Learning together: behavioral, computational, and neural mechanisms underlying social learning in adolescence

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Chapter 3

Can I (still) trust you? Examining adolescents' learning about others' trustworthiness

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Westhoff, B., Blankenstein, N. E., Crone, E. A, *&* van Duijvenvoorde, A. C. K. Can I (still) trust you? Examining adolescents' learning about others' trustworthiness

Abstract

Across adolescence, social interactions with others increase in importance and complexity. For building positive social relations it is important to be able to learn whom (not) to trust and to quickly adjust to changes in other people's trust behavior. One's trust learning abilities may be affected by their experienced parenting practices. Here, we studied the development of social trust learning and social reversal learning in 10-24 year-olds, and the effects of self-reported experienced parenting practices. We used an adapted version of a trust game to assess how adolescents learn about trustworthy and untrustworthy social environments, and flexibly adjust their own trust behavior accordingly. Results showed age-related improvements in overall trust learning performance. However, participants performed better at learning whom not to trust than learning whom to trust. In the reversal block, others' trust levels reversed unannouncedly. Here, participants performed better when switching their behavior to an untrustworthy environment than to a trustworthy environment, which was particularly prominent for the younger ages. Moreover, in this reversal block, trust learning performance in the untrustworthy environment was reduced for participants who reported having experienced poorer parental monitoring. Together, the current study provides insights into the age-related differences trust (reversal) learning across adolescence, and suggest that one's family environment may relate to adolescent' social trust learning abilities.

Introduction

Adolescence is a life phase in which the social environments become more diverse (i.e., school, sports clubs, social gatherings) and social interactions become increasingly important and prevalent (Blakemore & Mills, 2014; Crone & Dahl, 2012; Sawyer et al., 2018). Moreover, social-cognitive skills continue to improve across adolescence (Crone & Dahl, 2012; Dumontheil et al., 2010). An important aspect in building reciprocal social relations is making adequate social decisions. An important social decision is whether to show trust in others. That is, when your decision to trust someone is reciprocated, this may contribute to cooperative social interactions, and ultimately result in a positive social relationship. However, when your trust is violated, you may become less likely to trust the other to prevent wasting your resources. Thus, it is important to be able to learn whom and whom not to trust. Besides learning whom to trust, one should also be able to quickly adjust to changes in other people's behavior. That is, our social world is dynamic, and others may change their trustworthiness, calling for a shift in strategies and subsequent social decision-making. The current study examines how children, adolescents, and young adults (10-24 y.o.) learn about others' trustworthiness, and adjust their trusting behavior when others' trustworthiness levels change.

Trust decisions and trust learning across adolescence

In the past years, multiple studies on trust and trust learning have been conducted. To study how people learn about the trustworthiness of others, these studies have typically used economic games such as the trust game (Berg et al., 1995). Although multiple variations in the specific setup are possible (e.g., one-shot games versus multi-round games), the trust game allows studying trust decisions in a controlled way, across a wide age range. Several studies using a trust game did not observe age-related differences in trust behavior across adolescence (Fett, Shergill, et al., 2014; Lemmers-Jansen et al., 2017; van de Groep et al., 2018). However, this is suggested to be due to their included age range, which did not include (late) childhood (Burke et al., 2020; Li, 2017). Several other cross-sectional studies did show age-related increases in trust behavior across adolescence (Fett, Gromann, et al., 2014; Sutter & Kocher, 2007; van den Bos et al., 2010; van den Bos, van Dijk, et al., 2012). Besides these cross-sectional studies, also a recent longitudinal study that investigated trust learning when confronted with untrustworthy others in early adolescents (12-15 y.o.) observed an age-related improvement (Schreuders, Buuren, et al., 2021). In our recent study, we targeted an adolescent sample with a broad age range (10-24 years), and examined interactions with both trustworthy and untrustworthy others (Westhoff et al., 2020). Here, across adolescence, learning not to trust untrustworthy others slightly improved, whereas learning to trust trustworthy others improved markedly. Together, these findings suggest that from late childhood into adolescence, the sensitivity to detect the level of others' trustworthiness improves, which

adolescents can increasingly use to adaptively adjust their behavior in repeated social interactions. The age-related improvement in adjusting to trustworthy (Westhoff et al., 2020), and untrustworthy others (Schreuders, Buuren, et al., 2021; Westhoff et al., 2020) may depend on social-cognitive development such as perspective taking and inequality aversion (Fett, Shergill, et al., 2014; van de Groep et al., 2018; Westhoff et al., 2020), and learning processes (Westhoff et al., 2020). However, the developmental differences in *dynamic* trust learning are not yet well understood.

Reversal trust learning

An essential part of being able to adaptively navigate our social world is the ability to respond to changes in other people's behavior and update our formed beliefs accordingly. That is, if the trustworthiness levels of others change, it may be costly or wasteful if one does not adjust their behavior to the changing social environment. Cognitive flexibility – the ability to respond adaptively towards changing environmental demands (Izquierdo et al., 2017; Peters & Crone, 2014) – in learning is often studied using (non-social) probabilistic reversal learning paradigms. In these paradigms, the reward probabilities change (e.g. from low to high and vice versa), and participants' performance after such reversals are of interest, with higher performance indicating greater cognitive flexibility that benefit reversal learning. Numerous reversal learning studies have been conducted in adult and clinical samples to examine cognitive flexibility (see (Izquierdo et al., 2017; Uddin, 2021) for reviews). A previous developmental study using a non-social probabilistic reversal learning paradigm has shown that adolescents outperformed children and young adults on reversal learning (van der Schaaf et al., 2011). Moreover, another study showed that, compared to adults, adolescents were quicker at adjusting their behavior when the feedback was more negative than expected (Hauser et al., 2015), indicating increased cognitive flexibility in adolescence. Together, these studies point towards adolescence as a phase of heightened cognitive flexibility in learning, especially when outcomes are more negative than expected. Yet, to the best of our knowledge, reversal learning has not yet been studied in a social context across development. Here, we build on our previous study on learning whom (not) to trust (Westhoff et al., 2020) and extend this with a reversal learning manipulation to examine the development of trust learning and trust reversal learning in trustworthy and untrustworthy environments across adolescence.

Parenting practices

Given the vital role of adaptive trust behavior for healthy social interactions and relations (Güroğlu, 2021; Uchino, 2009), it is important to examine the factors that influence the development of trust (learning) across development. The caregiving environment is likely to be a particularly important factor, as previous findings have shown that negative parental practices may shape cognitive development, resulting in reduced cognitive flexibility and learning

difficulties (Savitz et al., 2008; Scheuplein et al., 2021). It has been widely recognized that if people are raised in a warm and safe environment, this contributes to positive long-term outcomes, such as individual wellbeing, social connections, and educational achievements (Ioannidis et al., 2020; Smetana & Rote, 2019). However, households with mostly negative parenting practices (e.g., expressing negative emotions, handling roughly), physical and emotional neglect, or even maltreatment (e.g., physical and emotional abuse), may result in more internalizing and/or externalizing behavioral problems early in life (Cecil et al., 2012; Jaffee, 2017; Smetana & Rote, 2019). In addition, individuals risk long-term consequences, such as a hyperactive stress response, low self-esteem, impaired mental health, and impaired social functioning (Gobin & Freyd, 2014; McCrory & Viding, 2015; Overbeek et al., 2020). However, it is yet unknown whether environmental variables such as parenting practices also affect adolescent's social trust learning. One hypothesis is that growing up in a volatile environment with negative and/or inconsistent parenting practices may make people more sensitive to social cues, leading individuals to be hypersensitive to the outcomes (both positive and negative) of social interactions. This pattern would lead individuals to update their beliefs about others too quickly (*cf*. tit-for-tat strategy), hampering social learning in general (e.g., van Harmelen et al., 2014). Alternatively, growing up with mostly negative parental practices may result in a stronger negativity bias (Toth et al., 2011). Consequently, in these individuals, learning to trust trustworthy others would be hampered compared to learning not to trust untrustworthy others (Hanson et al., 2017). Here, we aim to disentangle these hypotheses by examining the relations between parenting practices, trust learning, and trust reversal learning in a sample of typically developing adolescents (10-18 y.o.). Besides negative parenting practices we also exploratively assessed effects of positive parenting practices on trust (reversal) learning.

The current study

In the current study, we recruited a sample of 160 children, adolescents, and adults (10-24-years old). Participants played a version of the trust game similar to the version we previously used in (Westhoff et al., 2020), which was extended with a reversal learning block, and filled in self-reports on parenting practices (e.g., parental involvement and inconsistent discipline). The trust game consisted of multiple repeated one-shot games, in which participants encountered players from different social environments. These environments showed either low or high levels of trust, and over trials, participants could learn whether to trust a player from a particular environment or not. This set-up enabled us to assess how participants learn about others' trustworthiness level and accordingly adjust their trust behavior to other players in that environment. Note that, although trust choices generally are not a matter of 'good' and 'bad' decisions, in the current setup trust choices can be labeled as more optimal and suboptimal with regard to one's own outcome. Therefore we use the term performance as an indication of how well someone has adjusted to a certain environment.

An ongoing debate is whether social (reversal) learning patterns are specific to learning in a social environment (e.g., Lockwood et al., 2020; Ruff & Fehr, 2014). To allow a direct comparison between social and non-social learning, we additionally included a non-social condition in which participants interacted with slot machines.

The current study aimed to investigate: 1) the age-related differences in learning whom (not) to trust in social and non-social environments, 2) the ability to flexibly adjust behavior towards changing levels of others' trustworthiness (i.e., reversal learning) and its corresponding age-related differences, and 3) the effects of positive and negative parenting practices on trust learning and trust reversal learning.

First, in line with previous studies, we hypothesized an age-related improvement in trust learning across adolescence (Schreuders, Buuren, et al., 2021; van den Bos, van Dijk, et al., 2012; Westhoff et al., 2020), in which learning whom to trust shows greater age-related improvement than for learning whom to distrust (Westhoff et al., 2020). Exploratively, we examined whether these developmental patterns were specific to social trust learning.

Second, considering the development of cognitive flexibility in non-social paradigms across adolescence (Hauser et al., 2015; van der Schaaf et al., 2011), we expected an age-related improvement in the flexibility in learning about others' trustworthiness (reversal learning). As previous studies have observed a negativity bias resulting in faster adjusting to negative than positive outcomes, we expected that participants adjust more easily when a trustworthy environment becomes untrustworthy than vice versa.

Finally, we expected that trust learning and reversal learning performance would be affected for individuals who reported having experienced more negative parenting practices. Specifically, higher ratings of self-reported negative parenting practices would potentially result in impaired trust learning performance in both the trustworthy and untrustworthy environment (volatility hypothesis). Alternatively, individuals who reported having experienced more negative parenting practices would show an asymmetry in learning, in which learning whom to trust (or who switches from untrustworthy to trustworthy) is more impaired compared to learning to distrust untrustworthy others (negativity bias hypothesis).

Methods and Materials

Participants

In total, 160 participants between ages 10 and 24 took part in this study. Participants were recruited through local advertisements and schools. The majority of the participants (96.2%) were born in the Netherlands. Social-economic status (SES), based on the highest achieved parental educational level, indicated that most participants were raised in families with a high (58.0 %) or middle (36.9 %) SES (low SES = 5.1%). Three participants were excluded from analyses because they only filled in the questionnaires but did not perform the learning task.

The final sample, therefore, consisted of 157 healthy participants (78 boys, 79 girls) aged 10-24 years (Mean = 17.51, SD = 4.33; see Figure S1A). The distribution of boys and girls was balanced across age cohorts ($\chi^2(4) = 0.21$, $p = .995$). The IQ scores, estimated with the Similarities and Block Design subtests of the WISC-V (Wechsler, 2008) and WAIS-IV (Wechsler, 2014), were within the normal range varying between 80 and 135 (mean IQ = 106.85, SD = 10.95), and did not correlate with age ($r = -0.12$, $p = .142$). Control analyses showed that sex and IQ did not confound performance on trust learning or reversal learning, and did not influence any of our observed age-related differences (see Supplementary Tables 1 and 3). For the analyses focusing on the effects of parenting practices on trust learning and reversal learning, we only included participants up to 18 years old, as the parenting questionnaire has only been validated for these ages (Frick et al., 1999). This sample consisted of 94 participants aged 10.0 – 18.8 (Mean = 14.49, SD = 2.56) for trust learning and 93 participants for reversal learning analyses.

All procedures were approved by the Medical Ethics Committee of the Leiden University Medical Centre (reference: NL56438.058.16) and performed in accordance with the relevant guidelines and regulations. Adult participants and caregivers of minors provided written informed consent, and minors provided written assent. This study was part of a larger imaging study (data not included in the current article). Participants were therefore screened for MRI contraindications and psychiatric or neurological disorders, and had normal or corrected-to-normal vision.

Procedure

First, participants filled out questionnaires at their homes before the experimental session, via Qualtrics (www.qualtrics.com). During the experimental session, participants were first accustomed to the MRI environment using a mock scanner. Subsequently, they received instructions on the learning task in a quiet laboratory room. Instructions for the task were displayed on a screen and were read out loud by an experimenter. Within the instructions, control questions were incorporated regarding the outcomes of the task to ensure understanding of the point distributions (i.e., indicating how many points each player was winning in a certain choice combination). If participants failed one of the control questions, the instruction was repeated until participants understood the procedure of the game. Participants played 8 practice trials in both the social and non-social conditions (16 trials in total) to familiarize themselves with the game and its timings. In these practice trials, the behavior of both environments was 50% trustworthy to avoid learning effects that could potentially affect behavior in the actual learning task. The outcomes of the practice trials were not paid out. The actual learning task was performed in the MRI scanner; despite handedness, they responded with their right index and middle finger using a button box.

During the experimental session, besides subtests of the WISC-V (for participants ≤ 16 y.o.) and WAIS-IV (for > 16 y.o.), also other measures (not relevant to the current study) were

obtained. After completion of the experimental session (3-3.5 hour), participants received a goodie bag and financial compensation. This compensation consisted of a flat rate, which amount was age-dependent (€20 for 10-12 y.o.; €25 for 13-17 y.o.; €30 for 18-24 y.o.) and a bonus (ranging €5 - €15) based on performance in all tasks (part of a larger study) during the experimental session.

Trust Learning task

Participants completed an incentivized economic game: A trust game, with a within-subject social condition and a non-social condition (Figure 1). The game was composed of 28 trials in total: each trial was a one-shot game with a new anonymous player (indicated with a new avatar). In every trial the participants chose between 2 options (A or B) to distribute points between themselves and the other. In the social condition, the other player was an unknown peer, whereas in the non-social condition, the other player was a slot machine. After their decision, participants could see the choice of the other player (X or Y) and the outcomes for themselves and the other player. Outcomes for self and the other resulted from their combined choices. The social condition of the trust game (Figure 1B) was characterized by payoff matrix $\begin{bmatrix} \mathbf{3},3 & \mathbf{2},2 \\ \mathbf{1},5 & \mathbf{2},2 \end{bmatrix}$, with earnings for self indicated in bold. The non-social condition of the trust game (Figure 1D) was characterized by a similar payoff matrix, but only the participants received payoffs.

In each of the conditions, two environments were consisting of 14 players each. Environments were set up as such that we created a 'Trustworthy' (78.5% trustworthy choices, i.e., 11 out of 14 trials) and an 'Untrustworthy' environment (78.5% untrustworthy choices, i.e., 11 out of 14 trials) (see Figure 1). The color of the players indicated to which environment they belonged. It was randomized across participants which color was related to the trustworthy or untrustworthy environment. Over the course of the trials, participants could learn the tendency of choosing X for each environment of other players and adjust their responses accordingly. Participants were incentivized as their points were converted to a financial bonus ranging €2 - €8.

Participants could maximize their earnings by choosing A ('trust'; top row) when matched with a member of the Trustworthy environment, and choosing B ('distrust'; bottom row) when matched with a member of the Untrustworthy environment. The inconsistent choices within an environment (e.g., Y when playing with someone of the environment that generally prefers X) were semi-randomized and appeared between trials 2 and 4, between trials 6 and 8, and between trials 10 and 12. Interactions with players from trustworthy and untrustworthy environments were presented in semi-random order, with the limitation that an environment can appear twice in a row at most.

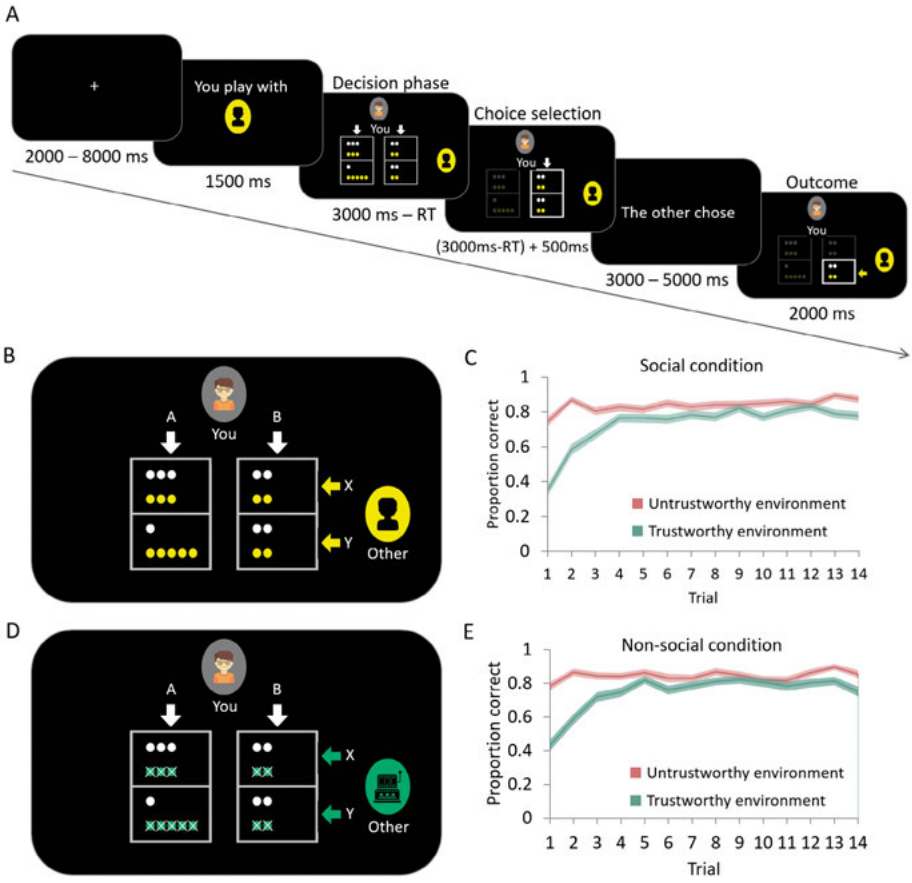

Figure 1. Task assessing learning about trustworthy and untrustworthy environments. **(A)** Example trial. The participant (shown on top) can choose between the left and right columns (arrow A or B). After choice selection, the participant is shown the choice (top or bottom row, indicated with arrow X or Y) of the other player (shown on the right). The combined choices of the participant and the other player determine the monetary outcome for both players (number of dots; white dots for the participant, colored dots for the interaction partner). The background color of the other player indicates to which of the two environments they belong. In each trial there was a one-shot game with a new anonymous player, indicated with a new avatar. Note that in the non-social condition, the interaction partner (slot machine) does not receive any outcome, as indicated with the crosses through the colored dots (see panel d). **(B)** In the social condition, participants interact with players from a 'Trustworthy' environment (who tend to choose X) or an 'Untrustworthy' environment (who tend to choose Y). Participants' own monetary payoffs are maximized by choosing to trust (choose A) a player from a Trustworthy environment, and to withhold trust (choose B) from a player from the Untrustworthy environment. **(C)** Proportion correct choices over trials per social environment averaged over the first and second social block, and pooled across all participants. Over trials, participants adjusted their choices by directing their trust towards players from the Trustworthy environment, and away from players from the Untrustworthy environment. **(D)** In the Non-Social condition, participants' monetary payoffs are also maximized by matching the choices of their co-players. Again, the environments differ in their tendencies to choose either X or Y. Similarly to the social condition, participants' own monetary payoffs are maximized

by choosing to trust (choose A) a player from a Trustworthy environment (prefers X), and to withhold trust (choose B) from a player from the Untrustworthy environment (prefers Y). **(E)** Proportion correct choices over trials per environment averaged over the first and second block, and pooled across all participants. Overall, participants learned to adjust their choice behavior to the non-social environments. Shaded areas in panels c and e represent standard errors of the mean (s.e.m.).

For the analyses, participants' decisions were coded as either correct or incorrect. That is, choosing to trust (A) when confronted with an interaction partner from a *trustworthy* environment (tends to choose X), or choosing to withhold trust (B) when interacting with a player from an *untrustworthy* environment (tends to choose Y), is coded as a correct decision (coded as 1). Whereas choosing to trust (A) when confronted with an interaction partner from an *untrustworthy* environment, or choosing to withhold trust (B) when interacting with a player from *trustworthy* environment, is coded as an "incorrect" decision (coded as 0). Note that due to the probabilistic nature of the task, a round coded as incorrect can result in an outcome that resembles a correct decision (e.g., outcome A-X when playing with an untrustworthy environment), and vice versa.

In total, participants completed four blocks of 28 trials (14 trials per environment), with a short break in between. In each block, participants were confronted with two new environments, indicated with new colors. Participants completed two social and two non-social blocks. The order of these blocks was alternated and counterbalanced between participants (i.e., either: social – non-social – social – non-social, or: social – non-social – non-social – social). These differences in block order did not affect performance (*ps* > .09).

The fifth block (28 trials, 14 per environment), included a between-subject manipulation to assess reversal learning (see Figure S2). That is, participants encountered new players from the same environments as the previous block (block four). However, unbeknownst to the participants, the new players switched their response tendency. That is, the Trustworthy environment from block 4, became an Untrustworthy environment in block 5, and vice versa. Given the counterbalanced order of the blocks, half of the subjects encountered a social reversal, and the other half a non-social reversal.

Parenting questionnaire

As a measure of parenting practices, participants filled out the Alabama Parenting Questionnaire (APQ) (Frick et al., 1999). This questionnaire consists of 42 items across five domains: Parental Involvement (10 items per parent; e.g. for maternal involvement: "You play games or do other fun things with your mum", Cronbach's alpha: .744; e.g., paternal involvement, Cronbach's alpha: .852), Positive Parenting (6 items; e.g., "Your parents tell you that you are doing a good job"; Cronbach's alpha: .788), Poor Monitoring/Supervision (10 items; e.g., "You go out without a set time to be home"; Cronbach's alpha: .665), Inconsistent Discipline (6 items; e.g., "Your parents threaten to punish you and then do not do it"; Cronbach's alpha:

.511). The Corporal Punishment subscale was not administered in the current study. All items can be answered on a 5-point scale (i.e., (1) never, (2) almost never, (2) sometimes, (4) often, (5) always). The Positive Parenting, Maternal Involvement, and Paternal Involvement scales reflect more positive aspects of parenting, while the Inconsistent Discipline and Poor Monitoring/Supervising scales reflect more negative aspects of parenting. The target audience for the APQ is 6 – 18 year-olds, therefore in analyses concerning the APQ, we only included participants up to 18 years. Note that, although we have included a typical developing sample, the variation in these measures (see Figure S3) was deemed sufficient to probe individual differences in parental relations.

Statistical analyses

To analyze trust learning and reversal learning in the social and non-social condition of the trust game, we fitted logistic generalized linear mixed models (GLMMs) to the 'correct' decisions made. First, we assessed learning in social and non-social conditions (block 1-4; *N* = 157). This GLMM included fixed effects of environment (i.e., Trustworthy environment, Untrustworthy environment), age in years (both linear and quadratic polynomial), and condition (i.e., social, non-social), as well as the two- and three-way interactions between these predictors.

Second, we assessed social and non-social reversal learning (block 5; *N* = 155). This GLMM included fixed effects of environment (i.e., Trustworthy environment, Untrustworthy environment), age in years (linear and quadratic polynomial), and condition (i.e., social, non-social).

Third, we assessed relations with parenting practices on trust learning for the participants up to 18 years old. A GLMM on blocks 1-4 (N=94) included main effects of environment (i.e., Trustworthy environment, Untrustworthy environment), condition (i.e., social, non-social), all parenting subscales (Positive parenting, Poor monitoring, Inconsistent discipline, Maternal involvement, Paternal involvement), as fixed effects, as well as the two- and three-way interactions between these predictors. As this analysis focused on individual differences in parenting, age (linear) was included as covariate. A similar GLMM was performed on reversal learning (block 5, *N* = 93). Note that, although some of these parenting subscales are correlated (see Table S5), there is no multicollinearity (i.e., VIF values < 1.9).

All GLMM models included a random-intercept per participant to handle the repeated nature of the data. Where appropriate, the environment (trustworthy, untrustworthy) and condition (social, non-social) was entered as a random slope in our analyses to handle the differences between individuals in their responsiveness to learning different levels of trustworthiness.

Mixed-effects analyses were conducted in R 4.0.5, using the lme4 package (Bates et al., 2014; R Core Team, 2020). All numeric variables were mean-centered and scaled, and categorical predictor variables were specified by a sum-to-zero contrast (e.g., sex: – 1 = boy, 1 = girl). For all models the optimizer "bobyqa" (Powell, 2009) was used, with a maximum number of

1×10^5 iterations. P-values are obtained with the lmerTest package (Kuznetsova et al., 2017). Full statistics are reported in Tables S1-S5.

Results

Age-related improvement in learning whom (not) to trust in social and non-social environments

Our first aim was to assess age-related differences in adjusting to trustworthy and untrustworthy environments in the social and non-social condition of the trust game. One-sample t-tests showed that participants performed above change level (50%) in each block, in both the trustworthy and untrustworthy environments, and in both conditions (*t*s > 12.8, *p*s < .001), demonstrating that they are able to learn to trust trustworthy others, and to withhold trust from untrustworthy others over trials. Using a mixed-effects model, we observed that older participants performed better than younger participants (main effect of Age linear, $B = 0.312$, $p < .001$, Figure 2, Table S1).

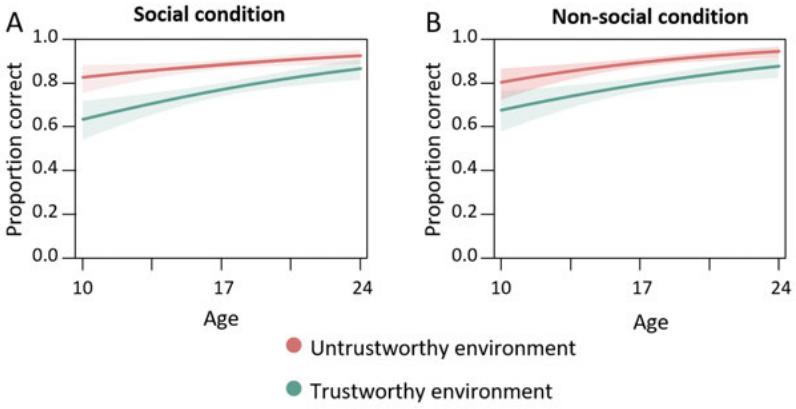

Figure 2. Age-related improvement in trust learning performance. Proportion correct across age when playing with a trustworthy and an untrustworthy environment, **(A)** in a social condition, and **(B)** in a non-social condition. The age-related improvements are similar for both environments and both conditions. Note that age was scaled in the analyses, therefore the age values on the x-axes are an indication of the values from the mixed-effects models. Shaded areas indicate the 95% confidence interval.

Although overall performance was somewhat better in the non-social condition than in the social condition (main effect of Condition, $B = 0.057$, $p = .038$), this did not differ with age (Age linear x Condition, $p = .350$). Moreover, participants performed better when learning to withhold trust from untrustworthy others than when learning to trust trustworthy others

(main effect of Environment, *B* = 0.408, *p* < .001). This pattern was similar for the social and non-social condition (Condition x Environment, *B* = -0.008, *p* = .724), and did not change with age (Age x Environment, B = -0.009, *p* = .870; Age x Condition x Environment, *B* = 0.038, *p* = .076). Together, these results suggest that participants find it easier to learn to adjust to an untrustworthy environment than a trustworthy environment.

Reversal learning: flexibility in learning about others' trustworthiness

Our next goal was to assess age-related differences in trust reversal learning in the social and non-social condition (see Table S2). A mixed-effect model revealed that participants performed better when switching to an untrustworthy environment (Trustworthy → Untrustworthy reversal) than when switching to a trustworthy environment (Untrustworthy → Trustworthy reversal) (main effect of Environment, *B* = 0.403, *p* < .001), suggesting that participants were more sensitive for signaling a change towards untrustworthy than to trustworthy behavior. Moreover, results showed an Age linear x Environment interaction (*B* = -0.139, *p* = .049, see Figure 3A).

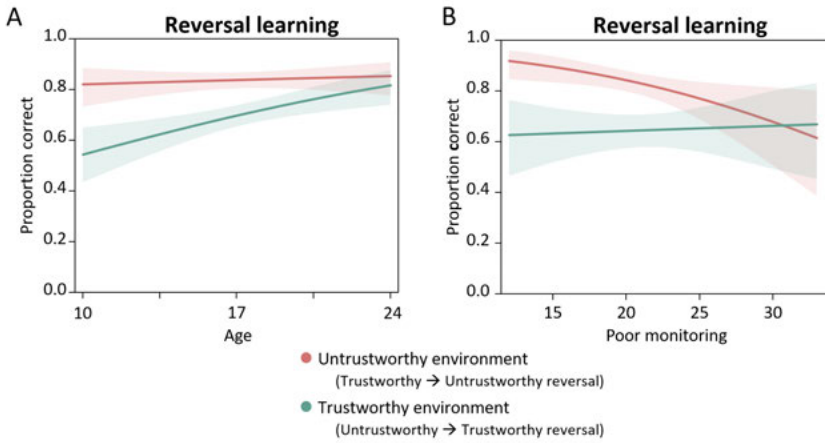

Figure 3. Reversal learning: Developmental asymmetry and differential effect of poor monitoring **(A)** Proportion correct across age for interacting with players from a Trustworthy and an Untrustworthy environment in the reversal block (10-24 y.o., *N* = 155). Performance across age is stable when interacting with the untrustworthy environment (which was trustworthy prior to the reversal), whereas performance shows age-related improvements when playing with the trustworthy environment (which was untrustworthy prior to the reversal). Note that age was scaled in the analyses, therefore the age values on the x-axis are an indication of the values from the mixed-effects models. **(B)** Relation between proportion correct and poor parental monitoring in the reversal block (10-18 y.o., *N* = 94). Higher levels of reported parental poor monitoring result in lower differentiation in performance for learning to trust trustworthy others and to withhold trust from untrustworthy others. In both panels, effects are collapsed across conditions and shaded areas indicate the 95% confidence interval.

Post-hoc tests per environment revealed that participants from all ages adjusted well to an untrustworthy environment (Trustworthy → Untrustworthy reversal; main effect of Age, B = 0.045, p = .708), whereas adjusting to a trustworthy environment (Untrustworthy → Trustworthy reversal) was subject to age-related improvements (main effect of Age, B = 0.331 p = .001). When controlling for performance in the pre-reversal block, this pattern remains (see Table S2). Finally, we observed that reversal learning did not differ between the social and non-social condition (main effect of Condition, p = .669; Age linear x Condition, p = .268; Environment x Condition, p = .551). Together, these findings show that it is harder to adjust trust behavior towards interactions with a trustworthy environment, versus behavior towards interaction with an untrustworthy environment, and that this pattern was particularly pronounced for the younger participants.

Individual differences in parenting affect trust learning and reversal learning

Our final aim was to assess whether parenting practices affected performance in trust learning and reversal learning in participants up to 18 years old (see Table S3). In a mixed-effects model assessing trust learning in block 1-4, we did not observe main effects of the parenting subscales, nor interactions with environment or condition (p's > .06, see Table S3).

Finally, we assessed the effects of parenting on reversal learning. Results showed a Reversal type x Poor monitoring interaction (B = -.029, p = .023), which indicates that participants who reported having experienced poorer parental monitoring showed little differentiation between the Untrustworthy and Trustworthy environment in the reversal block, whereas participants who reported *lower* levels of poor monitoring show a larger differentiation (see Figure 3B). The other parenting subscales did not affect learning performance in the reversal block (see Table S4).

Discussion

The aim of this study was to investigate (1) the development of learning whom (not) to trust across adolescence in social and non-social environments, (2) the ability to flexibly adjust trusting behavior when others' trustworthiness levels change (reversal learning), and its corresponding age-related differences, and (3) how reported parenting practices affect trust learning and reversal learning performance. To this end, we used an experimental paradigm based on the traditional trust game, which enabled us to assess how participants learn about others' trustworthiness and adjust their own trust behavior accordingly. The results of this study revealed that participants' performance in both environments were above change level, indicating that they were able to learn to trust trustworthy others, and to withhold trust from untrustworthy others over trials. Moreover, as expected, performance in trust learning improved with age.

Also, people adjusted better to environments that required not trusting others, compared to environments that required trusting others. Contrary to our expectations, learning performance in untrustworthy versus trustworthy environments did not differ across age. Second, as expected, we observed that in the reversal learning block, learning to trust others (who were untrustworthy before reversal) was more difficult than learning whom not to trust (who were trustworthy before reversal). In addition, we observed that this effect was more pronounced for younger participants. Third, parental poor monitoring was found to affect reversal learning, as higher ratings of poor parental monitoring/supervision were related to reduced performance in switching towards an untrustworthy environment. Finally, although overall performance was slightly better in the non-social than the social condition, we did not observe any differences between the social and non-social condition in reversal learning performance, nor in effects of age or parenting practices. The discussion is organized alongside these main findings.

Learning whom (not) to trust across adolescence

Across our learning and reversal learning paradigm, we observed an asymmetry in performance depending on the environment people needed to adjust to. Specifically, participants performed better at learning whom *not* to trust than learning whom to trust. Similarly, in our reversal learning block participants were better at adjusting their trust behavior to untrustworthy others that were previously trustworthy, than vice versa. These results suggest that participants were more sensitive for signaling and adjusting to untrustworthy behavior than to trustworthy behavior. With regard to trust learning, such an asymmetry was also observed in our previous study which showed better performance for learning whom not to trust than for learning whom to trust in 8-23 year-olds (Westhoff et al., 2020). Also in adults, this bias has been observed (e.g., Siegel et al., 2018; Vanneste et al., 2007). For example, a recent comprehensive study on the traits of 'bad' and 'good' others in adults showed that participants were more quickly and accurately in detecting the bad others than the friendly others, and their impressions of the former were more rapidly updated as well (Siegel et al., 2018). Such a *negativity bias* is a general principle that has been found across a broad range of psychological phenomena, and it is thought that it would generally be adaptive for individuals to respond more strongly to negative than to positive actions or outcomes (Baumeister et al., 2001). Our results suggest that this negativity bias extends to trust learning.

We observed little age-related differences in learning to adjust to trustworthy or untrustworthy environments. Based on previous findings we expected the asymmetry in learning to adjust to trustworthy versus untrustworthy environments to be larger for younger ages (Westhoff et al., 2020). In reversal learning, however, we did observe this asymmetry: performance in adjusting towards an untrustworthy environment (trustworthy before reversal) was stable across ages, whereas adjusting to the trustworthy environment (untrustworthy before reversal) showed age-related improvements. Potentially, younger individuals are particularly

at a disadvantage in adjusting to an untrustworthy environment if the learning situation is more challenging. That is, the reversal block likely requires more cognitive control, as previously build up stimulus-response associations need to be reversed. This ability to inhibit prepotent responses may depend prominently on brain areas such as the prefrontal cortex which slowly develop across adolescence (Luna et al., 2013). In future research this neural hypothesis should be further supported.

Finally, although adolescent' flexibility has been studied in terms of age-related differences in cognitive flexibility (Crone et al., 2008; Luna et al., 2013; van Duijvenvoorde et al., 2008) and handling volatile environments in reversal learning paradigms (Hauser et al., 2015; Jepma et al., 2020; van der Schaaf et al., 2011), the application in a social environment is relatively unexplored. A recent study examined age-related differences in response to continuously changing (non-social) environments and showed that, compared to adults, adolescents overestimated the environmental volatility (i.e., unpredictable change in stimulus-outcome or action-outcome associations) (Jepma et al., 2020). This overestimation of the volatility of an environment in adolescence may especially be adaptive in this developmental phase as it is characterized by changes in social relations, such as building new friendships, and engaging in a diversity of social environments including school, sports clubs, and social gatherings (Fuligni, 2019). These findings may suggest that adolescents may have a specific advantage to adjusting to highly volatile or unpredictable environments. Whereas the current study informs us on the ability to flexibly change a learned association in a relatively stable learning environment, future studies could study flexibility in social learning more thoroughly by including volatile or unpredictable social environments.

Parenting effects on social reversal learning

An additional aim of the current study was to assess the effects of participants' reported parenting practices on trust learning and social reversal learning. We observed that participants who reported having experienced poorer parental monitoring showed increased levels of trust to untrustworthy others, but only when these others were previously trustworthy. Performance in the trustworthy environments was stable across the range of reported poor monitoring values. These findings contradict the two hypotheses we initially posed: the volatility hypothesis (i.e., hypersensitivity towards both positive and negative social interactions and thus reduced performance in both environments), and the negativity hypothesis (i.e., reduced sensitivity to positive compared to negative social interactions, thus reduced performance in the trustworthy environment only). It is conceivable that other individual differences may have biased the results. For example, poor parental monitoring has been also been related to more disadvantageous risk taking (Pollak et al., 2020), cyberbullying (Pascual-Sanchez et al., 2021) and several other behavioral problems (Racz & McMahon, 2011).

We did not observe any associations between the trust (reversal) learning performance and the other parenting practices (i.e., inconsistent discipline, maternal and paternal involvement, positive parenting); future studies are needed to replicate this null result. One potential factor that may have biased our associations with parental practices is social support. That is, previous research has suggested that social support (high quality, supportive social relations), may buffer the effects of parental maltreatment on several behavioral outcomes (Scheuplein et al., 2021). This may also be true for less severe negative parenting situations. Consequently, participants who reported having experienced more negative parenting practices, may have had a good social support network, and therefore their social learning abilities were less affected. Future studies could investigate this hypothesis by including a focus on the social support network, such as the role of friendship quality. Recent studies combined such social network analyses (social network within the classroom) with choices in a trust game choices. Although social network positions did not affect adaptations of trust behaviors towards untrustworthy others in early adolescents (+/- 12 y.o.) (Sijtsma, Buuren, et al., 2020), in older adolescents (16-18 y.o.) participants with less central social positions were *more* adaptive towards trustworthy others when they expected those others to be untrustworthy (Sijtsma, Lee, et al., 2020). Although one's social network position may not be an indication of the quality of friendships that person has, these findings highlight that social dynamics other than parenting practices may influence trust decisions and trust learning. Moreover, these effects may change across adolescence alongside the stabilization of friendships. The exact mechanisms of how social buffering and risk factors relate to social (reversal) learning need to be confirmed in future (longitudinal) studies.

Social versus non-social learning

In the current study, we assessed whether there are differences between social and non-social trust learning. An active debate in the literature is whether social learning is only dependent on processes that are socially specific, or that it arises solely from general associative (non-social) learning (Heyes, 2012; Lockwood et al., 2020; Olsson et al., 2020; Ruff & Fehr, 2014). Therefore, when studying social learning, an appropriate control condition is essential for falsification purposes. Previous studies have used computer opponents in their control condition (Apps et al., 2013; Ramnani & Miall, 2004; Sanfey et al., 2003). However, as humans may anthropomorphize computers (Nass & Moon, 2000), we attempted to overcome this by using slot machines as an alternative. Thus, as a control condition, we included a similar trust game but with slot machines (not receiving any payoff) as interaction partners to remove the social component of trust learning. Our results showed a main effect of condition, indicating that overall performance in non-social trust learning was better than in social trust learning. However, we did not find a condition difference in reversal learning performance, nor did we find interactions with environment, age, or parenting practices. Our results, therefore, suggest

that these social and non-social learning processes are either at least largely overlapping, or, alternatively, distinct subprocesses may have resulted in similar behavioral outcomes (Morton, 2010). There are multiple levels on which social learning may differ from non-social learning on e.g., observed behavior, computational processes such as reinforcement learning, and underlying neural circuitry (Lockwood et al., 2020). Although the current study provided valuable insights on the behavioral level, follow-up studies are necessary to disentangle on which levels and which processes would be uniquely social in the case of trust learning. These studies would benefit from computational modeling and neuroimaging analyses to provide more insights into the mechanistic understanding of the subprocesses involved in trust learning and social reversal learning, and thus are needed to reveal whether there are neurocognitive processes are uniquely involved in *social* (trust) learning.

Limitations and future directions

There are a few limitations that have to be taken into account when interpreting the results. First, although the current sample is relatively large and is evenly distributed across age and sex, it is, however, rather homogenous, especially with regard to ethnicity and SES. Moreover, only typically developing children, adolescents and young adults were included, and the majority of these participants would not have experienced parenting adversity. It is not unlikely that negative parenting practices are related to lower participation rates in scientific studies; research setups that are less demanding for the parents, for example by testing in schools, would improve sampling of these more vulnerable children. Future studies are encouraged to invest in more diverse recruitment, as greater demographic and clinical diversity result in more power to detect effects of individual differences in e.g., parenting experiences on social decision making and (reversal) learning.

Second, the current trust learning paradigm only included interaction partners with low and high levels of trust. However, especially when investigating a sample of participants who have grown up in an unpredictable environment, it would be interesting to include interaction partners who are unpredictable in their trust behavior (i.e., 50% trustworthy) or more volatile in their trust behavior (i.e., often switching from trustworthy to untrustworthy behavior) to resemble more realistic characteristics with regard to their environment's trust behavior.

Moreover, in the current study we only examined interactions with unfamiliar peers. However, interacting with different targets, such as friends, foes, and family members could reveal whether trust learning behavior is differs between different targets. Previous social-decision making studies involving such targets have shown differential effects (Brandner et al., 2020; Schreuders et al., 2018; Spaans et al., 2018, 2019; van de Groep et al., 2020). For example, a recent study showed that adolescents were more prosocial towards their friends and more selfish towards disliked peers (Schreuders et al., 2018). An interesting follow-up study would

include different targets in order to shed light on ingroup-outgroup (e.g., friends or parents as ingroup versus strangers as outgroup) processes, and how these affect social learning.

Finally, although we examined age-related and individual differences in social Learning, tracking these factors longitudinally would be powerful and essential for examining true developmental trajectories of social learning (Crone & Elzinga, 2015). Moreover, a longitudinal setup allows for investigating the stability in for example friendships and parental relations, and how they relate to social learning (Schreuders, Braams, et al., 2021). Therefore, future studies would benefit from following these participants with similar learning paradigms (Telzer et al., 2018).

Conclusion

Here, we studied the development of social trust and reversal learning in 10-24 year-olds and included a first step to determine whether individual differences in family environment also affect social (reversal) learning. We observed that adjusting to a trustworthy environment (particularly if those others were untrustworthy before) is more difficult than adjusting to an untrustworthy environment. Particularly for younger adolescents updating their expectations of others' trustworthiness is more difficult than for older adolescents and adults. These findings highlight an increasing cognitive flexibility in learning across adolescence that also extends to a social environment. Finally, parental poor monitoring impacted trust reversal learning. Thus, the environment in which we grow up may affect our future social interactions and how we learn about others. However, adolescence is a developmental phase in which peers play a large role on several social domains (Chein et al., 2011; Crone & Dahl, 2012; van Hoorn et al., 2016), and social experiences during childhood and adolescence, for example at school, may affect our social decision making to a larger extent than how we are raised by our parents. Therefore, future studies on the development of social learning may benefit from assessing social experiences, social status, and adolescents' social network.

Supplementary materials

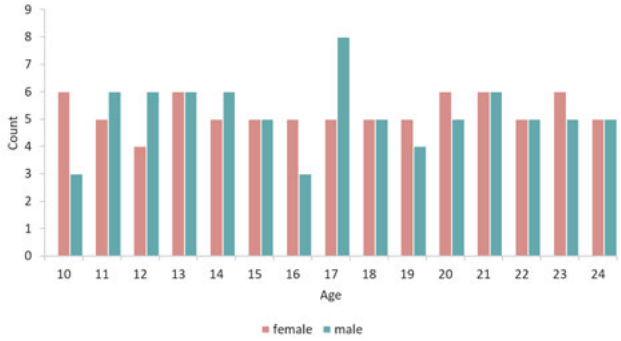

Figure S1. Age and sex distribution across participants of the full sample (N=157). Note that for analyses including parenting effects, we only included participants up to 18 y.o. (N=94).

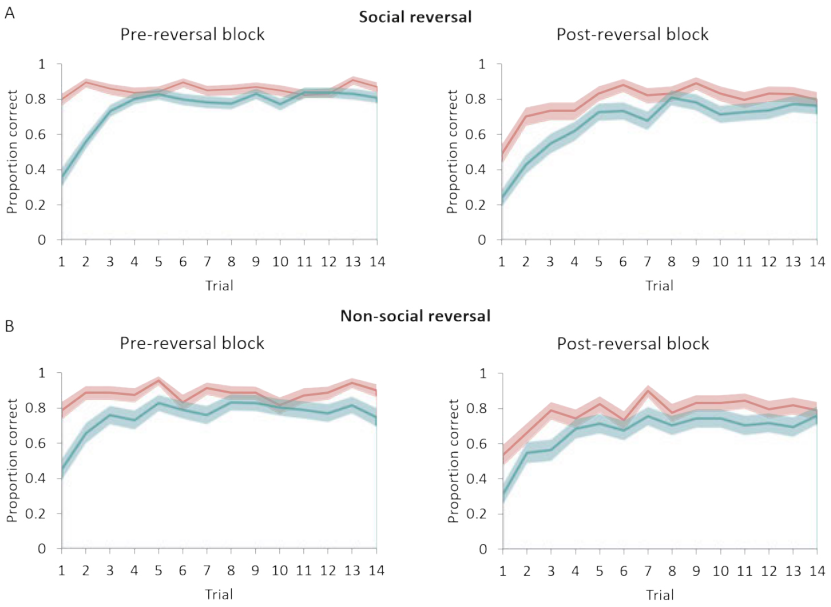

Figure S2. Trust learning performance in the block before and after the reversal. Proportion correct choices over trials per social environment in the pre-reversal block and the post-reversal block. About one half of the participants received a social reversal (shown in panel a), the other half the non-social reversal (panel b). The plots showing the pre-reversal block (left panels) only include data from participants who received the corresponding reversal. Data are pooled across all participants. Over trials, participants adjusted their choices by directing their trust towards players from the Trustworthy environment, and away from players from the Untrustworthy environment.

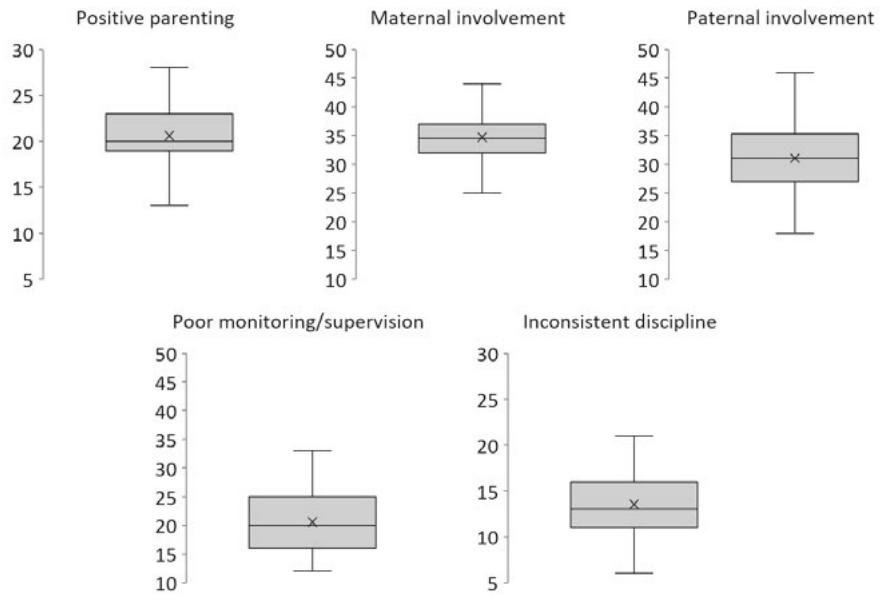

Figure S3. Boxplots for individual differences in parenting subscales. The value range on the y-axis are limited to the possible subscale values.

Supplementary Table 1. Mixed-effects model assessing social and non-social trust learning Results of the binomial generalized linear mixed models (GLMM) testing the effects of Age (linear and quadratic), and all 2-way and 3-way interactions with Environment (Trustworthy vs. Untrustworthy) and Condition (social vs. non-social), on choice behavior (i.e.., "correct" decision) in the trust game. Significant effects are in bold. This GLMM is described fully in the main text.

Predictors	**Main model**					**Main model + sex + IQ**				
	B	*SE*	*Odds Ratios*	*CI*	*p*	*B*	*SE*	*Odds Ratios*	*CI*	*p*
Intercept	1.694	0.077	5.44	4.68 – 6.33	**<.001**	1.693	0.076	5.43	4.68 – 6.31	**<.001**
Age linear	0.312	0.077	1.37	1.18 – 1.59	**<.001**	0.095	0.075	1.38	1.19 – 1.60	**<.001**
Environment	0.408	0.053	1.50	1.36 – 1.67	**<.001**	0.115	0.076	1.50	1.35 – 1.67	**<.001**
Condition	0.057	0.027	1.06	1.00 – 1.12	**.038**	0.323	0.076	1.06	1.00 – 1.12	**.036**
Age quadratic	-0.125	0.076	0.88	0.76 – 1.03	.102	0.408	0.053	0.88	0.76 – 1.02	.093
Age linear * Environment	-0.009	0.053	0.99	0.89 – 1.10	.870	0.057	0.027	0.99	0.89 – 1.10	.879
Age linear * Condition	0.025	0.027	1.03	0.97 – 1.08	.350	-0.127	0.076	1.03	0.97 – 1.08	.343
Environment * Condition	-0.008	0.022	0.99	0.95 – 1.04	.724	-0.008	0.053	0.99	0.95 – 1.04	.724
Environment * Age quadratic	-0.075	0.053	0.93	0.84 – 1.03	.157	0.026	0.027	0.93	0.84 – 1.03	.160
Condition * Age quadratic	-0.009	0.027	0.99	0.94 – 1.04	.728	-0.008	0.022	0.99	0.94 – 1.04	.720
Age linear * Environment * Condition	0.038	0.021	1.04	1.00 – 1.08	.076	-0.074	0.053	1.04	1.00 – 1.08	.077
Environment * Condition * Age quadratic	0.017	0.021	1.02	0.98 – 1.06	.422	-0.010	0.027	1.02	0.98 – 1.06	.428
Sex						0.038	0.021	1.10	0.95 – 1.28	.207
IQ						0.017	0.021	1.12	0.97 – 1.30	.127

Supplementary Table 1. *Continued*

Predictors	**Main model**	**Main model + sex + IQ**
Random Effects		
σ^2	3.29	3.29
τ_{00}	0.83_{subject}	0.82_{subject}
τ_{11}	$0.04_{\text{subject.Condition}}$	$0.04_{\text{subject.Condition}}$
	$0.35_{\text{subject.Environment}}$	$0.35_{\text{subject.Environment}}$
ρ_{01}	0.21	0.23
	0.11	0.1
ICC	0.27	0.27
N	157_{subject}	157_{subject}
Observations	17367	17367
Marginal R^2 / Conditional R^2	0.060 / 0.316	0.064 / 0.316

Supplementary Table 2. Mixed-effects model assessing reversal trust learning Results of the binomial GLMM testing the effects of Age (linear and quadratic), and all 2-way and 3-way interactions with Environment (Trustworthy which was Untrustworthy before the reversal vs. Untrustworthy which was Trustworthy before the reversal) and Condition (social vs. non-social), on choice behavior (i.e.., "correct" decision) in the block after the reversal in the trust game. Significant effects are in bold. This GLMM is described fully in the main text.

Predictors	**Main reversal model**					**Main reversal model + performance in pre-reversal block (2nd half)**				
	B	*SE*	*Odds Ratios*	*CI*	*p*	*B*	*SE*	*Odds Ratios*	*CI*	*p*
(Intercept)	1.236	0.084	3.44	2.92 – 4.06	**<.001**	1.229	0.071	3.42	2.97 – 3.92	**<.001**
Age linear	0.186	0.084	1.20	1.02 – 1.42	**.027**	0.032	0.073	1.03	0.89 – 1.19	.663
Environment	0.403	0.071	1.50	1.30 – 1.72	**<.001**	0.398	0.070	1.49	1.30 – 1.71	**<.001**
Condition	-0.036	0.084	0.96	0.82 – 1.14	.669	-0.032	0.071	0.97	0.84 – 1.11	.647
Age quadratic	-0.013	0.085	0.99	0.84 – 1.16	.874	0.078	0.072	1.08	0.94 – 1.24	.280
Age linear * Environment	-0.139	0.071	0.87	0.76 – 1.00	**.049**	-0.139	0.071	0.87	0.76 – 1.00	**.050**
Age linear * Condition	-0.093	0.084	0.91	0.77 – 1.07	.268	-0.059	0.071	0.94	0.82 – 1.08	.406
Environment * Condition	-0.042	0.071	0.96	0.83 – 1.10	.551	-0.042	0.070	0.96	0.84 – 1.10	.553
Environment * Age quadratic	0.037	0.071	1.04	0.90 – 1.19	.606	0.041	0.071	1.04	0.91 – 1.20	.558
Condition * Age quadratic	0.083	0.085	1.09	0.92 – 1.28	.326	0.073	0.071	1.08	0.94 – 1.24	.305
Age linear * Environment * Condition	-0.061	0.071	0.94	0.82 – 1.08	.390	-0.061	0.071	0.94	0.82 – 1.08	.391
Environment * Condition * Age quadratic	0.021	0.071	1.02	0.89 – 1.17	.766	0.019	0.071	1.02	0.89 – 1.17	.792
Performance pre-reversal block (2nd half)						0.584	0.072	1.79	1.56 – 2.06	**<.001**
Random Effects										
σ^2	3.29					3.29				
τ_{00}	$0.84_{subject}$					$0.51_{subject}$				
τ_{11}	$0.51_{subject.Environment}$					$0.51_{subject.Environment}$				
ρ_{01}	$0.14_{subject}$					$0.13_{subject}$				
ICC	0.29					0.24				
N	$155_{subject}$					$155_{subject}$				
Observations	4314					4314				
Marginal R^2 / Conditional R^2	0.050 / 0.326					0.113 / 0.322				

Supplementary Table 3. Mixed-effects models with IQ and sex effects in reversal trust learning

Predictors	**Main reversal model + sex + IQ**				
	B	*SE*	*Odds Ratios*	*CI*	*p*
(Intercept)	1.235	0.084	3.44	2.92 – 4.05	**<.001**
Sex	0.096	0.084	1.1	0.93 – 1.30	.254
IQ	0.053	0.085	1.05	0.89 – 1.25	.534
Age linear	0.187	0.085	1.21	1.02 – 1.42	**.027**
Environment	0.404	0.071	1.50	1.30 – 1.72	**<.001**
Condition	-0.032	0.084	0.97	0.82 – 1.14	.701
Age quadratic	-0.013	0.084	0.99	0.84 – 1.16	.875
Age linear * Environment	-0.139	0.071	0.87	0.76 – 1.00	**.050**
Age linear * Condition	-0.092	0.084	0.91	0.77 – 1.08	.274
Environment * Condition	-0.043	0.071	0.96	0.83 – 1.10	.545
Environment * Age quadratic	0.038	0.071	1.04	0.90 – 1.19	.596
Condition * Age quadratic	0.083	0.084	1.09	0.92 – 1.28	.327
Age linear * Environment * Condition	-0.061	0.071	0.94	0.82 – 1.08	.387
Environment * Condition * Age quadratic	0.021	0.071	1.02	0.89 – 1.17	.765
Random Effects					
σ^2	3.29				
τ_{00}	0.83_{subject}				
τ_{11}	$0.51_{\text{subject.Environment}}$				
ρ_{01}	0.15_{subject}				
ICC	0.29				
N	155_{subject}				
Observations	4314				
Marginal R^2 / Conditional R^2	0.052 / 0.326				

Supplementary Table 4. Mixed-effects model assessing effects of individual differences in parenting on social and non-social trust learning Significant effects are in bold. This GLMM is described fully in the main text.

Predictors	**Main model + parenting (10-18 y.o.)**				
	B	*SE*	*Odds Ratios*	*CI*	*p*
Intercept	1.451	0.094	4.27	3.54 – 5.13	**<.001**
Age linear	0.348	0.117	1.42	1.13 – 1.78	**.003**
Environment	0.460	0.056	1.58	1.42 – 1.77	**<.001**
Condition	0.048	0.034	1.05	0.98 – 1.12	.159

Supplementary Table 4. *Continued*

Predictors	**Main model + parenting (10-18 y.o.)**				
	B	*SE*	*Odds Ratios*	*CI*	*p*
Positive Parenting	-0.048	0.114	0.95	0.76 – 1.19	.672
Poor Monitoring	-0.163	0.128	0.85	0.66 – 1.09	.204
Inconsistent Discipline	0.003	0.100	1.00	0.82 – 1.22	.973
Involvement Mother	-0.047	0.126	0.95	0.75 – 1.22	.709
Involvement Father	0.096	0.124	1.10	0.86 – 1.40	.439
Age linear * Environment	0.219	0.069	1.24	1.09 – 1.43	**.002**
Age linear * Condition	0.005	0.043	1.00	0.92 – 1.09	.910
Environment * Condition	-0.045	0.026	0.96	0.91 – 1.01	.085
Environment * Positive Parenting	0.003	0.067	1.00	0.88 – 1.14	.966
Condition * Positive Parenting	0.018	0.041	1.02	0.94 – 1.10	.668
Environment * Poor Monitoring	-0.140	0.075	0.87	0.75 – 1.01	.061
Condition * Poor Monitoring	0.003	0.045	1.00	0.92 – 1.10	.949
Environment * Inconsistent Discipline	0.047	0.059	1.05	0.93 – 1.18	.420
Condition * Inconsistent Discipline	-0.005	0.036	0.99	0.93 – 1.07	.885
Environment * Involvement Mother	0.098	0.073	1.10	0.96 – 1.27	.180
Condition * Involvement Mother	-0.031	0.043	0.97	0.89 – 1.06	.478
Environment * Involvement Father	-0.135	0.072	0.87	0.76 – 1.01	.061
Condition * Involvement Father	0.010	0.043	1.01	0.93 – 1.10	.809
Age linear * Environment * Condition	-0.014	0.033	0.99	0.92 – 1.05	.679
Environment * Condition * Positive Parenting	-0.012	0.032	0.99	0.93 – 1.05	.703
Environment * Condition * Poor Monitoring	-0.015	0.034	0.99	0.92 – 1.05	.663
Environment * Condition * Inconsistent Discipline	0.047	0.028	1.05	0.99 – 1.11	.086
Environment * Condition * Involvement Mother	-0.038	0.032	0.96	0.90 – 1.03	.235
Environment * Condition * Involvement Father	0.048	0.033	1.05	0.98 – 1.12	.147
Random Effects					
σ^2	3.29				
τ_{00}	0.76_{subject}				
τ_{11}	$0.04_{\text{subject.Condition}}$				
	$0.21_{\text{subject.Environment}}$				
ρ_{01}	0.59				
	0.09				
ICC	0.24				
N	94_{subject}				
Observations	10371				
Marginal R^2 / Conditional R^2	0.076 / 0.294				

Supplementary Table 5. Mixed-effects model assessing effects of individual differences in parenting on reversal trust learning Significant effects are in bold. This GLMM is described fully in the main text.

Predictors	**Reversal model + parenting (10-18 y.o.)**				
	B	*SE*	*Odds Ratios*	*CI*	*p*
Intercept	1.416	0.200	4.12	2.78 – 6.10	**<.001**
Age linear	0.436	0.235	1.55	0.98 – 2.45	.064
Environment	0.593	0.163	1.81	1.31 – 2.49	**<.001**
Condition	-0.030	0.200	0.97	0.66 – 1.44	.881
Positive Parenting	0.075	0.149	1.08	0.81 – 1.44	.615
Poor Monitoring	-0.225	0.154	0.80	0.59 – 1.08	.145
Inconsistent Discipline	0.016	0.119	1.02	0.80 – 1.28	.895
Involvement Mother	-0.082	0.162	0.92	0.67 – 1.27	.612
Involvement Father	-0.018	0.159	0.98	0.72 – 1.34	.909
Age linear * Environment	0.120	0.191	1.13	0.78 – 1.64	.530
Age linear * Condition	-0.163	0.235	0.85	0.54 – 1.35	.488
Environment * Condition	0.008	0.163	1.01	0.73 – 1.39	.962
Environment * Positive Parenting	-0.003	0.121	1.00	0.79 – 1.26	.977
Condition * Positive Parenting	0.029	0.149	1.03	0.77 – 1.38	.844
Environment * Poor Monitoring	-0.285	0.125	0.75	0.59 – 0.96	**.023**
Condition * Poor Monitoring	0.059	0.154	1.06	0.78 – 1.44	.701
Environment * Inconsistent Discipline	-0.020	0.097	0.98	0.81 – 1.19	.838
Condition * Inconsistent Discipline	-0.022	0.119	0.98	0.77 – 1.24	.851
Environment * Involvement Mother	0.119	0.131	1.13	0.87 – 1.46	.362
Condition * Involvement Mother	-0.013	0.162	0.99	0.72 – 1.36	.937
Environment * Involvement Father	-0.118	0.128	0.89	0.69 – 1.14	.355
Condition * Involvement Father	0.072	0.159	1.07	0.79 – 1.47	.650
Age linear * Environment * Condition	-0.002	0.191	1.00	0.69 – 1.45	.991
Environment * Condition * Positive Parenting	-0.166	0.121	0.85	0.67 – 1.07	.169
Environment * Condition * Poor Monitoring	-0.067	0.125	0.94	0.73 – 1.20	.594
Environment * Condition * Inconsistent Discipline	0.005	0.097	1.00	0.83 – 1.21	.963
Environment * Condition * Involvement Mother	-0.146	0.131	0.86	0.67 – 1.12	.264
Environment * Condition * Involvement Father	0.179	0.128	1.20	0.93 – 1.54	.161
Random Effects					
σ^2	3.29				
τ_{00}	0.88_{subject}				
τ_{11}	$0.49_{\text{subject.Environment}}$				
ρ_{01}	0.02_{subject}				
ICC	0.29				
N	93_{subject}				
Observations	2583				
Marginal R^2 / Conditional R^2	0.093 / 0.359				

Supplementary Table 5. Intercorrelations of individual differences in parenting subscales

Spearman correlations	Poor monitoring / supervision	Inconsistent discipline	Maternal involvement	Paternal involvement
Positive parenting	**-.306****	-.027	**.563****	**.516****
Poor monitoring /supervision		**.266****	**-.383****	**-.313****
Inconsistent discipline			-.140	-.017
Maternal involvement				**.650****

*Note: ** = p < .01 (2-tailed). Significant effects in bold.*

Supplementary Table 6. Correlations between age and parenting subscales in subjects up to 18 years

	Positive parenting	Poor monitoring /supervision	Inconsistent discipline	Maternal involvement	Paternal involvement
Age	*rs = -.120* *p = .211*	***rs = .591*** ***p > .001***	*rs = .044* *p = .644*	***r = -.209*** ***p = .028***	*rs = -.168* *p = .077*

Note: Significant effects in bold.