Curiosity and surprise enhance memory differently in adolescents than in children

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Abstract

Curiosity - broadly defined as the desire to acquire new information – enhances learning and memory in adults. Surprise about information facilitates later memory as well. To date, it is not known how states of curiosity and surprise about information enhance memory in childhood and adolescence. We used a trivia paradigm in which children and adolescents (N = 60, 10–14 years) encoded trivia questions and answers associated with high or low curiosity. States of high pre-answer curiosity enhanced later memory for trivia answers in both children and adolescents. However, higher positive post-answer surprise enhanced memory for trivia answers beyond the effects of curiosity in adolescents, but not in children. These results suggest that curiosity and surprise have positive effects on learning and memory in childhood and adolescence, but might need to be harnessed in differential ways across child development to optimize learning.

Keywords: curiosity, motivation, interest, surprise, learning, memory, children

Introduction

A fledgling research field on curiosity has suggested that intrinsic states of curiosity – the desire to acquire new information – enhances learning and memory (for a review, see Gruber, Valji, & Ranganath, 2019). In line with these findings, neuroimaging studies in adults have demonstrated that 'pre-information' curiosity states elicit increased neural activity in memory- and reward-related brain regions, including the hippocampus and the striatum, respectively (Gruber, Gelman, & Ranganath, 2014; Jepma, Verdonschot, van Steenbergen, Rombouts, & Nieuwenhuis, 2012; Kang et al., 2009; Ligneul, Mermillod, & Morisseau, 2018). These enhancements in neural activity associated with pre-information curiosity predict the beneficial effects of curiosity on later memory performance (Gruber et al., 2014).

In addition to these benefits, the subjective interestingness or surprise associated with the actual information also affects later memory (Fastrich, Kerr, Castel, & Murayama, 2018; Marvin & Shohamy, 2016; McGillivray, Murayama, & Castel, 2015). For example, Marvin and Shohamy (2016) calculated information prediction errors (IPEs) which reflect the difference between the subjective interestingness associated with the information and the initial curiosity about the information. The authors showed that IPEs modulated memory in adults with greater memory enhancement for positive IPEs such that participants were more likely to remember information when it was more interesting than the initial level of pre-information curiosity (see also Fastrich et al., 2018).

But how do curiosity and surprise affect memory in children? Especially in educational settings, curiosity has been praised for its positive effects on learning and teachers have been encouraged to stimulate curiosity in the classroom (Engel, 2011; Hidi & Renninger, 2006; Montessori, 1948/2004; Oudeyer, Gottlieb, & Lopes, 2016). Indeed, exploration and surprise have been shown to drive learning in infants and young children (Kidd & Hayden, 2015; Schulz, 2012). For example, infants explore information guided by their own interest (Begus, Gliga, & Southgate, 2014, 2016) and prefer material of intermediate complexity (Kidd, Piantadosi, & Aslin, 2012). Preschoolers prefer to play with toys for which they do not completely understand the underlying mechanism (Schulz & Bonawitz, 2007), suggesting that children structure exploration to enhance information gain. However, to the best of our knowledge, the relations between curiosity states and surprise, and their individual or combined effects on memory have not been investigated in older children and adolescents. Thus, it is an open question whether curiosity and surprise affect memory in children and adolescents, and if so, how these effects on memory differ across child development.

The effects of curiosity and surprise on memory performance might be particularly relevant during adolescence relative to earlier childhood. It has been suggested that adolescents are more sensitive to extrinsic rewards due to enhanced modulation of reward-related brain regions (Blakemore & Robbins, 2012; Galvan et al., 2006; Somerville & Casey, 2010; Somerville, Jones, & Casey, 2010). In one study, adolescents showed better memory for pictures associated with positive compared to negative reward prediction errors (i.e., surprise about the receipt of a high monetary reward), suggesting that increased reward sensitivity can have beneficial effects on learning and memory (Davidow, Foerde, Galván, & Shohamy, 2016; see also Hallquist, Geier, & Luna, 2018; van den Bos, Cohen, Kahnt, & Crone, 2012). In addition, a recent longitudinal study in 8 - 29 years old participants demonstrated that learning from feedback increased in the transition between childhood and adolescence (Peters & Crone, 2017). As the effects of surprise associated with intrinsically valuable information have only recently been demonstrated in adults (Fastrich et al., 2018; Marvin & Shohamy, 2016; McGillivray et al., 2015), it is an open question to what extent they are also present at the transition from childhood to adolescence. The findings of age differences in the effects of extrinsic rewards between childhood and adolescence suggest that adolescents may show a more adult-like pattern and benefit more from encountering surprisingly interesting information. In stark contrast, the findings that the effects of surprise on learning are present already in infancy and early childhood suggest that encountering surprising information may entail memory benefits across child development. Thus, the current study aims to (i) close an important knowledge gap on the effects of surprise on memory between childhood and adolescence, and (ii) examine the memory effects of surprise in relationship with curiosity. Understanding the effects of curiosity and surprise in later childhood and adolescence could have important educational implications as it may point to a tailored approach for enhancing learning across different ages.

Here, we investigated how curiosity and surprise enhance memory in children and adolescents (N = 60, 10–14 years). To induce curiosity, we used a trivia paradigm in which participants consecutively encoded trivia questions that were associated with varying degrees of curiosity and anticipated the correct answer (see Figure 1). Studies with adults have repeatedly shown that answers to trivia questions associated with high curiosity are better remembered than answers to low-curiosity trivia questions (Fastrich et al., 2018; Galli et al., 2018; Gruber et al., 2014; Kang et al., 2009; Marvin & Shohamy, 2016; McGillivray et al., 2015; Stare, Gruber, Nadel, Ranganath, & Gómez, 2018; Wade & Kidd, 2019). The paradigm consisted of a screening phase in which we selected participant-specific trivia questions for which the answers were unknown and which varied in subjective curiosity. In the subsequent encoding phase, a trivia question was presented and participants anticipated the correct answer over a delay of 13 seconds. During the anticipation phase, we presented an incidental image of an adult face in order to investigate potential memory enhancements for incidental information encountered during high- and low-curiosity states (as has been shown for adults: Galli et al., 2018; Gruber et al., 2014; Stare et al., 2018). After the correct answer was shown, participants rated its interestingness. Measuring post-answer interestingness and pre-answer curiosity allowed us to delineate the effects of pre-answer curiosity and surprise on memory in children and adolescents. Surprise was operationalized as the discrepancy between participants' initial curiosity expectation and the actual value of the presented information, as reflected in the post-answer interest ratings. Memory for the faces presented during anticipation was tested after a 20 min delay, followed by a cued-recall test of the answers to the trivia questions.

The design, predictions, and planned analyses were preregistered on Open Science Framework (https://osf.io/qyf9m/). We had the following key predictions: (1) Children and adolescents would demonstrate a curiosity-related memory enhancement for trivia answers associated with high- compared to low-curiosity trivia questions. We also expected a curiosity-related memory enhancement for incidental face images encountered during high- as opposed to low-curiosity states. (2) Higher post-answer interest ratings would be associated with enhanced memory in children and adolescents. (3) We predicted that a positive IPE (i.e., positive surprise) would result in enhanced memory for an answer, and that this IPE effect on memory would be larger in adolescents than in children.

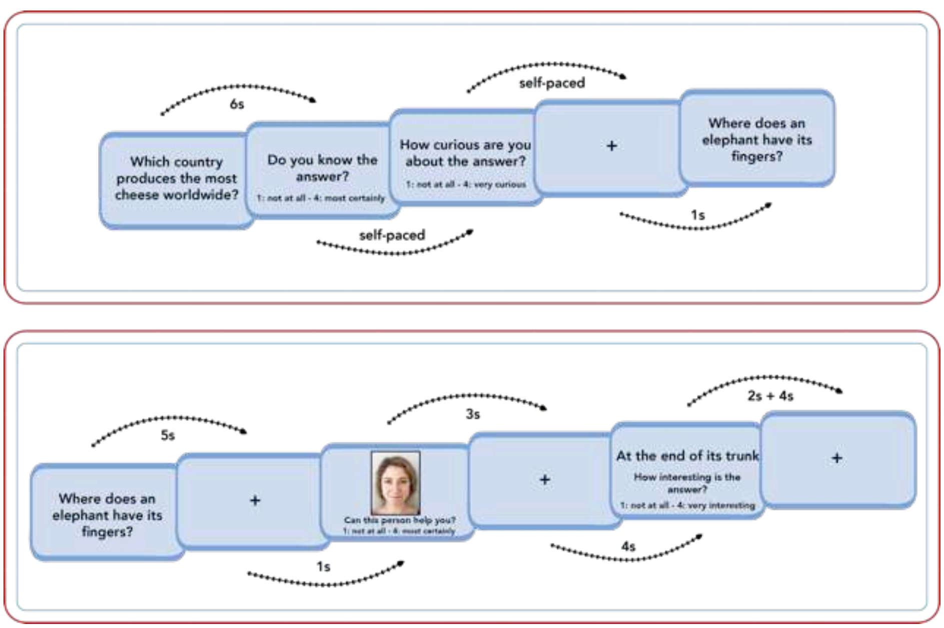

Figure 1. Experimental paradigm. Upper panel represents the screening phase, and the lower panel represents the subsequent study phase of the experiment.

Methods

Participants

As outlined in the OSF preregistration, we aimed to acquire a total of *N* = 30 complete data sets from children (10–12 years, M_{age} = 11.37 years, SD_{age} = 0.81 years; 15 females) and *N* = 30 adolescents (13–14 years, M_{age} = 14.05 years, SD_{age} = 0.64 years; 15 females). The planned sample size for both groups was based on the adult sample size in Gruber et al. (2014), which used the same paradigm. Data sets were considered complete when data from all four experimental phases were available. In total, 69 children were recruited from the database of the Max Planck Institute for Human Development in Berlin, Germany. Data of six participants were excluded due to technical problems that resulted in participants seeing certain stimuli more than once or not at all. Two additional participants did not complete all four phases of the experiment, and one participant was excluded due to non-compliant behavior during the memory test. Children were native German speakers (i.e., German is the main language spoken at home), had no history of neurological or psychiatric disorders, were not born prematurely (before 37th week of pregnancy) and had normal or corrected-to-normal vision. Families received 25 Euros for their participation in the study. The study was approved by the local ethics committee of the Max Planck Institute for Human Development.

Material

Trivia questions and answers. We generated a pool of 445 trivia questions along with their corresponding answers from online trivia websites (see https://osf.io/5tp8j/ for a full list of the questions). The questions belonged to trivia categories expected to elicit different levels of curiosity in children: computer games and media, geography and history, science and medicine, religion and politics, general knowledge, sports, languages and books, art and music. The pool contained trivia questions for which the answers were likely to be unknown to the majority of participants.

Faces. The face stimuli presented in the experiment were identical to the faces used by Gruber et al. (2014). Each picture showed the face of an adult with a neutral face expression, in front of a naturalistic background. A total of 90 faces were divided into three subgroups of 30 stimuli each, which were counterbalanced across participants for the following three experimental components: the high- and low-curiosity conditions as well as new faces for the surprise recognition test.

Post-experimental questionnaires and eye-tracking. To explore the extent to which potential curiosity-related and IPE-related memory enhancements were associated with individual variability in personality characteristics related to curiosity, participants completed a set of questionnaires at the end of the experiment (see OSF preregistration for details, https://osf.io/qyf9m/). These measures have not been analyzed for this manuscript.

Task Procedures

Participants underwent a four-stage paradigm with (1) a screening phase, (2) a study phase, (3) a ~20-minute delayed surprise recognition test phase for incidental face images, and (4) a subsequent surprise recall test for trivia answers presented during the study phase (Figure 1). We kept the paradigm as similar as possible as the paradigm previously used in young adults by Gruber et al. (2014). The Cogent 2000 toolbox (http://www.vislab.ucl.ac.uk/cogent.php) was used for all experimental phases. In all four phases of the experiment, stimuli were presented on a gray background in the center of the computer screen.

(1) Screening phase. Because the level of curiosity elicited by different trivia questions is likely to vary between participants, we used participants' ratings to sort trivia questions into participant-specific high- and low-curiosity categories (30 questions each). Trivia questions were randomly selected from the aforementioned pool and were consecutively presented on the screen. After a trivia question was presented for 6 s, participants were instructed to give two self-paced ratings on four-point scales. First, they rated how confident they were that they knew the answer to a trivia question ("Do you know the answer?" [Weisst du die Antwort?]; extreme points: 1 = "no idea" [keine Ahnung] and 4 = "pretty sure" [ziemlich sicher]). Second, participants rated their level of curiosity about the answer to a trivia question ("How curious are you about the answer?" [Wie neugierig bist du auf die Antwort?]; extreme points: 1 = "not curious at all" [gar nicht neugierig] and 4 = "very curious" [sehr neugierig]). After a response was given for the second rating, an inter-trial cross hair was presented for 1 s. If participants did not indicate that they knew the answer to a trivia question (i.e. they did not rate their answer confidence with a 4), trivia questions with responses 1 or 2 to the curiosity rating were allocated to the low-curiosity condition and responses 3 and 4 were allocated to the high curiosity condition. For each participant, the screening phase lasted until 30 trivia questions had been allocated to each curiosity condition.

(2) Study phase. In the subsequent study phase, the selected 60 trivia questions were presented along with the associated answers. A trial started with the presentation of a trivia question for 5 s, followed by an anticipation period of 13 s. During the anticipation period (i.e. from the onset of the trivia question to the onset of the trivia answer), a cross hair was presented after the trivia question. The cross hair was replaced by an emotionally neutral adult face (incidental item) from 6 to 9 s after the onset of the trivia question. During the presentation of the face, participants were instructed to judge on a four-point scale as to whether the person depicted on the image could help them figure out the answer ("Can this person help you?"

[Kann dir diese Person helfen?]; extreme points: 1 = “not at all” [gar nicht] and 4 = “most certainly” [auf jeden Fall]). This encoding judgment ensured that faces were likely to be encoded with a similar level of attention across both curiosity conditions.

After the presentation of the trivia answer for 2 s, a post-answer interest rating was presented for 4 s (“How interesting is the answer?” [Wie interessant ist die Antwort?]; extreme points: 1 = “not interesting at all” [gar nicht interessant] and 4 = “very interesting” [sehr interessant]). Subsequently, a cross hair was again presented during the inter-trial interval, which was temporally jittered for 4–4.5 s. To remain consistent with the study by Gruber et al. (2014), 10% of the trials in each condition (3 out of 30 trials) were catch trials in order to ensure participants' attention throughout the phase. In these trials, the letter string 'xxxxx' was presented instead of the trivia answer. We divided the study phase into four blocks (15 trials each). After the study phase, children played board games with the experimenter that were not related to the task in any way.

(3) Recognition memory test for incidental items. Approximately 20 min after the end of the study phase, participants took part in a surprise recognition memory test for the incidental face images. All 60 faces from the study phase and 30 new faces were randomly presented in consecutive order. Each face was presented for 3 s. Participants had to decide whether they were confident that the face image had been presented during the earlier study phase or it was novel (i.e., “confident new” [sicher neu], “unconfident new“ [nicht so sicher neu], “unconfident old“ [nicht so sicher alt], and “confident old“ [sicher alt]). Participants were encouraged to try to give a response as accurately and quickly as possible. The inter-trial interval displaying a cross hair was temporally jittered with a 5–5.5 s duration.

(4) Recall test for trivia answers. Immediately following the recognition memory test for incidental items, participants were presented with all trivia questions from the study phase in random order. A question was presented on the screen and participants were asked to verbally recall the answer or to say "I don't know" [Weiss ich nicht] if they did not remember the answer to a trivia question. We discouraged the guessing of answers. The experimenter recorded the participants' answers on an Excel sheet and then proceeded to present the next question on the screen.

In all phases, responses on the four–point scale were given on a computer keyboard using the left and right middle and index fingers. Prior to each experimental phase, participants were instructed for the upcoming phase and practiced on items that were not used in the main task to ensure that they used the rating categories correctly. When comparing response distributions across the four rating options, there were no significant age differences for curiosity or interest ratings (all ps > .10). After all experimental phases were completed, participants filled out different post-experimental questionnaires (see details in OSF preregistration). The whole visit to the laboratory lasted approximately 2.5 hours.

Eye-tracking. Eye gaze and pupil dilations were continuously recorded on a subset of children (N = 46) throughout the study phase. In addition, we recorded spontaneous eye-blink rates in short sessions at three time points during the experiment: prior to the screening phase (5 min), between the screening and study phase (3 min), and following the study phase (3 min). These data were not analyzed for the present manuscript.

Behavioral analyses

We used ANOVAs to test for age differences between children (10–12 years, N = 30) and adolescents (13–14 years, N = 30) in the effects of pre-answer curiosity and post-answer interest on memory recall. The high-curiosity condition included “3” and “4” curiosity ratings, and the low-curiosity condition included “1” and “2” curiosity ratings. High post-answer interest included interest ratings “3” and “4”, and low post-answer interest included ratings “1” and “2”. To examine the effects of surprise, IPE was computed for each trial as the difference between the initial curiosity rating and the post-answer interest rating (Marvin & Shohamy, 2016). Thus, IPEs reflect the discrepancy between the actual value of the presented information relative to the participants’ initial curiosity expectation. To examine the interactive effects of curiosity and IPE, we performed linear mixed-level analyses on trial-level data (see Marvin & Shohamy, 2016; McGillivray et al., 2015). Mixed-effect models allow within-person examination of curiosity and surprise effects with more fine-grained distinctions between levels of curiosity and IPE, while at the same time accounting for variability across participants. To test the effects of curiosity on memory for incidental information (i.e., faces), we computed face recognition accuracy as hits (i.e., a confident or unconfident “old” response to a studied face) minus false alarms (i.e., a confident or unconfident “old” response to a novel face; Snodgrass & Corwin, 1988). Follow-up exploratory analyses examined curiosity effects on face memory separately for “confident” and “unconfident” responses during face recognition.

All analyses were performed in R (R Core Team, 2013). ANOVAs were performed using the ezANOVA package (https://cran.r-project.org/web/packages/ez/ez.pdf). For all ANOVAs we divided the sample into child and adolescent groups. Given the continuous age range in the present study, we followed up on significant main or interactive effects of age group with correlation analyses (i.e., *Pearson’s r*, one-sided) treating age as a continuous variable to confirm that results were not driven solely by the group split.

Mixed-effects models were implemented using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015). Mixed effects logistic regressions were fit to single-trial data, with intercepts varying by participant. In a first step, z-transformed curiosity ratings, IPE scores, and their interactions were included as fixed effects. In a second step, we tested whether adding participants' age (z-scored, as a continuous variable) to the model increased model fit as assessed by a significant change in the chi-square statistic. Results are reported for the finally retained model. We report the exponential of the corresponding regression coefficients, which represents the odds ratio (OR) of recalling the answer of a trivia question if the corresponding predictor variable increases by one unit (cf. McGilivray et al., 2015).

False discovery rate (FDR) corrections were applied for multiple comparisons in all reported analyses. For the ANOVAs, missing data in one condition resulted in removal of all of the respective participant's data. For mixed models, we used maximum likelihood estimation that is robust to missing data. Partial eta-squared (η_p^2 = SS(effect) / [SS(effect) + SS(error for that effect)]) is reported as a measure of effect size.

Results

Does pre-answer curiosity modulate memory for trivia answers in childhood?

An ANOVA on the proportion of correctly recalled trivia answers with the within-subjects factor pre-answer curiosity (high vs. low) and the between-subjects factor age group (children vs. adolescents) revealed a significant main effect of curiosity ($F_{(1, 58)}$ = 26.02, p < .001, η_p^2 = .31, $M_{difference}$ = 7.4%). There was neither a significant main effect of age group ($F_{(1, 58)}$ = 1.32, p = .26, η_p^2 = .02) nor a significant curiosity-by-age group interaction ($F_{(1, 58)}$ = 0.53, p = .47, η_p^2 = .01) (Figure 2A, Table 1). These results suggest that curiosity did indeed enhance memory for trivia answers, and the enhancement effect was similar in children and adolescents.

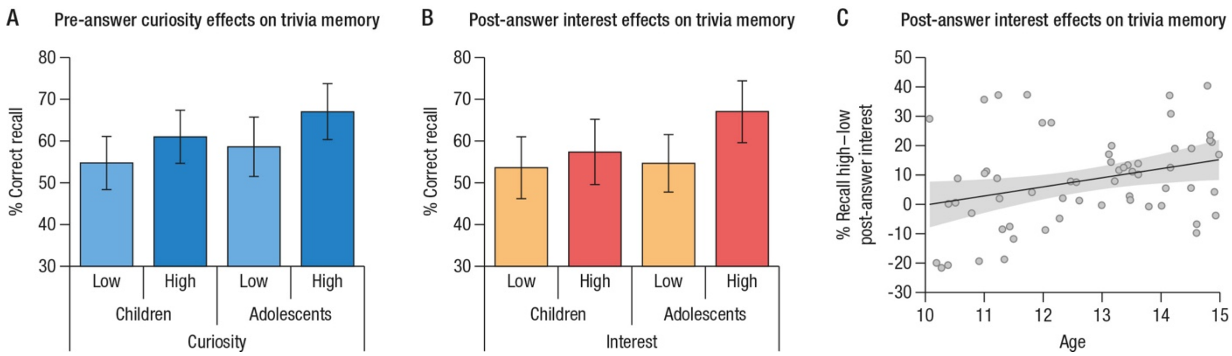

Figure 2. **A**. Pre-answer curiosity-related effects on memory for trivia answers in children and adolescents **B**. Post-answer interest effect on memory for trivia answers in children and adolescents **C**. Correlation between participants' age and interest-driven memory advantage for trivia answers. Error bars (A, B) and shaded area (C) show 95% confidence intervals. High curiosity or interest is defined as ratings "3" or "4" on the corresponding scale, low curiosity or interest is defined as ratings "1" or "2" on the corresponding scale.

Does post-answer interest modulate memory for trivia answers in childhood?

An ANOVA on the proportion of correctly recalled answers with the within-subjects factor post-answer interest (high vs. low) and the between-subjects factor age group (children vs. adolescents) revealed a main effect of interest ($F_{(1,58)}$ = 17.60, p < .001, η_p^2 = .23) along with a significant age group-by-post-answer interest interaction ($F_{(1,58)}$ = 4.92, p = .03, η_p^2 =.08). The main effect of age group was not significant ($F_{(1,58)}$ = 1.29, p = .26, η_p^2 = .02). Paired-sample post-hoc tests within each age group showed that recall did not differ significantly between high- and low post-answer interest in younger children ($t_{(29)}$ = 1.19, p_{adj} = .24, $M_{difference}$ = 4%). In contrast, older children were significantly more likely to remember answers that received high as compared to low post-answer interest ratings ($t_{(29)}$ = 5.73, p_{adj} < .001; $M_{difference}$ = 12%) (Figure 2B, Table 2). In line with the group analyses, the post-answer interest-driven memory enhancement (proportion correct recall for high versus low post-answer interest) was positively correlated with participants' age (*Pearson's r* = .31, $p_{one\text{-}tailed}$ = .01; Figure 2C).

How do information prediction errors modulate memory for trivia answers in childhood?

One possible mechanism by which post-answer interest may modulate the effects of curiosity on episodic memory is via the extent to which it reflects positive or negative surprise, or the discrepancy between the actual value of the presented information relative to the participants' initial curiosity expectations.

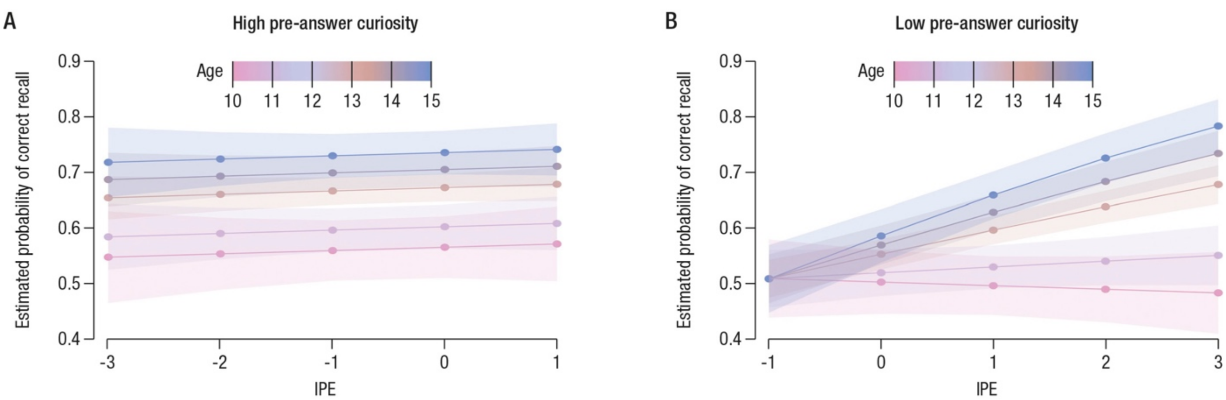

Figure 3. Estimated probability of correct recall for different ages by level of IPE for (A) high-curiosity questions and (B) low-curiosity questions. Shaded areas indicate standard errors around the estimate for different ages. Age was used as a continuous variable in the model, and was split in the figure for display purposes. IPE = information prediction error

To account for the different aspects of IPE, we performed trial-level analyses predicting recall accuracy by (z-scored) curiosity, IPE, and their interaction. In a second step we tested whether age (as a continuous variable) modulated those effects. Including age significantly increased model fit ($\Delta\chi^2$ = 11.65, *df* = 4, *p* = .02). Both curiosity (*OR* = 1.416, *p* < .0001) and IPE (*OR* = 1.231, *p* < .0001) enhanced the likelihood for correctly recalling a trivia answer in children and adolescents. Critically, we observed a significant curiosity-by-IPE-by-age interaction (*OR* = 0.917, *p* = .038). To unpack this interaction, we examined the effects of IPE, age, and their interaction separately for questions associated with high versus low pre-answer curiosity. For high-curiosity questions, there was a significant effect of age (*OR* = 1.26, *p* = .039), but no effect of IPE (*OR* = 1.04, *p* = .61) nor an IPE-by-age interaction (*OR* = 1.00, *p* = .98; Figure 3A) suggesting that adolescents showed enhanced memory for high-curiosity questions. For low-curiosity questions, IPE had a significant effect on memory accuracy (*OR* = 1.23, *p* = .002), whereas the main effect of age was not significant (*OR* = 1.12, *p* = .32). In addition, we observed a significant IPE-by-age interaction (*OR* = 1.14, *p* = .037) such that higher age was associated with a more pronounced effect of IPE on recall of low-curiosity questions (Figure 3B). We obtained similar results if, instead of using IPE, we predicted trivia answers recall with curiosity and raw post-interest ratings as separate factors.

Taken together, while states of curiosity were associated with enhanced memory in children and adolescents, when curiosity was low, only adolescents' later recall benefited from encountering a positively surprising answer.

Do children and adolescents show enhanced memory for incidental information presented during high- compared to low-curiosity states?

An ANOVA on recognition memory accuracy [hits – false alarms] for the incidental face images with the factors pre-answer curiosity (high vs. low) and age group (children vs. adolescents) revealed no significant effects of age group, ($F_{(1,58)}$ = 2.73, *p* = .10, η_p^2 = .05), curiosity, ($F_{(1,58)}$ = 0.43, *p* = .52, η_p^2 = .01), nor a curiosity-by-age group interaction($F_{(1,58)}$ = 0.58, *p* = .45, η_p^2 = .01, Table 3). In a follow-up exploratory analysis, we examined the curiosity effect on incidental information separately for faces recognized with high vs. low confidence. For high-confidence face recognition, we found a main effect of age group ($F_{(1,56)}$ = 4.203, *p* = .05, η_p^2 = .07), but again no effects of curiosity or a curiosity-by-age group interaction (*all ps* > *.22*). None of the effects reached significance for low-confidence recognition (*all ps* > .72).

Based on the hypothesis that enhanced memory for incidental information would reflect a potential spill-over effect from the pre-answer curiosity about the trivia questions, it is quite possible that the curiosity-based enhancement of face memory was stronger in participants who showed a more pronounced curiosity-based advantage in trivia answer recall. To test this in exploratory analyses, we correlated the curiosity-based enhancement of trivia answer recall (proportion recall for high – low curiosity) with the curiosity-based enhancement of face recognition (memory accuracy for high – low curiosity). The results showed a significant positive correlation (*Pearson's* $r = .23$, $p_{one\text{-}tailed} = .036$; Figure 4) such that children who showed a greater benefit of curiosity for trivia answer recall were also most likely to show an enhancement in face memory between the high- and low-curiosity conditions.

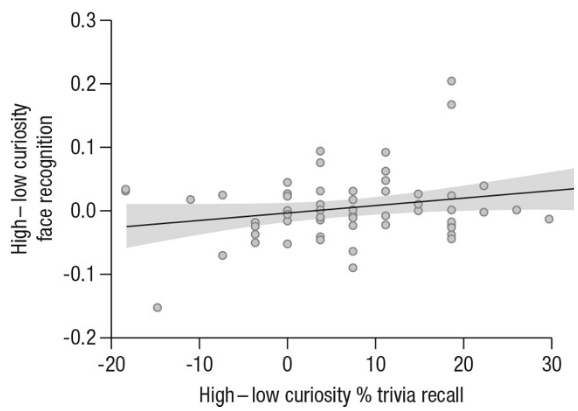

Figure 4. Exploratory correlation between curiosity-related enhancement of face recognition (difference in hits – false alarms for high- vs. low-curiosity condition) and curiosity-related enhancement of trivia answer recall (difference in % recall for high- vs. low-curiosity condition).

Discussion

The present study investigated the effects of curiosity and post-answer interest on memory for answers to trivia questions in children and adolescents aged between 10 and 14 years. Our results revealed that (1) both children and adolescents showed better memory for questions associated with higher states of curiosity; (2) adolescents compared to children showed a greater memory enhancement when they found the answer interesting; (3) surprising answers, as reflected in higher positive IPEs, were better remembered by adolescents, but not by children. Answers associated with higher positive IPEs were remembered by adolescents at levels comparable to their memory for information associated with high curiosity states, suggesting that high positive surprise can offset the effects of lower states of curiosity in adolescence.

Corroborating previous findings in younger and older adults (for a review, see Gruber et al., 2019), states of high curiosity were associated with better memory for trivia answers in children and adolescents. Curiosity is often considered a powerful tool in educational contexts (Engel, 2011). As many of our questions included topics associated with educationally-relevant content, our results suggest that children and adolescents who are curious about a question are indeed more likely to remember the associated answer. Memory benefits associated with states of high curiosity have been demonstrated after longer delays in adults (Gruber et al., 2014; Kang et al., 2019; Stare et al., 2018) and future studies are needed to test their persistence in children and adolescents over extended periods of time.

We found that post-answer interest effects on memory for trivia answers were more pronounced in adolescents than in children. Post-answer interest effects have been shown to largely mediate the effects of pre-answer curiosity on memory in adults (Fastrich et al., 2018), and the present findings suggest that a similar pattern is present in adolescents, but not in children. These age differences are unlikely to reflect lower average interest in the trivia answers, as the distribution of post-answer interest ratings was similar in children and adolescents. Furthermore, variation in IPEs both in terms of valence and strength did not modulate the effects of curiosity on children's memory. These behavioral results suggest that children's learning may be strongly guided by their expectations rather than the value of information. This interpretation is in line with evidence that, compared to adolescents, children rely more strongly on model-free learning (Decker et al., 2016), marked by lower sensitivity to changes in outcome value, and suggest that educational interventions to trigger curiosity may be particularly promising for facilitating learning.

Adolescence is a period marked by changes in motivated behavior and increased sensitivity to rewards (Galvan et al., 2006; van Duijvenvoorde, Peters, Braams, & Crone, 2016). While increased reward sensitivity has been repeatedly associated with increased risk-taking behavior, it has also been shown to positively affect cognitive functioning. For example, extrinsic rewards influence cognitive control (Geier & Luna, 2012), decision-making strategies (van den Bos et al., 2012), and episodic memory in adolescents (Davidow et al., 2016). To date, the effects of intrinsic rewards in adolescence have rarely been examined (e.g., Satterthwaite et al., 2012). The present study corroborates and extends previous research by demonstrating that greater surprise associated with particular information can positively bias episodic memory, and that the memory-enhancing effects of surprise increase in the transition into adolescence. This finding is in line with studies demonstrating increased magnitude of prediction error signals during reinforcement learning in adolescence (Cohen et al., 2010; Hauser, Iannaccone, Walitza, Brandeis, & Brem, 2015) and the effects of positive reward prediction errors on memory in adults (Jang, Nassar, Dillon, & Frank, 2019).

In young and older adults, curiosity states also enhance memory for incidental face images that are encountered during high- compared to low-curiosity states (Galli et al., 2018; Gruber et al., 2014; Stare et al., 2018). In contrast to our prediction, we did not observe that high-curiosity states increased memory for incidental face images in children and adolescents. One potential explanation for this null finding on the group level is that although we found significant curiosity-related memory enhancements for trivia answers, the magnitude (~7%) was smaller than in comparable studies with young adults (~18%) (Gruber et al., 2014; Stare et al., 2018), potentially reflecting a wider variation in curiosity stimulation across children and adolescents, resulting in a lower average memory benefit than that observed in young adults. This interpretation is consistent with the exploratory correlational analyses, which suggested that children demonstrating a greater curiosity-related memory benefit for trivia answers also tended to show a curiosity-related benefit for incidental information.

Another potential explanation for the lack of a curiosity benefit for incidental information at the group level is that memory performance for incidental faces in our sample was higher than in previous young adult studies (Gruber et al., 2014; Stare et al., 2018). As it has been shown that spillover effects on memory are only evident for weakly encoded items (Dunsmoor, Murty, Davachi, & Phelps, 2015), encoding of the face images might potentially have been too strong to isolate spillover effects. Finally, Gruber and colleagues (2014) have shown that curiosity-related spillover effects depend on individual differences in activity and functional connectivity between reward- and memory-related brain regions. Future neuroimaging studies would need to address whether variability in brain activity in these regions predicts the magnitude of potential curiosity spillover effects on memory in children and adolescents.

In conclusion, curiosity enhances memory in children and adolescents. Moreover, adolescents - but not children - showed an additional memory benefit when they were positively surprised about the information, thereby counteracting the effects of low curiosity on later memory. As teachers need to spark students' motivation to learn, these results indicate that curiosity and surprise play a critical role in learning and can be effectively harnessed as a tool in educational settings. Importantly, different strategies to trigger curiosity and surprise in the classroom may result in distinct memory benefits across child development.

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Contributions

Experimental design: Y.F. and M.J.G. Experiment programming: M.J.G. Data collection and analyses: Y.F. Manuscript writing: Y.F. and M.J.G.

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Tables

Table 1. Mean (standard deviations) percentage correct recall for trivia answers according to pre-answer high- and low-curiosity ratings.

	High curiosity	Low curiosity
Children	61.0% (17.1%)	54.7% (17.0%)
Adolescents	67.0% (18.0%)	58.6% (19.1%)

Table 2. Mean (standard deviations) percentage correct recall for trivia answers according to post-answer high- and low-interest ratings.

	High interest	Low interest
Children	57.4% (SD 20.9%)	53.6% (SD 20.0)
Adolescents	67.0% (SD 19.7%)	54.6% (SD 18.4)

Table 3. Mean (standard deviations) memory accuracy (hits – false alarms) for incidental face images presented during high- and low-curiosity states.

	High curiosity	Low curiosity
Children	49.6% (SD 22.3%)	49.7% (SD 23.7%)
Adolescents	58.3% (SD 13.1%)	57.3% (SD 16.0%)