InnoWell Pty Ltd, which aims to transform mental health services through the use of innovative technologies.

## Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The University of Sydney, Australia's Human Research Ethics Committee (HREC) approved the Youth Choice Study (2015/804) on 29 February 2016, and the study methods and data confidentiality were carried out in accordance with the relevant guidelines and regulations. The HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Human Research (2007), NHMRC and Universities Australia Australian Code for the Responsible Conduct of Research (2007) and the CPMP/ICH Note for Guidance on Good Clinical Practice.

## Informed consent

All participants were issued Participants Information Statements (PIS) as part of the recruitment process to be informed about the study. Upon receiving all the necessary information contained in the PIS, participants were asked to give consent, then asked to sign their Participants Consent Form (PCF). All data was de-identified during statistical analysis. All data of individual participants identified. Participants received a monetary voucher for actualized payouts of their economic task to the value of AU$17–$20 each.

## Additional information

**Supplementary information** The online version contains supplementary material available at https://doi.org/10.1057/s41599-023-02347-w.

**Correspondence** and requests for materials should be addressed to Ian B. Hickie.

**Reprints and permission information** is available at http://www.nature.com/reprints

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.