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Age Differences in Processes Underlying Hindsight Bias: A Life-Span Study

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ABSTRACT
Hindsight bias is the tendency to overestimate one's prior knowledge of a fact or event after learning the actual fact. Recent research has suggested that age-related differences in hindsight bias may be based on age-related differences in inhibitory control. We tested whether this explanation held for 3 cognitive processes assumed to underlie hindsight bias: recollection bias, reconstruction bias, and the tendency to adopt newly acquired knowledge as old. We performed a typical hindsight-bias study with 9-year-olds, 12-year-olds, young adults, and older adults. Participants first gave numerical judgments to difficult almanac questions. They later received the correct judgments for some of the questions while trying to recall their own earlier judgments. To experimentally test the impact of inhibitory control, the correct judgment was presented either in a weak or in a strong manner that was difficult to ignore. Hindsight bias was larger in the strong condition than in the weak condition and followed a U-shaped life-span pattern with young adults showing the least hindsight bias in line with an inhibitory-control explanation. Yet, the mixture of underlying processes differed considerably between age groups, so inhibitory control did not suffice as a sole explanation of age differences.

Hindsight bias is the tendency to overestimate one's own original knowledge about a question or event once the correct solution or outcome is known. Assume someone answers a difficult knowledge question like, "*How many keys are on a piano?*" with "*60*." Later, she learns the correct judgment of "*88*" and is asked to recall her own prior judgment. Now, in hindsight, people tend to recall judgments that are closer to the correct judgment than the original judgment had been (e.g., "*70*"). This is an example of hindsight bias, which has been investigated extensively and mainly with young adults (for overviews, see Bernstein, Aßfalg, Kumar, & Ackerman, 2016; Blank, Musch, & Pohl, 2007; Guilbault, Bryant, Brockway, & Posavac, 2004; Hoffrage & Pohl, 2003; Pezzo, 2011; Pohl & Erdfelder, 2017; Roese & Vohs, 2012).

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In developmental studies, greater hindsight bias has been found in children as well as older adults compared with young adults, but only one study has tested hindsight bias across the whole life span (Bernstein, Erdfelder, Meltzoff, Peria, & Loftus, 2011). Some researchers have suggested that lack of inhibitory control, which shows a similar life-span pattern (Bedard et al., 2002; Cepeda, Kramer, & Gonzalez De Sather, 2001), may be responsible for these age differences in hindsight bias (Bayen, Pohl, Erdfelder, & Auer, 2007; Pohl, Bayen, & Martin, 2010). We scrutinized this account by looking at the distinct cognitive mechanisms underlying hindsight bias (following the suggestion by Erdfelder & Buchner, 1998). The goals of our study were 1) to replicate age differences in hindsight bias across the life span using the same materials and procedure for all age groups, 2) to experimentally test the impact of inhibitory control, and 3) to investigate which cognitive processes contribute to hindsight bias at what age and thus test whether age differences in inhibitory control may serve as an explanation for age differences in hindsight bias.

In the next section, we introduce hindsight-bias research and explain how processes underlying hindsight bias can be measured. Then, we summarize previous findings on age-related differences in hindsight bias and discuss their explanation before we turn to our own study.

Hindsight bias

In typical hindsight-bias studies (following the memory design; see Pohl, 2007; Pohl & Erdfelder, 2017), participants answer difficult numerical almanac questions (original judgment [OJ]). After a delay, participants receive the same questions again. This time, experimental questions are accompanied by the correct judgments (CJs), whereas no CJs are provided for control questions. Finally, participants are asked to remember their own OJs (recall of the original judgment [ROJ]). Typically, for experimental questions, the ROJ lies on average numerically closer to the CJ than the OJ did, thus showing hindsight bias. For control questions, by contrast, there is no such systematic shift.

Since Fischhoff's (1975, 1977) seminal work on hindsight bias, hundreds of studies have investigated this phenomenon, including two meta-analyses (Christensen-Szalanski & Willham, 1991; Guilbault et al., 2004). The most important findings were that the bias is very robust across experimental procedures, materials, and measures (see Pohl, 2007; Pohl & Erdfelder, 2017) and that it is almost impossible to avoid (e.g., Pohl & Hell, 1996). In search of explanations for hindsight bias, most theorists have focused on and found empirical support for cognitive processes, such as automatic knowledge assimilation and subsequently biased reconstruction (e.g., Erdfelder & Buchner, 1998; Hawkins & Hastie, 1990; Pohl, Eisenhauer, & Hardt, 2003; Stahlberg & Maass, 1998).

Several studies have demonstrated the occurrence of hindsight bias in the real world, such as in legal domains (for a review, see Giroux, Coburn, Harley, Connolly, & Bernstein, 2016), medical decision making (e.g., Arkes, 2013), economic fields (e.g., Biais & Weber, 2009), and ordinary decision making (Pieters, Baumgartner, & Bagozzi, 2006). Louie, Rajan, and Sibley (2007) reported a number of further real-world occurrences of hindsight bias and discussed their potential consequences (cf. Pezzo, 2011; Roese & Vohs, 2012).[1]

Generally, hindsight bias can be viewed as an instance of retroactive interference, where learning new information (here, the CJ) changes what people report when asked about their memory for old information (here, the OJ). Similar phenomena elicited by slightly different procedures include the knew-it-all-along effect (e.g., Fischhoff & Beyth, 1975), the curse of knowledge (e.g., Birch, 2005), the anchoring effect (e.g., Bahník, Englich, & Strack, 2017), and the eyewitness misinformation effect (e.g., Mazzoni & Vannucci, 2007). Birch and Bernstein (2007) also emphasized parallels between hindsight bias and theory-of-mind problems. The commonality between these and other phenomena (for a comprehensive collection, see Pohl, 2017) seems to be that new information conflicts with older information and that it is necessary to ignore the new information for an unbiased judgment or retrieval of the old information. This view has also been endorsed by researchers who consider lack of inhibitory control responsible for hindsight bias (e.g., Bayen et al., 2007; Pohl et al., 2010). The rationale behind this idea is that the CJ is a task-irrelevant distractor that needs to be inhibited such that it does not influence information processing. A few studies have tested the assumed relation between hindsight bias and inhibitory control and showed some evidence, albeit weak (Bernstein, Atance, Meltzoff, & Loftus, 2007; Coolin, Bernstein, Thornton, & Thornton, 2014; Coolin, Erdfelder, Bernstein, Thornton, & Thornton, 2015, 2016; Groß & Bayen, 2015b; Pohl, 2008).

We tested the inhibitory-control account by means of an experimental manipulation (instead of correlational analyses as in most previous studies). We also tested whether this account extended to the specific cognitive mechanisms assumed to lead to hindsight bias. Researchers have mainly focused on three such mechanisms, namely recollection bias, reconstruction bias, and CJ adoption (see Bayen et al., 2007; Erdfelder & Buchner, 1998; Pohl et al., 2010; Stahlberg & Maass, 1998). *Recollection bias* occurs when knowledge of the CJ impairs recollection of the OJ, a process leading to lower probability of correctly recalling one's OJ for experimental items compared with control items (see Erdfelder, Brandt, & Bröder, 2007). In the example in the opening paragraph, the participant may fail to recollect her OJ of "*60*" piano keys because she has been informed of the CJ of "*88*." *Reconstruction bias* occurs when the CJ is used to reconstruct an OJ that cannot be recalled, a process leading to a shift of the ROJ toward the CJ (cf. Hawkins & Hastie, 1990; Hoffrage, Hertwig, & Gigerenzer, 2000; Pohl et al., 2003). In the example, an ROJ of "*70*" represents such a shift. Finally, *CJ adoption* is an extreme case of reconstruction; that is, the participant gives the CJ as the ROJ response. CJ adoption may result from source confusion between the OJ and CJ in memory. In the example, in the case of a CJ adoption, a participant would give "*88*" as the ROJ. Traditional shift measures of hindsight bias (see

[1]Ash (2009, p. 916) gave an instructive real-world example of hindsight bias: Former U.S. Secretary of Defense Donald Rumsfeld said in 2002, "No terrorist state poses a greater or more *immediate threat* [italics added] to the security of our people and the stability of the world than the regime of Saddam Hussein in Iraq." Later, after no weapons of mass destruction had been found in Iraq, Rumsfeld responded in a 2004 CBS interview when asked about the reality of the "immediate threat" claim: "Well, you're the—you and a few other critics are the only people I've heard use the phrase '*immediate threat*' [italics added]. I didn't. The president didn't. And it's become kind of folklore that that's—that's what's happened." Apparently, now in hindsight, he could not remember his earlier use of the phrase.

Pohl, 2007) are typically a global conglomerate measure of all three of these sources of hindsight bias. Thus, they tell us little about the specific underlying processes.

The HB13 model of hindsight bias

To disentangle the three potential sources of hindsight bias (recollection bias, reconstruction bias, and CJ adoption), which are not directly observable, and to estimate probabilities of their occurrence, Erdfelder and Buchner (1998) developed and validated a multinomial processing-tree (MPT) model of hindsight bias, the "*HB13*" model. In general, MPT models are stochastic models that allow us to estimate probabilities of unobservable cognitive states or processes from frequencies of observable events (for introductory reviews of MPT models, see Batchelder & Riefer, 1999; Erdfelder et al., 2009). A major advantage of MPT models is that they provide process-pure measures of assumed underlying processes. The HB13 model of hindsight bias includes independent parameters that measure recollection bias, reconstruction bias, and CJ adoption. Figure 1 shows the core model assumptions (for greater detail, refer to Erdfelder & Buchner, 1998).

When asked to recall their OJ, participants recollect the OJ from memory with probabilities r_C and r_E for control items and experimental items, respectively. Recollection bias is defined as the difference $r_C - r_E$. When participants cannot recollect the OJ and are presented with the CJ (for experimental items), they may, with probability b, use the CJ to reconstruct the OJ, resulting in reconstruction bias. In the case of a biased reconstruction, participants may adopt the CJ as their ROJ response, with probability c.

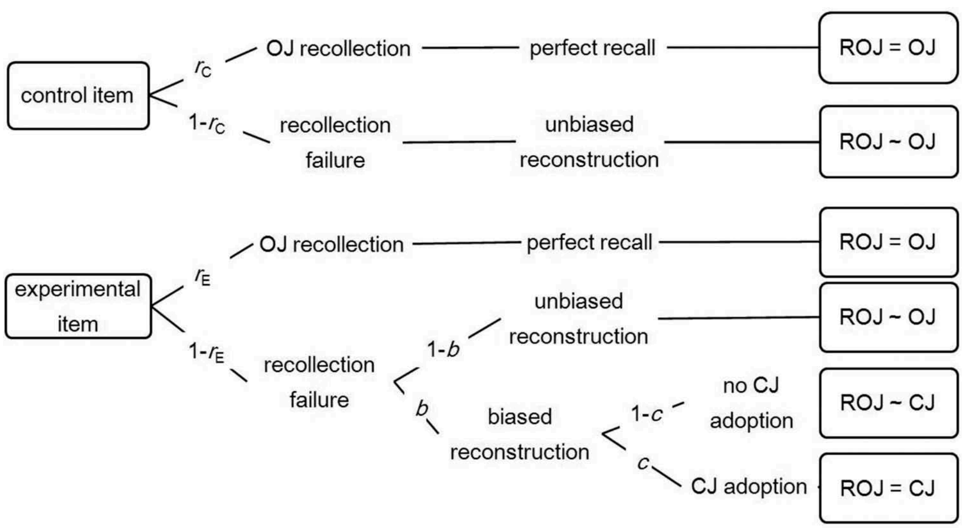

Figure 1. Core assumptions of the HB13 model of hindsight bias (Erdfelder & Buchner, 1998). Rectangles show observable events. Parameters of the model: r_C = probability of recollecting the original judgment (OJ) of a control item; r_E = probability of recollecting the OJ of an experimental item; b = probability of a biased reconstruction; c = probability of adopting the correct judgment (CJ) . Adapted from Erdfelder, Brandt, and Bröder, 2007, p. 117. Copyright, 2007 Guilford Press. Reprinted with permission of Guilford Press.

These model parameters are estimated from the observed frequencies of the potential rank orders of *OJ, CJ*, and *ROJ*. We describe technical details of goodness-of-fit tests, parameter estimation, and parameter tests in the Analyses and Results section.

The HB13 model and variants thereof were successfully applied in various hindsight-bias studies. The main results were that in young adults, hindsight bias is almost exclusively based on reconstruction bias, whereas recollection bias and CJ adoption play minor roles if any (Erdfelder et al., 2007).

Age differences in hindsight bias

A few studies have examined developmental differences in hindsight bias and compared young adults to children (Bernstein, Atance, Loftus, & Meltzoff, 2004; Pohl et al., 2010; Pohl & Haracic, 2005) or to older adults (Bayen, Erdfelder, Bearden, & Lozito, 2006; Coolin et al., 2014, 2015; Groß & Bayen, 2015a, 2015b). So far, only one study compared age groups across the whole life span, with participants aged 3 to 95 years (Bernstein et al., 2011). Taken together, the main result of these studies was a U-shaped life-span pattern, with larger hindsight bias in children and older adults compared with young adults (see also Bayen et al., 2007). Given that several studies have shown that lack of inhibitory control follows the same life-span pattern (Bedard et al., 2002; Cepeda et al., 2001), it is plausible to assume that age differences in hindsight bias may be caused by age differences in inhibitory control (e.g., Bayen et al., 2007; Pohl et al., 2010). Two studies have assessed inhibitory control independently from hindsight bias in different age groups, but they showed only weak evidence for the assumed relation (Coolin et al., 2015; Groß & Bayen, 2015b).

One reason for these findings could be that hindsight bias is not a unitary phenomenon but depends on several cognitive mechanisms discussed earlier that may not equally depend on inhibitory control. Thus, it makes sense to look at age differences in these mechanisms first. Accordingly, some of the data from these studies were analyzed with MPT models of hindsight bias (see Bayen et al., 2006; Bernstein et al., 2011; Coolin et al., 2015; Groß & Bayen, 2015a; Pohl et al., 2010). Recollection bias was typically small in these studies (cf. Erdfelder et al., 2007) and showed no clear age-related differences (Bayen et al., 2006; Bernstein et al., 2011; Coolin et al., 2015; Groß & Bayen, 2015a). However, Pohl et al. (2010) found recollection bias in 9-year-olds only and not in 12-year-olds or young adults.

Reconstruction bias, by contrast, was generally large and showed clearer age effects, albeit not consistently: One study showed larger reconstruction bias in younger children compared with older children and young adults (Pohl et al., 2010), whereas another study revealed no significant differences (Bernstein et al., 2011). Bayen et al. (2006) found larger reconstruction bias in older adults than younger adults when the CJ was either available in the visual environment (Experiment 1 in which the participants saw the CJ in print during ROJ) or in working memory (Experiment 2 in which participants were instructed to remember the CJ for a later memory test). When, however, the CJ was neither available in the visual environment nor in working memory (Experiment 3 in which the CJ immediately preceded the ROJ with no instruction to remember the CJ), the age difference reversed; that is, young adults showed larger reconstruction bias than older adults. These results suggest that older adults had difficulties inhibiting CJ information that was easily available. However, the comparison of these age differences was done across experiments and therefore needs replication with random assignment to different levels of CJ availability.

Finally, CJ adoptions contributed unequivocally to the larger hindsight bias in children (Bernstein et al., 2011; Pohl et al., 2010), and to some degree, they also contributed to that of older adults (Bayen et al., 2006, Experiment 2). In contrast, none of these studies showed a significant probability of CJ adoption for younger adults. So far, however, the findings have been scarce and not always consistent, and only one study used the same material and procedure across age groups from the whole life span (Bernstein et al., 2011). Thus, further research is needed to elucidate these relations.

The current study

Our study had several objectives. First, we wanted to investigate hindsight bias from a life-span perspective. Only one study so far has tested age differences across the whole life span using the same material and procedure for all age groups (Bernstein et al., 2011). All other studies that have compared either children to young adults or younger adults to older adults used different materials and procedures, thus impairing comparisons and generalizations across studies. We therefore included participants ranging from school age to older adulthood and used the same materials and procedure for all (cf. Bernstein et al., 2011).

Further, this study is the first to experimentally test the inhibitory-deficit account of age differences in hindsight bias. More specifically, we tested the impact of inhibitory control in all age groups by experimentally manipulating the strength of the CJ such that the CJ was more or less available to participants during ROJ (cf. Bayen et al., 2006; Wasserman, Lempert, & Hastie, 1991; Wood, 1978). Specifically, we used numerical almanac questions as material in a control condition (i.e., no CJ presented) and in two experimental conditions (i.e., CJ presented) with varying strength in the CJ presentation. In all three conditions, each question was printed on a paper questionnaire, and simultaneously, a picture of the main object in the question was shown on a wall screen. The presentation of the CJ differed between conditions: In the *weak-CJ* condition, the experimenter merely read the CJ aloud. In the *strong-CJ* condition, the CJ was additionally printed in the recall questionnaire (in which participants wrote their ROJs) and was presented on the wall screen (along with the picture of the questioned object). Thus, in this condition, the CJ was presented via three channels and was visually available during the ROJ.

A strong CJ, which is easily available in the retrieval environment, is presumably more difficult to inhibit than a weak CJ, which is less available in the retrieval environment. We thus expected to find larger hindsight bias in the strong-CJ condition than in the weak-CJ condition (cf. Bayen et al., 2006; Wasserman et al., 1991; Wood, 1978). If inhibitory control is weaker in children and older adults than in younger adults, then the U-shaped age function of hindsight bias suggested in previous studies (Bayen et al., 2006; Bernstein et al., 2004, 2011; Coolin et al., 2014; Pohl et al., 2010; Pohl & Haracic, 2005) should be more pronounced in the strong-CJ condition than in the weak-CJ condition. With the manipulation of CJ strength, we thus expected to magnify age differences in overall hindsight bias. Bayen et al. (2006) also used weak-CJ and strong-CJ conditions, and adult age differences appeared larger in the strong-CJ condition. However, in this previous work, the two CJ-strength conditions were in different experiments and thus could not be conclusively compared due to lack of random assignment. In our current experiment, we therefore randomly assigned participants to a weak-CJ or a strong-CJ condition.

Age and strength manipulation should not only affect overall hindsight bias, but also its component processes: recollection bias, reconstruction bias, and CJ adoption. Only a few previous studies looked at age differences in the underlying processes leading to hindsight bias (HB) (again, mostly not comparable across studies). We present the first study that disentangled these component processes of hindsight bias not only across the life span, but also across two CJ-strength conditions. We did so using a data-analytical (multinomial) model that was ideally suited for this purpose. If lack of inhibitory control is the only (or main) mechanism behind these three processes, then different age groups would show similar mixtures of these processes and strengthening the CJ would increase age effects in these processes. The existent literature, by contrast, has suggested there may be age-specific mixtures of cognitive processes underlying hindsight bias. Specifically, we expected all groups to show reconstruction bias that moreover would follow a U-shaped pattern with larger reconstruction bias in children and older adults compared with young adults. In addition, we expected children might show some recollection bias but certainly a large probability of CJ adoption, whereas young adults should show neither and older adults would possibly show only the latter. If thus the mixture of the three component processes of hindsight bias indeed varied with age, then inhibitory control can hardly be the only explanation for age-related differences in hindsight bias.

Methods

Participants

There were a total of 278 participants in four different age groups (74 nine-year-olds, 74 twelve-year-olds, 62 young adults, and 68 older adults; see Table 1 for details). We chose these specific age groups of children to keep the results comparable to previous studies (Pohl et al., 2010; Pohl & Haracic, 2005). In addition, this age range allowed us to use the same type of materials as in many other studies. Starting at 9 years of age, children understand the included tasks, numbers up to 100, and various units of measurement. For children younger than 9 years, it would have been difficult to devise a sufficient number of appropriate items. Setting $\alpha = .05$, the power to detect a medium effect ($f = .25$; Cohen, 1988) in an analysis of variance (ANOVA) across age groups was .95 (computed with *G*Power*; Faul, Erdfelder, Buchner, & Lang, 2009).

We recruited children in public schools in Würzburg. They came from three third-grade classes (9-year-olds) and three sixth-grade classes (12-year-olds). The young adults were 1st-year or sophomore psychology majors at the University of Mannheim. The older adults were recruited in Düsseldorf via newspaper advertisements. They reported on average 10.68 years (SD = 1.90 years) of school education (elementary school + high

Table 1. Number, sex, and age of participants in each age group.

Age group	*N* (female;male)	Mean age (*SD*)	Age range
9-year-olds	74 (43;31)	9;5 (4 months)	8;9–10;5
12-year-olds	74 (44;30)	12;5 (5 months)	11;6–13;7
Young adults	62 (53;9)	21;6 years (32.4 months)	19–31 years
Older adults	68 (50;18)	67;10 years (68.4 months)	60–82 years

Note. We recorded children's age in years and months (years;months), but adults' age in years only. To adjust the age of adult groups we added 6 months to their means.

school). Forty-nine of them reported additional education or professional training for *M* = 3.19 years (*SD* = 1.33 years), 27 of them studied at a university. On a vocabulary test (Riegel, 1967), we observed the typical age pattern, namely older adults (*M* = 16.4 out of 20, *SD* = 2.6) outperforming younger adults (*M* = 14.1, *SD* = 2.6), $t(128) = 4.92$, $p < .0001$, Cohen's $d = 0.88$.

The adults completed a health questionnaire. We excluded individuals with a history of Parkinson disease, kidney dialysis, diabetes, heart attack, stroke, chronic lung disease, brain trauma, depression in the previous 6 months, alcoholism, or drug addiction. We assessed near and far vision in all older adults. All were able to fluently read both in near vision (14-point font-size printed text) and in far vision (22-point font-size text projected onto the wall). These font sizes corresponded to those used in the experiment.

Before the experiment, adult participants signed consent forms and children signed assent forms. We also obtained written consent from parents or guardians of the children and permission from school officials and the Bavarian Ministry of Education. The study was exempt from ethics review at the Universities of Mannheim and Düsseldorf (where we collected the adult data) because the research was noninvasive and participation did not exceed risks that are usually encountered in daily life. Children received small toys and candy for their participation. The psychology students received course credit, and the older adults received monetary compensation.

Design

The design was a 4 × 3 mixed factorial with age group (9-year-olds, 12-year-olds, young adults, older adults) as a between-subjects factor and CJ condition (weak CJ, strong CJ, no CJ) as a within-subjects factor. The weak-CJ and strong-CJ conditions served as experimental conditions, whereas the no-CJ condition served as the control condition.

Materials

We used 48 almanac-type questions that required numerical answers (e.g., *How many months are elephants pregnant?*) and were generated from children's encyclopedias and similar sources. Similar materials have been used in other studies on age differences (e.g., Bayen et al., 2006; Bernstein et al., 2011; Coolin et al., 2014, 2015, 2016; Groß & Bayen, 2015a, 2015b; Pohl et al., 2010; Pohl & Haracic, 2005). The CJs ranged from 12 to 91, which is a range of numbers that should be manageable by even the youngest children in our sample. The answers required the use of units of measurement that, according to teacher judgment, are known by 9-year-olds (e.g., years, kilograms, or centimeters).

We constructed two paper-and-pencil questionnaires, one for OJs and one for ROJs, both with the 48 questions in the same fixed random order for all participants. The OJ questionnaire was identical for all participants. Each question was accompanied by a blank response box followed by the unit of measurement for the numerical answer (e.g., months). The ROJ questionnaire was identical to the OJ questionnaire except that for one third of the questions, the CJ was printed on the questionnaire (strong-CJ condition; e.g., *How many months are elephants pregnant? The correct answer is 21 months. What was your previous answer?*). For the remaining two thirds of the questions (weak-CJ and no-CJ conditions), the CJ was not given on the questionnaire (see the Procedure section for further details).

We created three item sets of equal size and counterbalanced them across participants and conditions, so that—within each age group—all items were presented about equally often in the control condition and in each of the two experimental conditions. On each ROJ questionnaire, the three CJ conditions alternated in fixed order.

Along with each question, we showed 1 of 48 color pictures (mostly photographs) of the objects that were mentioned in the respective question (e.g., a photo of an elephant cow and her calf with the question about the length of elephant pregnancies). We included these pictures to maintain motivation, especially in the younger children, and to help activate relevant knowledge.

Procedure

The children were tested in group sessions in their respective classrooms. Adults were tested in groups of up to 20 in university rooms. Young and older adults were tested in separate sessions. The older adults received the vision tests prior to the experiment.

All materials were presented in test booklets. The experimenter read the instructions aloud for each task and asked if there were questions before the task started. Questions were carefully answered to ensure that everyone understood the task.

The experiment had four time-controlled phases, and the first three followed the typical memory design (Pohl, 2007; Pohl & Erdfelder, 2017): the OJ phase (30 min), a retention interval (25 min, filled with cognitive testing), and the ROJ phase (30 min). In the fourth phase, we collected further data from the adults.

Phase 1

In the OJ phase, the experimenter first handed out the OJ questionnaire and informed participants they would receive several difficult knowledge questions that they should answer as best they could. They were asked to work at the pace set by the experimenter's commands. As soon as the picture for the current question was projected onto the wall screen, the experimenter read the question aloud. Participants then entered their answer (OJ) in the appropriate response box on the questionnaire. After 30 s (which we had found to be sufficient in pilot testing), the picture disappeared and the next one appeared; the experimenter read the corresponding question, and so forth. After participants had answered all 48 questions, the experimenter collected the questionnaires.

Phase 2

To prevent rehearsal of items and OJs during the retention interval, participants worked through a booklet of unrelated cognitive tests, again paced by the experimenter. The retention interval lasted 25 min and was the same for all age groups.

Phase 3

In the ROJ phase, participants received the ROJ questionnaire. They were asked to recall their previous answers (from the OJ phase) as exactly as possible and to ignore the CJs that were now provided for two thirds of the questions. Specifically, they were told, “Please do not let yourself be influenced by these correct answers, but try to remember *your own* answer that you previously wrote down. It is thus best if you write down the very same answer that you previously wrote.” Each trial then proceeded similarly to the OJ phase; that is, the experimenter read the question aloud while the corresponding picture appeared on the wall screen. The task was repeated aloud for every question (*What was your previous answer?*). As in the OJ phase, participants had 30 s for each question to recall and write down their ROJ. The major change in comparison with the OJ phase was that participants received the CJ for experimental items. For these items, the experimenter read the CJ aloud (e.g., *How many months are elephants pregnant? The correct answer is 21 months. What was your previous answer?*). In the strong-CJ condition, the CJ was additionally printed on the questionnaire and also appeared next to the accompanying picture on the wall screen. In the weak-CJ condition, the CJ was only read aloud by the experimenter. For control items, the CJ was not presented at all. After all 48 items had been answered, the experimenter collected the questionnaires.

Phase 4

In the final phase, additional data (e.g., demographics) were collected. All adults completed a vocabulary test and a health questionnaire.

Analyses and results

Preliminary data analyses

From the total of 26,688 answers (OJs and ROJs from 278 participants × 48 questions), 49 OJs and 79 ROJs were missing (0.5%). Questions for which a person failed to provide the OJ, ROJ, or both were excluded for that person, because hindsight-bias indices and model parameters can only be calculated with both responses. From the set of complete OJ–ROJ pairs, we deleted 769 extreme values of OJs or ROJs (2.9%; see Pohl, 2007). These values were larger than the median of all answers (OJs and ROJs) plus 5 times the interquartile range (cf. Tukey, 1977), computed separately for each item. We further excluded cases of correct OJs (i.e., OJ = CJ), because hindsight bias was not defined in these cases. On average, participants answered 1.7 of the 48 questions correctly (3.5%). There were no age differences in correct OJs, $F(3, 274) = 1.922$, $p = .13$; that is, the questions were equally difficult for all age groups. In all, 12,705 pairs of OJs and ROJs (i.e., 95.2% of the maximally possible set) remained in the data set.

Traditional shift analysis

According to a 4 (age groups) × 3 (CJ conditions) ANOVA, the rate of correctly recalled OJs (i.e., ROJ = OJ) differed significantly between age groups, $F(3, 274) = 40.763$, $p < .0001$, $\eta_p^2 = .31$, showing the expected inverted U-shaped function with rates of 35.1%, 46.8%, 59.9%, and 52.3% for the four age groups (in increasing age order). The rate also differed between CJ conditions, $F(2, 548) = 6.943$, $p = .001$, $\eta_p^2 = .02$, with 48.6%, 45.5%, and 49.8% for the weak-CJ, strong-CJ, and no-CJ conditions, respectively.[2] There was no interaction between age group and CJ condition, $F < 1$.

To analyze the incorrectly recalled OJs (i.e., ROJ ≠ OJ) separately, we removed correctly recalled OJs, leaving 5,898 pairs of OJs and ROJs in the data set.[3] For these pairs, we computed the shift measure Δz (Pohl, 1992, 2007). A positive Δz indicates that compared with the OJ, the ROJ shifted toward the CJ (thus signaling hindsight bias). The mean Δz values by age group and CJ condition are presented in Figure 2. We first analyzed the data with a 4 (age groups) × 3 (CJ conditions) ANOVA. Compared with the no-CJ control condition, in which Δz was .012, the overall shifts in the two experimental conditions (weak-CJ and strong-CJ conditions) were significantly larger, namely .188 and .276,

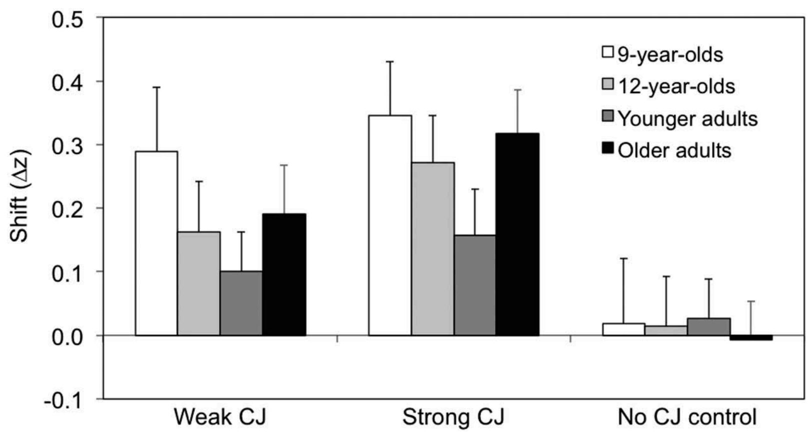

Figure 2. Mean shift values (Δz) by age group and correct judgment (CJ) condition. Larger values indicate larger hindsight bias. Error bars represent 95% confidence intervals.

[2]These percentages of correctly recalled OJs are comparatively large and are due to the short retention interval of only 25 min. Pohl et al. (2010) also used a 25-min retention interval and reported similar values of around 50%. Many other studies used a longer retention interval of 1 week and revealed lower recollection rates of 25% to 35% (Pohl & Erdfelder, 2017). Generally, perfect recollections are less interesting than the remaining potentially biased reconstructions, so low recollection rates would be preferable. However, to reduce the recollection rate, we would have needed longer retention intervals necessitating two separate sessions. Two separate sessions, in turn, bear the danger that participants (especially children) talk to each other about the questions and their answers in the meantime. Another way to decrease correct recollections would have been to use a longer item list (list-length effect; Roberts, 1972). However, it would have led to fatigue, especially in the youngest and oldest age groups. We therefore decided to not use more than 48 items with a short retention interval and to run the study within one session.

[3]We removed correct recollections because including them in an overall index can obscure underlying mechanisms. Pohl (2007) discussed several findings from the literature that may be misleading because they confounded percentages of perfect recollections and amount of bias for the remaining questions. For example, if two groups differ in overall hindsight bias (as measured with Δz or similar indices with perfect recollections included), it may be due to either different percentages of correct recollections alone (without any real "bias") or to different degrees of bias in the imperfectly recalled answers alone or to a mixture of both. These cases cannot be differentiated if the overall index includes perfect recollections.

respectively, thus indicating the presence of hindsight bias, $F(2, 542) = 43.268$, $p < .0001$, $\eta_p^2 = .14$.

Next, we examined the two experimental CJ conditions only. A 4 (age groups) × 2 (experimental CJ conditions) ANOVA revealed a main effect of CJ condition, $F(1, 273) = 10.410$, $p = .001$, $\eta_p^2 = .04$, showing that as expected, the shift was significantly larger in the strong-CJ condition than in the weak-CJ condition. In addition, there were significant differences between age groups with mean shift values of .317, .219, .128, and .254 for the four age groups, $F(3, 273) = 6.626$, $p = .0002$, $\eta_p^2 = .07$, in increasing age order. Thus, the amount of hindsight bias followed a U-shaped life-span function. A post-hoc test (Fisher's Protected Least Significant Difference [PLSD]) revealed significant shift differences between 9-year-olds and 12-year-olds, between 9-year-olds and young adults, between 12-year-olds and young adults, and between young and older adults. The interaction between age group and CJ condition was not significant, $F < 1$, suggesting that the same age differences existed in both experimental conditions.[4]

To test the curvilinear trend of hindsight bias across age, we ran a multiple regression analysis across all participants with log(age) and squared log(age) as predictors and Δz as the dependent measure. The model was significant both in the weak-CJ condition, $F(2, 273) = 4.767$, $p = .009$, $\eta_p^2 = .03$, adjusted $R^2 = .027$, and in the strong-CJ condition, $F(2, 274) = 6.040$, $p = .003$, $\eta_p^2 = .04$, adjusted $R^2 = .035$. Importantly, squared log(age) was a significant predictor in both conditions, with $\beta = 2.127$, $p = .005$, in the weak-CJ condition, and $\beta = 2.579$, $p < .001$, in the strong-CJ condition, thus confirming the U-shaped function of hindsight bias across age in both experimental conditions.

Simonsohn (2017) recently questioned whether significant quadratic regression coefficients would suffice to show a U-shaped function. On the suggestion of a reviewer, we followed Simonsohn's "two-line" approach and ran another multiple regression analysis testing two separate slopes for low and high values of age. When we predicted a U-shaped function of hindsight bias, the slope should have been negative for younger participants and positive for older participants. We determined the breakpoint between younger and older participants as suggested by Simonsohn. In both experimental conditions, the lowest fitted hindsight-bias value in the quadratic regression fell within the group of young adults. Determining the range of values for the flat part of the U-curve (called y_{flat} by Simonsohn) led to the inclusion of all young adults, but no one else. The median age that was used as the breakpoint was thus the same in both conditions, namely 20 years. A multiple regression that tested both slopes for younger and older participants simultaneously led to the following results. In the weak-CJ condition, the slope was negative (–.193) for participants aged 8 to 19 years, and it was positive (.136) for those aged 20 to 82 years. However, neither slope was significant ($p = .114$ and .111, respectively). In the strong-CJ condition, the slope was again negative (–.289) for participants aged 8 to 19 years and was positive (.197) for those aged 20 to 82 years, but in this condition, both were significant ($p = .017$ and .021, respectively). Thus, U-shaped age differences in

[4]To test whether these age-group differences were affected by potential fatigue effects due to the relatively long testing session (especially for the younger children), we computed Δz scores separately for the first half and second half of the questions. Two separate ANOVAs for each experimental condition revealed neither a main effect of question half nor an effect of its interaction with age groups. Thus, we considered fatigue effects to be negligible in our study.

hindsight bias appeared to be more pronounced in the strong-CJ condition compared with the weak-CJ condition. Note, however, that the ANOVA reported earlier revealed no interaction between age group and experimental condition, which suggests similar age differences in both conditions.

Multinomial modeling

The HB13 model (Erdfelder & Buchner, 1998) estimates the probability of correct recollection, of biased reconstruction, and of CJ adoption (with parameters *r*, *b*, and *c*, respectively; cf. Figure 1). To estimate parameters, the model uses the frequencies of 10 different rank orders of *OJ, CJ*, and *ROJ*. The frequencies aggregated over participants are listed in Appendix A. We fitted the model to these data with the multiTree software (Moshagen, 2010), separately for each age group. Each analysis included 30 frequencies (10 from each CJ condition), 3 model trees (1 for each CJ condition), 17 free parameters, and thus $df = 30 - 3 - 17 = 10$. We evaluated the fit of the model to the data with maximum-likelihood methods. The goodness-of-fit statistic was G^2, which is asymptotically chi-square distributed. The critical G^2 value ($\alpha = .05$, $df = 10$) to reject the model was 18.31. The observed G^2 values for the four age groups were 16.25, 11.81, 12.64, and 54.08, respectively, in increasing age order. Thus, the model fit the data well except for the older adults. Their data violated (for unknown reasons) a symmetry assumption of the model, namely that cases of CJ adoption (ROJ = CJ) should occur independently of whether the OJ overestimated or underestimated the CJ. We therefore excluded three items for which the asymmetry was largest (cf. Bayen et al., 2006; Bernstein et al., 2011; Coolin et al., 2015; Pohl et al., 2010). Excluding these items improved model fit for all age groups, especially older adults, namely 14.58, 7.35, 7.57, and 15.64, respectively. Importantly, the estimates for the model parameters changed only slightly so that the main findings of the HB13 analysis remained the same.[5] Figure 3 presents the resulting parameter estimates.

Analyses within age groups

We performed significance tests on the presence of recollection bias, reconstruction bias, and CJ adoption in each age group (see Table 2). In addition, we tested parameter differences between the weak-CJ and the strong-CJ conditions within each age group (see Table 3). Within the MPT-modelling framework, tests of model parameters are accomplished by setting the respective parameter equal to 0 or by equating two parameters. The observed decrement in model fit (ΔG^2) can then be used to assess statistical significance. If the observed decrement is large enough (i.e., $p < .05$), the respective parameter is significantly larger than 0 or the two parameters differ significantly from each other.

[5]To check whether these values were artifacts of the data aggregation across participants, we also ran the HB13 model separately for each participant. Note, however, that the experiment was not designed to allow for individual analyses, so the number of items per participant (i.e., 48 − 3 = 45) was too low to test meaningful individual models (with 20 data categories per person). As a consequence, too many cells were empty, which led to unstable and often extreme estimates. Accordingly, the model showed severe misfit for a large number of participants who thus had to be discarded. Nevertheless, the resulting mean parameter values for each age group deviated only slightly from those shown in Figure 3 and showed the same pattern, thus supporting the validity of the estimates derived from the aggregated data.

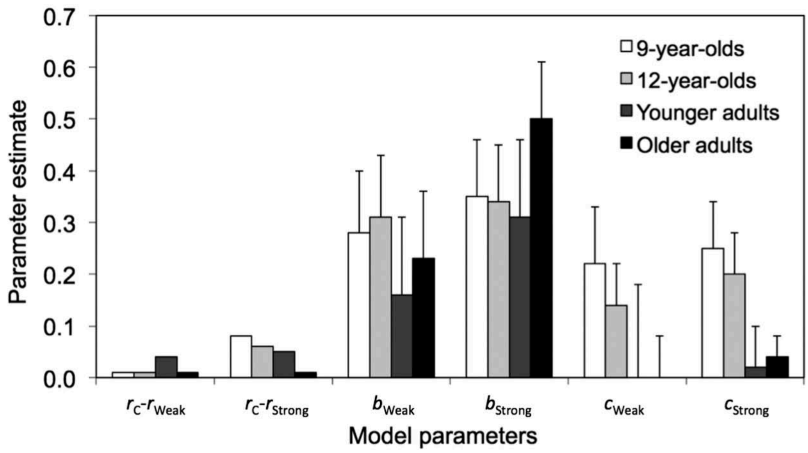

Figure 3. Parameter estimates of the multinomial model by age group and correct judgment (CJ) condition. Model parameters: $r_C - r_{Weak}$ and $r_C - r_{Strong}$ = probability of recollection bias (i.e., difference of correct recollections in control vs. experimental conditions); b = probability of reconstruction bias; c = probability of CJ adoption. Indices: Weak = weak-CJ condition; Strong = strong-CJ condition. Error bars represent 95% confidence intervals (not available for $r_C - r_{Weak}$ and $r_C - r_{Strong}$ differences).

Table 2. Tests of recollection bias, reconstruction bias, and CJ adoption within age groups and CJ conditions.

	$r_{Weak} = r_C$	$r_{Strong} = r_C$	$b_{Weak} = 0$	$b_{Strong} = 0$	$c_{Weak} = 0$	$c_{Strong} = 0$
9-year-olds	0.29	12.21*	30.04*	53.43*	26.70*	49.36*
12-year-olds	0.19	7.95*	26.27*	40.67*	14.08*	29.40*
Young adults	2.28	3.95*	4.17*	15.70*	< 0.00	0.19
Older adults	0.23	0.59	10.26*	46.95*	< 0.00	5.23*

Note. CJ = correct judgment. Model parameters: r = probability of correct recollection; b = probability of reconstruction bias; c = probability of CJ adoption. Indices: Weak = weak-CJ condition; Strong = strong-CJ condition; C = no-CJ control condition.

Given are the $\Delta G^2(1)$ values representing the decrement in model fit when testing the indicated parameter restriction compared with the unrestricted model. A significant decrement signifies that bias or CJ adoption differs from 0. * $p < .05$. Critical value of $\Delta G^2(1) = 3.84$.

Table 3. Tests of differences in recollection bias, reconstruction bias, and CJ adoption between the two experimental CJ conditions within age groups.

	$a_{Weak} = a_{Strong}$	$b_{Weak} = b_{Strong}$	$c_{Weak} = c_{Strong}$
9-year-olds	8.96*	1.34	0.24
12-year-olds	5.41*	0.29	1.34
Young adults	0.22	3.92*	0.19
Older adults	0.08	13.83*	1.44

Note. CJ = correct judgment. Model parameters: a = measure of differences in probability of recollection between the experimental and control conditions (recollection bias; see footnote 6); b = probability of reconstruction bias; c = probability of CJ adoption. Indices: Weak = weak-CJ condition; Strong = strong-CJ condition.

Given are the $\Delta G^2(1)$ values representing the decrement in model fit when equating the respective parameters compared with the unrestricted model. A significant decrement indicates a difference in parameters. * $p < .05$. Critical value of $\Delta G^2(1) = 3.84$.

Recollection bias occurs when correct recollection in an experimental condition is significantly lower than in the control condition (i.e., $r_C > r_E$). We observed such recollection bias for both groups of children and for young adults, but only in the strong-CJ condition (Table 2). That is, children and young adults showed significantly worse recollection of their OJs when the CJ was presented via three channels than when it was not presented at all. Older adults did not show recollection bias. There was no significant difference in recollection bias between the two experimental conditions in any of the age groups (Table 3).[6]

Reconstruction bias (parameter *b*) was significantly larger than 0 in all conditions of all groups (Table 2). The two groups of children had the same reconstruction bias in both experimental conditions, whereas the two adult groups had significantly smaller reconstruction bias in the weak-CJ condition compared with the strong-CJ condition (Table 3).

Both groups of children had significant probabilities of CJ adoption (parameter *c*) in both experimental conditions. Older adults showed a small but significant probability of CJ adoption in the strong-CJ condition (Table 2). There were no significant differences in probabilities of CJ adoption across experimental conditions in any of the age groups (Table 3).

Analyses between age groups

To test parameter differences *between* age groups, we combined the multinomial models for all age groups into an overall model (composed of 120 frequencies, 12 model trees, 68 free parameters, and thus $df = 120 - 12 - 68 = 40$). The critical G^2 value ($\alpha = .05$, $df = 40$) to reject the model was 55.76. Model fit was good, $G^2(40) = 45.15$ (the sum of the G^2 values of the age groups as reported earlier), $p = .27$. The results of testing group differences are presented in Table 4.

We found no age differences in recollection bias, with one exception: In the strong-CJ condition, 9-year-olds showed greater recollection bias than older adults (who had no recollection bias; see Table 2). Recollection biases of 12-year-olds and young adults had intermediate values and showed no age differences.

Reconstruction bias, too, showed only one significant age difference, again in the strong-CJ condition. Older adults showed larger reconstruction bias than younger adults. The children showed large reconstruction biases, too (see Table 2), but they were not significantly different from those of the adults.

Finally, the probability of CJ adoption differed significantly across age, with children showing a higher probability of CJ adoption than adults in both experimental conditions. There were no significant differences between the two groups of children nor between the two groups of adults.

[6]The HB13 model did not allow us to test differences in recollection bias (which is itself defined as a difference of two parameters) between two experimental conditions or groups. We therefore reparameterized the model by replacing the two r_E parameters (r_{Weak} and r_{Strong}) with two new ones (a_{Weak} and a_{Strong}), which measure the ratios of correct recollections in each of the two experimental conditions (weak and strong) and the control condition (see also Groß & Bayen, 2017). That is, $a_{Weak} = r_{Weak} / r_C$ and $a_{Strong} = r_{Strong} / r_C$. In all other aspects, the reparameterized model was identical to the original model. Model fit and parameter estimates were not influenced. The original *r* estimates are given in Appendix B.

Table 4. Tests of age differences in recollection bias, reconstruction bias, and CJ adoption.

	a_{Weak}	a_{Strong}	b_{Weak}	b_{Strong}	c_{Weak}	c_{Strong}
9-year-olds versus 12-year-olds	0.03	1.32	0.09	0.04	1.64	0.76
9-year-olds versus young adults	0.15	3.71	1.65	0.22	4.17*	12.70*
9-year-olds versus older adults	0.02	6.11*	0.26	3.12	9.87*	27.28*
12-year-olds versus young adults	0.43	0.70	2.56	0.08	3.30	9.34*
12-year-olds versus older adults	< 0.01	2.23	0.66	3.78	6.79*	15.98*
Young adults versus older adults	0.41	0.57	0.59	4.19*	< 0.01	0.26

Note. CJ = correct judgment. Model parameters: a = measure of differences in probability of recollection between the experimental and control conditions (recollection bias; see footnote 6); b = probability of reconstruction bias; c = probability of CJ adoption. Indices: Weak = weak-CJ condition; Strong = strong-CJ condition.
Given are the $\Delta G^2(1)$ values representing the decrement in model fit when equating the respective parameters for each pair of groups compared with the unrestricted model. A significant decrement signifies that the tested parameter differs between the respective two age groups. * $p < .05$. Critical value of $\Delta G^2(1) = 3.84$.

Discussion

The major goals of our study were to corroborate previous findings of age-related differences in hindsight bias by using the same materials and procedure across a large age span and to investigate how recollection bias, reconstruction bias, and CJ adoptions differed between age groups (cf. Bayen et al., 2006; Bernstein et al., 2004, 2011; Coolin et al., 2014, 2015; Groß & Bayen, 2015a, 2015b; Pohl et al., 2010; Pohl & Haracic, 2005). We tested four age groups (9-year-olds, 12-year-olds, young adults, and older adults) in a typical hindsight-bias memory design. That is, participants first provided OJs to difficult numerical almanac questions and were later given the CJs for some of the questions and were asked to recall their OJs (ROJs). To experimentally test an inhibitory-control account of age differences in hindsight bias, we manipulated the availability of the CJ during ROJ; that is, it was only read aloud by the experimenter (weak-CJ condition) or was also printed in the questionnaire and shown on the wall screen (strong-CJ condition).

A traditional overall shift measure (Pohl, 2007) revealed hindsight bias in all age groups and, more importantly, a U-shaped pattern across age groups with the largest amount of hindsight bias in younger children and older adults. Manipulation of CJ strength—that is, the difficulty to ignore the CJ during retrieval of one's OJ—also had clear effects. Strong CJs yielded larger hindsight bias overall than weak CJs (cf. Wasserman et al., 1991; Wood, 1978). Moreover, with strong CJs, the U-shaped life-span function of hindsight bias received more support than it did with weak CJs (according to analyses following Simonsohn, 2017). Thus, our results of life-span age differences in hindsight bias corroborate Bernstein et al.'s (2011) findings and are in line with other studies that have tested less diverse age groups (Bayen et al., 2006; Bernstein et al., 2004; Coolin et al., 2014, 2015; Groß & Bayen, 2015a, 2015b; Pohl et al., 2010; Pohl & Haracic, 2005).

So far, these results are in line with age-related differences in inhibitory control (Bayen et al., 2007; Pohl et al., 2010). The idea is that the CJ is a task-irrelevant distractor that needs to be excluded from any retrieval or reconstruction process. This control is typically accomplished via inhibitory functions of the frontal executive that vary by age, with children and older adults showing less effective control and thus greater interference compared with young adults (Bedard et al., 2002; Cepeda et al., 2001; Comalli, Wapner, & Werner, 1962; Kray, Eber, & Lindenberger, 2004; Reimers & Maylor, 2005; Williams, Ponesse, Schachar, Logan, & Tannock, 1999; Zelazo, Craik, & Booth, 2004; but see Verhaeghen, 2011). In addition, the strong-CJ condition afforded more inhibitory control than the weak-CJ condition and thus led to larger hindsight bias.

Only a few studies have directly tested the proposed relation from a developmental perspective by measuring both inhibitory control and hindsight bias. They have shown only partial support for the idea that age-related differences in inhibitory control may be responsible for age differences in hindsight bias (Coolin et al., 2014, 2015; Groß & Bayen, 2015b). Possible explanations for this dissatisfying situation could be that these studies employed a correlational design (and not an experimental design as we did) or that the mixture of specific cognitive processes leading to hindsight bias may vary with age. Thus, we employed the HB13 MPT model by Erdfelder and Buchner (1998) to disentangle the processes potentially leading to hindsight bias (i.e., recollection bias, reconstruction bias, and CJ adoption).

We found that both groups of children showed a large recollection bias (in the strong-CJ condition), a large reconstruction bias, and a large probability of CJ adoption, whereas young adults showed a small recollection bias (in the strong-CJ condition) and a large reconstruction bias but no CJ adoptions. This pattern nicely replicated earlier results (Pohl et al., 2010) and suggests that hindsight bias in children is based on all three processes, whereas that of young adults is mainly based on reconstruction bias alone.

Comparing younger and older adults also revealed some differences. Older adults showed larger reconstruction bias, but only in the strong-CJ condition and not in the weak-CJ condition. This finding is similar to those reported by Bayen et al. (2006) who found larger reconstruction bias in older adults than in young adults when the CJ was available in the visual environment during recall (Experiment 1), but not when the CJ was not visually available (anymore) during recall (Experiment 3). Importantly, in Bayen et al., the comparison was across experiments and thus lacked validity as the participants were not randomly assigned to conditions. In the current study, we addressed this shortcoming by experimentally manipulating the availability of the CJ. We even strengthened the CJ presentation further in comparison with Bayen et al. by providing visual CJ information via two different channels (i.e., on the questionnaire and on the wall screen). We were thereby able to confirm that older adults have particular difficulties ignoring the CJ when it is present in the visual recall environment. This result, when viewed alone, would still support an inhibitory-deficit account of adult age differences in hindsight bias.

Older adults in the current study also showed a small but reliable probability of CJ adoption, again in the strong-CJ condition, but no recollection bias. This finding also fits with those of other studies (Bayen et al., 2006; Bernstein et al., 2011; Coolin et al., 2015).

An important result is that differences between age groups in the cognitive processes underlying hindsight bias tended to be larger in the strong-CJ condition than in the weak-CJ condition. Age differences thus seemed most pronounced when the CJ was most difficult to ignore. It thus appears advisable to use strong-CJ manipulations when testing for age differences in hindsight bias and similar phenomena. It may explain why some previous studies (using weaker CJ presentations) did not reveal significant age differences between younger and older adults in hindsight bias (e.g., Bayen et al., 2006, Experiment 2) or in reconstruction bias (Bernstein et al., 2011; Bayen et al., 2006, Experiment 3, delay condition). One study even showed no reconstruction bias for some of the tested age groups (Bernstein et al., 2011). In addition, several studies did not find recollection bias, let alone age differences therein (Bayen et al., 2006; Bernstein et al., 2011; Coolin et al., 2015; Groß & Bayen, 2015a). These findings might all be due to the relatively weak CJ presentation used in these studies.

In sum, the mixture of cognitive processes leading to hindsight bias differs with age, and it thus appears difficult to attribute age differences in hindsight bias to one mechanism alone, namely an age-related lack of inhibitory control. The different mixtures may also explain why the evidence for the inhibitory-control explanation of hindsight bias has been rather weak so far. Our conclusion may thus have consequences not only for the studies on age-related differences, but also for the basic explanation of hindsight bias and possibly even beyond, for the explanation of other cases of retroactive interference.

One remedy for this theoretical challenge might be to not only disentangle different processes leading to hindsight bias (as we did), but to also disentangle different components of inhibitory control. Hasher and Zacks (1988), for example, suggested three such components (see also Lustig, Hasher, & Zacks, 2007): 1) The *access* function prevents task-irrelevant information from entering working memory; 2) the *deletion* or *suppression* function aims to delete or suppress irrelevant information that already entered working memory; and 3) the *restraint* function concerns inhibition of a dominant response or action. Possibly, these three components show different trajectories across the life span and may thus better explain age-related differences in the processes leading to hindsight bias and in other phenomena that depend on the failure to inhibit information.

In addition, other cognitive features that also follow an inverted U-shaped life-span function (such as capacity of working memory or quality of episodic memory; see, e.g., Dempster, 1981; Gilinsky & Judd, 1994; Li et al., 2004; Shing & Lindenberger, 2011; Yim, Dennis, & Sloutsky, 2013) should be scrutinized more intensively as potential explanations for age differences in hindsight bias (see, e.g., Groß & Bayen, 2015a; Calvillo, 2012; Coolin et al., 2014, 2015, 2016; Nestler, Blank, & Von Collani, 2008). Possibly, age differences in recollection bias, reconstruction bias, and CJ adoptions arise from different mechanisms.

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Appendix A

Frequencies aggregated over participants of the 10 possible rank orders of OJ, CJ, *and* ROJ *that were used in the multinomial modeling for all age groups and CJ conditions.*

	Number of rank order[a]									
	1	2	3	4	5	6	7	8	9	10
9-year-olds										
Weak CJ	119	285	172	27	65	31	126	69	18	68
Strong CJ	116	238	197	35	68	34	113	79	33	82
No CJ	135	280	136	6	53	59	135	63	6	81
12-year-olds										
Weak CJ	92	340	130	15	50	44	200	69	11	54
Strong CJ	102	319	134	23	63	41	184	92	20	58
No CJ	130	344	78	4	55	55	208	66	5	59
Young adults										
Weak CJ	69	367	92	6	25	43	191	56	3	24
Strong CJ	58	347	116	7	26	35	200	63	4	21
No CJ	73	395	75	7	19	45	203	40	7	24
Older adults										
Weak CJ	95	337	124	3	40	35	207	83	5	39
Strong CJ	63	359	165	5	30	27	178	97	9	39
No CJ	115	343	104	6	31	58	217	62	6	31

Note. CJ = correct judgment; OJ = original judgment; ROJ = recall of the original judgment. [a]The ordinal numbers of the rank orders conform to those given by Erdfelder and Buchner (1998): 1) *ROJ* < *OJ* < *CJ*; 2) *ROJ* = *OJ* < *CJ*; 3) *OJ* < *ROJ* < *CJ*; 4) *OJ* < *ROJ* = *CJ*; 5) *OJ* < *CJ* < *ROJ*; 6) *CJ* < *OJ* < *ROJ*; 7) *CJ* < *ROJ* = *OJ*; 8) *CJ* < *ROJ* < *OJ*; 9) *ROJ* = *CJ* < *OJ*; 10) *ROJ* < *CJ* < *OJ*.

Appendix B

Probability of correct recollections: Estimated r *parameter values of the HB13 model for all CJ conditions and age groups.*

	r_{Weak}	r_{Strong}	r_c
9-year-olds	.41	.34	.42
12-year-olds	.53	.48	.54
Young adults	.62	.61	.66
Older adults	.55	.55	.56

Note. CJ = correct judgment; *r* = probability of correct recollection. Indices: Weak = weak-CJ condition; Strong = strong-CJ condition; C = no-CJ control condition.