Adult Age Differences in Hindsight Bias

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Zusammenfassung

Der Begriff *Rückschaufehler* bezeichnet alle Fälle, in denen ein Urteil – oder die Erinnerung an ein vormals abgegebenes Urteil – systematisch in Richtung des Ergebnisses verzerrt ist. Das Ausmaß des Rückschaufehlers ist vom Alter abhängig: Sowohl Kinder als auch ältere Erwachsene zeigen einen größeren Rückschaufehler als jüngere Erwachsene, so dass sich eine u-förmige Funktion über die Lebensspanne ergibt (Bayen, Pohl, Erdfelder, & Auer, 2007).

Die vorliegende Dissertation befasst sich mit Altersunterschieden im Rückschaufehler Erwachsener. In einer Reihe von fünf Experimenten wurde untersucht, welche Rolle Altersunterschiede in der Zugangsfunktion der Inhibition, in Aufgabenbearbeitungsstrategien und in der Gedächtnisleistung für die eigenen Schätzungen für die gefundenen Altersunterschiede im Rückschaufehler spielen.

In Experiment 1 wurde untersucht, ob eine altersbedingte unzureichende Inhibition des Zugangs der Lösungsinformation zum Arbeitsgedächtnis für die Altersunterschiede im Rückschaufehler verantwortlich ist. Obgleich sowohl Altersunterschiede in der Inhibition als auch im Rückschaufehler gefunden wurden, war der Zusammenhang gering. Die Untersuchung der Aufgabenbearbeitungsstrategien (Experiment 2 und 3) ergab zwar Altersunterschiede in der intentionalen Nutzung der Lösungsinformation, jedoch zeigte sich kein Zusammenhang der Nutzung zum Rückschaufehler. In Experiment 4 zeigten sich zwar Altersunterschiede im Rückschaufehler bei Verwendung einer Gedächtnisaufgabe, nicht jedoch bei einer hypothetischen Variante ohne Gedächtnisaufgabe. In Experiment 5 wurde die Gedächtnisleistung für die eigenen Schätzungen bei jüngeren Probanden durch Verlängerung des Retentionsintervalls gesenkt und somit der der älteren Probanden angeglichen. Die Altersunterschiede im Rückschaufehler verschwanden.

Wenngleich die Ergebnisse bezüglich Altersunterschieden in der Inhibition des Zugangs der Lösung als auch in der Aufgabenbearbeitungsstrategie aufschlussreich sind, spielen diese Faktoren für Altersunterschiede im Rückschaufehler vermutlich keine wesentliche Rolle. Vielmehr ist entscheidend, dass es Unterschiede in der zugrundeliegenden Gedächtnisleistung zwischen jüngeren und älteren Erwachsenen gibt und diese in der Rückschaufehler-Aufgabe auch zum Tragen kommen.

Abstract

The term *hindsight bias* refers to all cases in which a judgment regarding an outcome – or the recall of a prior judgment – is systematically distorted towards the actual outcome. The magnitude of hindsight bias depends on age. That is, both children and older adults show stronger hindsight bias than younger adults. Thus, there is a U-shaped life span function of hindsight bias (Bayen et al., 2007).

This dissertation addresses adult age differences in hindsight bias. In a series of five experiments, we investigated the role of age differences in access inhibition, in task-execution strategies, and in the ability to recall prior judgments for the observed age differences in hindsight bias.

In Experiment 1, we investigated whether age-related deficiencies in the inhibition of access of the solution to working memory are responsible for age differences in hindsight bias. Albeit we found both age differences in inhibition and age differences in hindsight bias, the relationship was weak. Although the investigation of task-execution strategies (Experiments 2 and 3) revealed age differences in the intentional use of the solution, we found no relationship between use and hindsight bias. In Experiment 4, we found age differences in hindsight bias with a memory task, but not with a hypothetical version of the task. In Experiment 5, we lowered younger participants' recall performance for their prior judgments via a longer retention interval, such that their recall matched that of older adults. Age differences in hindsight bias disappeared.

Although the results are insightful with regard to age differences in the inhibition of access of the solution and in task-execution strategies, these factors presumably do not play a substantial role in age differences in hindsight bias. Rather, it seems crucial that age differences in recall ability exist, and that they can exert an influence on hindsight bias.

1. Theoretical and Empirical Background

1.1. Introduction

While our future oftentimes appears uncertain, in hindsight we usually realize the linear course of events leading to a specific outcome. This can result in the impression, that we could have predicted the outcome with high probability. However, this impression is a fallacy called *hindsight bias*. Hindsight bias refers to all cases, where a judgment – or the recall of a prior given judgment – is systematically distorted towards the outcome.

Fischhoff (1975) investigated the phenomenon for the first time in a systematic way. Participants in his study first read a short description of a historical or medical event, for example the war between the British and the Nepalese Gurka people at the beginning of the 19th century. To each event, four possible outcomes were described (e.g., British victory, Gurka victory, military stalemate with no peace settlement, military stalemate with peace settlement). Half of the participants, the *hindsight* group, was presented one of the outcomes as the "true" outcome. The other participants, the *foresight* group, was not presented a "true" outcome. All of the participants were then to assign a-priori probabilities to each outcome. Fischhoff discovered that labeling an outcome as the true outcome led to higher probability judgments, irrespective of whether the outcome was actually true or which of the outcomes was presented as being true. Therefore, his hypothesis of a *creeping determinism* was affirmed: Reporting the outcome of an event leads to impressions of its foreseeability.

Fischhoff's study in 1975 has inspired a variety of scientific research. Hindsight bias is still today an attractive field of study not only for psychologists, but also medical scientists (e.g., Berlin, 2000) and legal scientists (e.g., Schweizer, 2005). The reasons are evident (cf. Blank, Musch, & Pohl, 2007): First, hindsight bias reveals itself with different material (e.g., description of events, numerical judgments, visual material) and in different domains of life (e.g., historical events, medical diagnoses, sports results and election results, legal decisions). Thus, hindsight bias is omnipresent. Moreover, hindsight bias is difficult to avoid; even warnings and explanations of the effect led to little or no reduction (e.g., Fischhoff, 1977; Pohl & Hell, 1996). Finally, hindsight bias is highly relevant, as it can evoke negative consequences in certain settings. A physician who misses a tumor on a radiograph in a routine check-up may be held to account later, because the court gets to decide on the case with the benefit of hindsight, that is, when it is aware of the current diagnostic findings and the complete medical history (see Berlin, 2000, for a suchlike case; and Harley, 2007, for a review on hindsight bias in legal decision making).

The fruitful past of hindsight research has produced two meta-analyses so far. According to Christensen-Szalanski and Willham's (1991) assemblage of 122 effect sizes from hindsight studies collected until 1989, the average weighted effect size of hindsight bias was $r = .17$, with r indicating the correlation between the presence of feedback and the change in participants' judgments[1]. In Guilbault, Bryant, Brockway and Posavac's (2004) meta-analysis, 252 included effect sizes yielded an overall effect size of $d = 0.39$, similar to the one found by Christensen-Szalanski and Willham (1991). Thus, hindsight bias is a small to medium effect (Cohen, 1988), yet robust and hard to avoid.

Although hindsight bias proved to be a robust phenomenon, its magnitude seems to differ depending on the age of the participants (see Bayen et al., 2007, for a review on hindsight bias across the life span). Research on developmental characteristics is scarce, especially when it comes to aging (see Bayen, Erdfelder, Bearden, & Lozito, 2006; and Bernstein, Erdfelder, Meltzoff, Peria, & Loftus, 2011, for the two published studies on hindsight bias and aging).

The present thesis addresses the question why older adults show a stronger hindsight bias than younger adults. The potential causes being investigated are age differences in inhibitory processes, task-execution strategies, and recall ability. Prior to a detailed description of the empirical part of this thesis, theoretical and empirical background on core manifestations of hindsight bias, research designs, underlying cognitive processes and important moderators will be provided. Furthermore, previous findings on age differences

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[1] $r = .17$ translates into Cohen's $d = 0.35$ (Cohen, 1988).

in hindsight bias will be described, and possible explanations will be summarized. At the end of the theoretical part of this thesis, the research questions will be introduced.

1.2. The Hindsight Bias Phenomenon

1.2.1. Manifestations

There is consensus that hindsight bias is a complex phenomenon with multiple facets. Therefore, the term *hindsight bias* is actually an umbrella term for several manifestations (Blank & Nestler, 2006; Blank, Nestler, Collani, & Fischer, 2008; Nestler, Blank, & Egloff, 2010). According to Hawkins & Hastie's (1990) broad definition, hindsight bias is "a projection of new knowledge into the past accompanied by a denial that the outcome information has influenced judgment" (p. 311). It has been investigated with a variety of material in a variety of domains: almanac questions (e.g., "How many months are elephants pregnant?", Pohl, Bayen, & Martin, 2010), historical events (e.g., the war between British and Gurka, Fischhoff, 1975), medical results (e.g., participants' cholesterol level, Renner, 2003), election outcomes (e.g., the German parliament election in 1998, Blank, Fischer, & Erdfelder, 2003), decision-making settings (e.g., managerial decisions, Bukszar & Connolly, 1988), visual material (e.g., the perceptibility of blurred photographs, Harley, Carlsen, & Loftus, 2004), gustatory judgments (e.g., judgments of residual sugar in white wine, Pohl, Schwarz, Sczesny, & Stahlberg, 2003), and insight problems (e.g., anagrams, Hom & Ciaramitaro, 2001), to only name a few.

Manifestations of hindsight bias usually belong to one of two categories. On the one hand, outcome knowledge can bias recalls of earlier given judgments. Fischhoff and Beyth (1975) for example showed that recalled judgments of earlier assigned probabilities to various outcomes of President Nixon's trips to Peking and Moscow in 1972 (e.g., "The USA and the USSR will agree to a joint space program.") were higher for outcomes that the participants believed had occurred and lower for those that they believed had not occurred. Outcome knowledge can thus change our memory for preliminarily assigned outcome probabilities.

On the other hand, outcome knowledge can bias our impression of what we would have known without outcome information. In Fischhoff's study (1975), participants in the hindsight group were to assign a-priori probabilities to different possible event outcomes, after having received a "true" outcome. This outcome was assigned a higher mean probability than the same outcome in the foresight group, who did not receive a "true" outcome. Outcome knowledge can thus make us believe we would have known it all along (hence, *knew-it-all-along effect* is another commonly used term).

A different distinction of hindsight bias manifestations was suggested by Blank et al. (2008; also Nestler et al., 2010). They proposed three independent hindsight components: memory distortions, impressions of foreseeability, and impressions of inevitability. Each component is supposed to be self-contained and serves distinct psychological functions (see section 1.2.5). Empirical findings support a *Separate Component View*: Blank and his colleagues found different and sometimes even diverging hindsight effects for the three components (Blank & Nestler, 2006; Blank et al., 2008) and induced dissociations with experimental manipulations (Nestler et al., 2010). Foreseeability and inevitability judgments in the notion of Blank and his colleagues resemble biased judgments, while memory distortions are biased recalls of earlier judgments.

1.2.2. Research Designs

Along the lines of the two principal manifestations of hindsight bias - biased judgments and biased recalls of earlier given judgments – there are two prominent research designs: the memory design and the hypothetical design of hindsight bias. Both research designs are exemplified in Figure 1.

In the memory design, participants are asked for a judgment in response to a question (OJ, original judgment, e.g., "How high is the highest mountain on the moon (in meters)?"). After a retention interval, participants are to recall their own original judgments (recall of original judgment, ROJ). While the correct judgment (CJ) is provided for experimental items ("The highest mountain on the moon is 1738 meters high."), it is not provided for control items. Hindsight bias occurs, if recalled judgments of experimental items are closer to the CJ, compared to control items.

In the hypothetical design, participants provide a hypothetical judgment (HJ) only. For experimental items, the question is presented along with the CJ, and participants are asked to make a judgment "as if they did not know the correct judgment" (hence the term *hypothetical*). For control items, the question is presented without CJ. Similarly to the memory design, hindsight bias occurs if judgments are closer to the CJ for experimental compared to control items.

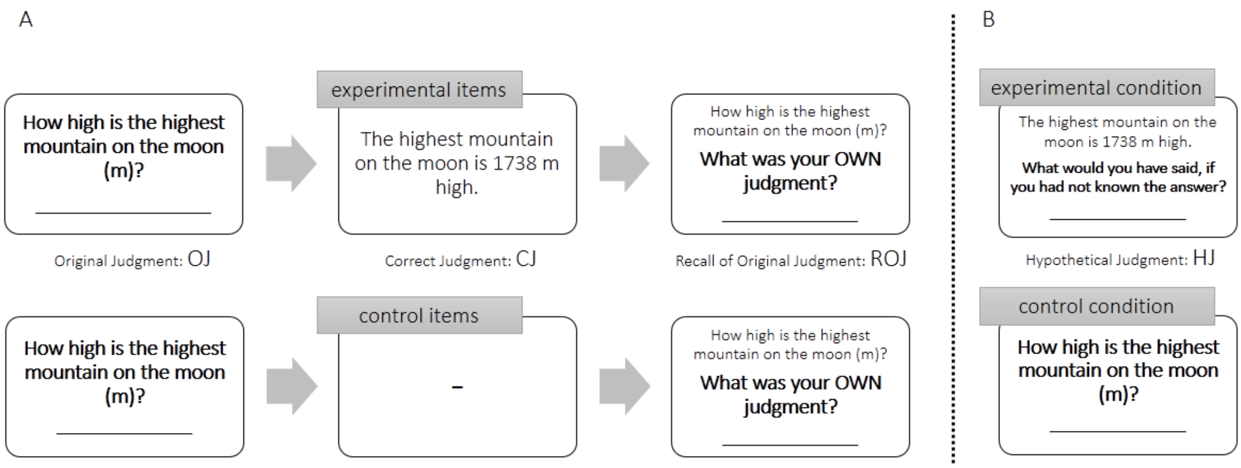

Figure 1. Research Designs of Hindsight Bias. A: Memory Design; B: Hypothetical Design.

Note that the hypothetical design of hindsight bias is highly similar to the *anchoring design*. In anchoring studies, participants are presented high or low anchor values and are then asked for two consecutive judgments: a comparative judgment ("Are more or less than 25% (65%) of the African nations in the UN?") and, subsequently, an exact numerical judgment. Typically, judgments are assimilated towards the given anchor. Importantly, the anchors do not have to be meaningful with regard to the question to yield an effect (see, e.g., Tversky & Kahneman, 1974, for anchors allegedly obtained with a wheel of fortune). Mussweiler and Englich (2005) showed that anchors exert their biasing influence even when presented subliminally. Thus, just as hindsight bias, the anchor effect is robust and hard to avoid.

1.2.3. Underlying Cognitive Processes

Hindsight Bias is mainly a result of cognitive processes. According to Hawkins and Hastie's (1990) general strategies to generate a response in hindsight studies (see also Erdfelder & Buchner, 1998), participants will first attempt to *directly recall the OJ*. CJ knowledge may impair OJ recollection, either because this knowledge alters the OJ memory trace, or reduces its accessibility (e.g., Fischhoff, 1975; Hell, Gigerenzer, Gauggel, Mall, & Müller, 1988). This may result in poorer memory for experimental items compared to control items, referred to as *recollection bias*[2].

The second strategy is *anchoring and adjustment*. It occurs when participants cannot recall the OJ and, when generating a hindsight response, anchor on their current belief and adjust for their incomplete foresight knowledge. The current belief should match the CJ in the case of an experimental item, but should be similar to the OJ in the case of a control item. The adjustment process, however, is usually insufficient, and thus results in a *reconstruction bias*.

The third strategy is *rejudgment*. Again, it occurs when the OJ cannot be recalled. As opposed to control items, information regarding the question has changed in the case of experimental items: New information has been gathered and CJ-inconsistent information may be less accessible (e.g., Hasher, Attig, & Alba, 1981). Thus, rejudging the OJ should lead to reconstruction bias as well.

There is evidence that both mechanisms, recollection and reconstruction bias, play a role in the emergence of hindsight bias. However, the impact of recollection bias is small. Erdfelder, Brandt, and Bröder (2007) analyzed recollection bias in 11 publications that used a memory design of hindsight bias and reported recollection estimates for experimental and control conditions. Averaging 34 conditions in total, the mean difference in recall rates was estimated at .03, with 24 differences being positive (i.e., control >

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[2] Clearly, to estimate the impact of recollection bias, a memory design of hindsight bias is needed. However, in the hypothetical design participants may as well try to directly recall their original belief (if existent), and outcome knowledge can likewise impair recollection.

experimental, indicating recollection bias), and five each being zero or negative. They concluded that there is a reliable recollection bias, although typically small.

Dehn and Erdfelder (1998) attempted to enhance the occurrence of recollection biases by reducing the depth of OJ processing and minimizing the distinctness between OJ and CJ. Whereas the first manipulation reduced correct recollections in general and the second manipulation diminished differences between OJ and ROJ, both were not effective in eliciting a significant recollection bias. Erdfelder & Buchner (1998), on the contrary, were effective in eliciting recollection bias with a 1-week retention interval (whereas recollection bias was not present with shorter retention intervals, Exp. 1, 2, and 4 in their article). Taken together, hindsight bias is primarily due to biased reconstructions, while recollection biases play only a minor role (Dehn & Erdfelder, 1998; Erdfelder & Buchner, 1998; Stahlberg & Maass, 1997).

1.2.4. Measuring Hindsight Bias

Materials. Pohl (2007) provides a comprehensive overview on how to measure hindsight bias. Material generally belongs to one of three categories. The first category are *events*, such as historical events (e.g., President Nixon's trip to Peking and Moscow, Fischhoff & Beyth, 1975; the Chernobyl catastrophe, Verplanken & Pieters, 1988); recent events (the Leipzig candidacy for the Olympics, Blank et al., 2003; election outcomes, Blank & Nestler, 2006), medical diagnoses (e.g., patient with rheumatic fever, Arkes, Wortmann, Saville, & Harkness, 1981), or outcomes of (fictitious) scientific studies (e.g., Slovic & Fischhoff, 1977), to name just a few examples.

The second category are difficult *assertions*, for example "Crocodiles are color-blind". Participants are to indicate, whether the statement is correct or not, and mark their confidence on a rating scale (e.g., Campbell & Tesser, 1983; Hasher et al., 1981; Musch, 2003). So-called *2AFC* (2-alternative-forced-choice) *questions* have been used as well, for example "The Galapagos Islands belong to (a) Equador or (b) Peru." (Hoch & Loewenstein, 1989; see also Hoffrage, Hertwig, & Gigerenzer, 2000; Winman, 1997).

The third category are *numerical estimates*, for example to difficult general knowledge questions (e.g., "How long is the Amazon river (in miles)?", Bayen et al., 2006; see also Dehn & Erdfelder, 1998; Erdfelder & Buchner, 1998; Hell et al., 1988). Irrespective of the type of material, questions are selected such that participants are familiar with the topic of the material, but only in rare cases know the correct answers.

Common dependent measures. A common index that can be used for data from both, the memory and the hypothetical design of hindsight bias, is the index proposed by Hell et al. (1988):

$$\frac{OJ - ROJ}{OJ - CJ} \times 100 \qquad (1)$$

Equation 1 illustrates the hindsight bias index for data collected with the memory design. It represents the percentage in shift of the ROJ towards the CJ. Cases of OJ = CJ need to be excluded from analyses, because the index then is not defined and, evidently, hindsight bias will not occur. Indices are calculated separately for control and experimental items and are then compared. Hindsight bias occurs, if the index is larger for experimental than for control items.

Hell et al. (1988) suggested to aggregate data using the median, because the index tends to produce extreme outliers. As it is a *relative* index, it can be used independently of the scales of the items and is therefore especially suitable in studies using difficult general knowledge questions that require numerical estimates and vary with regard to scaling. Unless the CJ represents the end-point of the scale, the index can take values above 100%. If the index is applied to data collected with the hypothetical design of hindsight bias, ROJ corresponds to judgments in the experimental condition (i.e., with outcome knowledge) and OJ corresponds to judgments in the control condition (i.e., without outcome knowledge).

Another commonly used dependent measure of hindsight bias is the index proposed by Pohl (1992). It is positive, if the ROJ is closer to the CJ than the OJ. Again, cases of OJ = CJ are excluded prior to analysis. Contrary to the *relative* index displayed in Equation 1, this *proximity* index is a difference measure between two distances:

$$|OJ - CJ| - |ROJ - CJ| \quad (2)$$

The values need to be (z-)standardized in order to be comparable across differently scaled items. Therefore, the index has been labeled "Δz", because it resembles a difference between z-scores (e.g., Pohl, 1992; Pohl & Hell, 1996).

Contrary to Equation 1, hindsight bias following Equation 2 is independent of whether feedback has switched to the "other side" of the CJ. Both indices provide a useful measure of whether hindsight bias has occurred, as well as of its approximate size.

Multinomial model. For data obtained with the hindsight bias memory design, there is another approach towards the investigation of hindsight bias: the multinomial modeling approach. Erdfelder and Buchner (1998) introduced a multinomial process tree (MPT) model that disentangles different types of cognitive processes underlying hindsight bias: recollection bias and reconstruction bias (cf. 1.2.3.). MPT models are designed to estimate probabilities of these otherwise unobservable events (e.g., recollection or reconstruction bias) from frequencies of observable events (e.g., the rank orders of CJ, ROJ, and OJ). Therefore, multinomial models are a solution to decomposition problems[3].

Figure 2 illustrates the core assumptions of the MPT model of hindsight bias (see Erdfelder & Buchner, 1998, for an illustration of the complete model). The MPT model of hindsight bias includes separate parameters for the recollection of control items (r_C) and the recollection of experimental items (r_E). It is assumed that first participants try to recollect their OJ from memory. Knowledge of the CJ can impair OJ recollection, leading to recollection bias. Thus, if model parameter r_C is significantly higher than r_E this indicates the presence of recollection bias. When participants are unable to recollect the OJ and have the CJ available, they may use the CJ for reconstruction of the OJ, leading to reconstruction bias, measured as parameter *b* in the model. Additionally, in some cases, participants adopt

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[3] If a participants' answer is of the rank order category ROJ=OJ<CJ, he/she may correctly have recalled the OJ, rejudged the OJ and obtained the same result, or have made a lucky guess. Comparing recollection rates (% OJ = ROJ) for control vs. experimental items is therefore only an approximation to the measurement of recollection bias.

the CJ as their own OJ, leading to CJ adoptions, measured as parameter *c* in the model. CJ adoptions can be understood as extreme cases of reconstruction bias. They play a minor role in adult hindsight bias and are more pronounced in children (Bernstein et al., 2011; Pohl et al., 2010). CJ adoptions may represent source confusions, when the CJ is not present in the retrieval environment during ROJ.

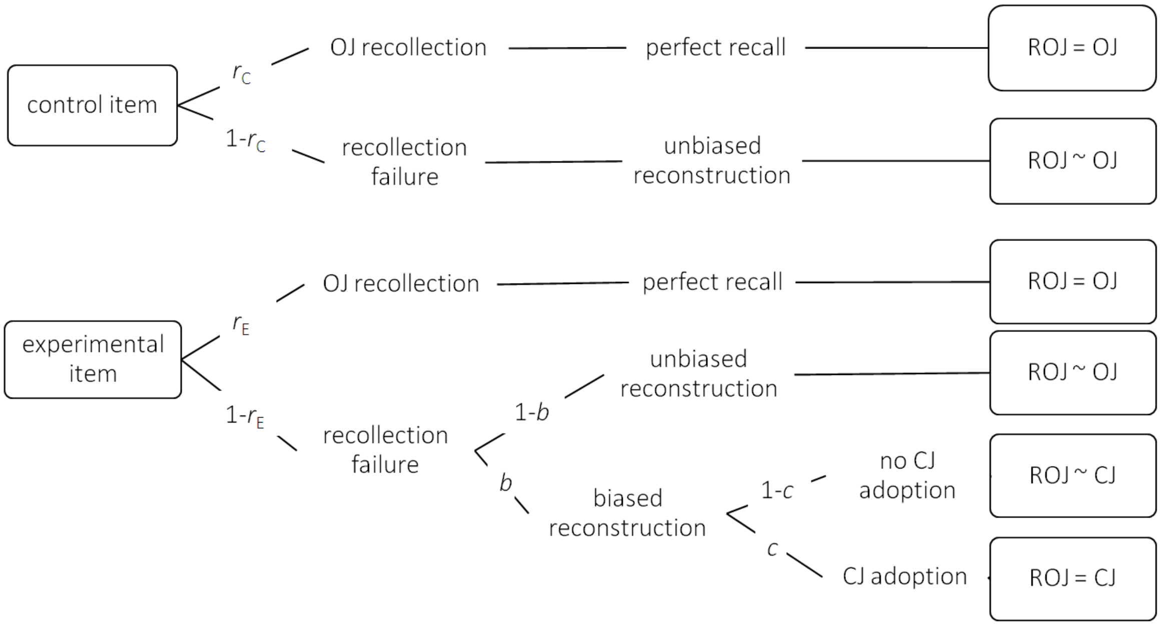

Figure 2. Core assumptions of the multinomial model of hindsight bias by Erdfelder and Buchner (1998). Rectangles represent observable events. r_C and r_E = OJ recollection probabilities for control and experimental items, respectively; *b* = probability of a biased reconstruction given a failure to recall the OJ; *c* = probability of CJ adoption, given a biased reconstruction. Adapted from "Recollection Biases in hindsight judgments," by E. Erdfelder, M. Brandt, and A. Bröder, 2007, *Social Cognition, 25,* p. 117. Copyright 2007 by Guilford Publications.

As with the traditional measures of hindsight bias, cases of OJ = CJ are excluded prior to analysis. This yields 10 rank orders each for control and experimental items (see Appendix A for all possible rank orders of CJ, OJ, and ROJ). Altogether, the MPT model of hindsight bias comprises 13 parameters, including the ones mentioned above (*b*, r_C, r_E, and *c*). Additional parameters indicate, for example, the probabilities of underestimating the CJ for control items and experimental items (l_C and l_E, respectively), or the probability of a chance

OJ or CJ hit in the case of unbiased reconstructions (parameter *h*). Fittingly, the model is also called HB-13 model.

To assess goodness-of-fit, one analyses the distance between model-predicted category frequencies and empirically observed frequencies using the likelihood-ratio statistic G^2 (cf. Hu & Batchelder, 1994). If deviations are statistically not significant, model fit is acceptable. Parameters are estimated via the maximum-likelihood method. There are significant differences in parameters between groups or conditions, if setting parameters equal leads to a significantly worse model fit.

The MPT model of hindsight bias has been successfully applied in various studies (e.g., Bayen et al., 2006; Dehn & Erdfelder, 1998; Pohl et al., 2010; Ruoß & Becker, 2001). Other domains of cognitive research that apply MPT models are, for example, storage and retrieval in memory (e.g., Batchelder & Riefer, 1986; Riefer & Batchelder, 1988), source monitoring (e.g., Bayen, Murnane, & Erdfelder, 1996), and prospective memory (Smith & Bayen, 2004; 2005).

1.2.5. Psychological Functions of Hindsight Bias

Motivational functions. Showing hindsight bias might fulfill a variety of motivational functions. It may, for example, satisfy one's need for controllability, or predictability (cf. Campbell & Tesser, 1983). Moreover, showing hindsight bias supposedly helps to cope with self-relevant, disappointing outcomes ("It was bound to happen!", e.g., Tykocinski, 2001; Tykocinski, Pick, & Kedmi, 2002). Hindsight bias may furthermore serve one's need for self-enhancement by appearing intelligent and knowledgeable. An estimate, or a recalled estimate, that is close to the CJ may make a good impression on oneself or others. In fact, Campbell and Tesser (1983) found positive correlations between hindsight bias and both, self-presentation and need for predictability. However, in general, evidence for *motivated response adjustment* (cf. Hawkins & Hastie, 1990) is rather weak.

Knowledge-Updating. Another question that has been widely discussed (yet sparsely investigated), is whether hindsight bias serves knowledge-updating or is a by-product of knowledge-updating (Hoffrage et al., 2000), or whether it actually prevents any kind of learning (e.g., Fischhoff, 1975). In three experiments, Bernstein and colleagues (2011) recently found the amount of hindsight bias to be unrelated to the amount of correctly recalled CJs. Blank (2012) suggested that hindsight bias may support assimilation-type learning (i.e., adding new facts without changing the knowledge structure) but may impede accommodation-type learning (i.e., re-structuring the existing knowledge structure). However, more research is needed to elucidate the role of knowledge-updating and learning in hindsight bias.

Blank and his colleagues (2008; also Nestler et al., 2010) propose a theoretical outline on manifestations of hindsight bias (foreseeability, inevitability, memory distortions), their underlying processes, and their psychological functions. According to their framework, impressions of inevitability ("It could not have turned out otherwise.") are suggested to serve the need to predict and control the future, and to cope with disappointments (e.g., Tykocinski, 2001). Impressions of foreseeability ("I knew it all along") serve self-enhancement (e.g., Campbell & Tesser, 1983) and self-protection. Memory distortions, finally, serve to keep our knowledge up-to-date (Hoffrage et al., 2000).

1.2.6. Important Moderators

Task properties. Despite its robustness, hindsight bias may vary considerably depending on task properties. Christensen-Szalanski and Willham (1991) in their meta-analysis found that the use of almanac questions produces larger effects than the use of case histories. Furthermore, hindsight bias is larger for events that occurred, compared to events that did not occur. In addition, Guilbault et al. (2004) found objective estimates to produce a larger bias than subjective estimates. Furthermore, neutral events or outcomes led to a larger bias compared to positive or negative outcomes. The degree of hindsight bias was independent of whether a memory design or a hypothetical design was used (but see, e.g., Davies, 1992; Fischhoff, 1977; and Musch, 2003, for significantly smaller effects in the memory compared to the hypothetical design).

Metacognitive influences. In several studies a *reversed* hindsight bias was observed (Mazursky & Ofir, 1990; Renner, 2003; Verplanken & Pieters, 1988). Thus, under certain circumstances people will deny the predictability of an outcome. One of these circumstances may be when participants draw on particular meta-cognitive information. Specifically, if outcomes elicit a strong *feeling of surprise*, hindsight bias may vanish or reverse. Müller and Stahlberg (2007) suggested that participants use their feeling of surprise as information about the initial OJ-CJ distance, if the direct OJ recall fails. Thus, a strong feeling of surprise following CJ information will result in low or even reversed hindsight bias. Furthermore, the feeling of surprise may trigger a sense-making process that is biased towards the experienced surprise. Participants will test hypotheses that are congruent with their feelings of surprise and thus contradict the CJ, resulting in low or reversed hindsight bias.

Another metacognitive influence may be the *accessibility experience*. As Sanna and Schwarz (2003) stated, judgments "are consistent with *what* comes to mind only when it comes to mind easily" (p. 287), thereby describing the interaction between the impact of the number of reasons a person generates pro or contra the outcome (labeled *accessible content*) and their perceived accessibility (Sanna, Schwarz, & Stocker, 2002; Schwarz, 1998). Thus, listing reasons against the outcome may only be effective in reducing hindsight bias, when those reasons are not too difficult to generate. This interaction effect can explain why in some studies, thinking about alternatives reduces hindsight bias (Arkes, Faust, Guilmette, & Hart, 1988; Koriat, Lichtenstein, & Fischoff, 1980; Slovic & Fischhoff, 1977), whereas this debiasing strategy may backfire in others (Sanna et al., 2002): If alternative reasons are hard to come up with, this may increase the feeling that the outcome was inevitable.

Personality. Individual differences are important moderators of hindsight bias as well (see Musch & Wagner, 2007, for an overview of individual differences in hindsight bias): Field-dependent participants are more prone to hindsight bias than field-independent participants[4] (e.g., Davies, 1992; Musch, 2003), participants with a high need for positive

[4] Field-dependence/independence refers to the cognitive style of a person and affects performance in various cognitive as well as social tasks (e.g., Witkin & Goodenough, 1977). Field-dependents tend to rely on external references as guides in information processing, while field-independents rely more on internal references.

self-presentation show stronger hindsight bias than participants with low self-presentation needs (e.g., Campbell & Tesser, 1983; Musch, 2003), and participants with high cognitive capacity show less hindsight bias than less capable participants (Stanovich & West, 1998).

However, most of the personality effects are present in the hypothetical design only. Musch and Wagner (2007) argue that lower reliabilities of memory hindsight measures compared to hypothetical hindsight measures, as found, for example, in Musch's study (2003), may cause the differential effects. Furthermore, the discrepancy may result from measuring separate and potentially independent hindsight components (Blank & Nestler, 2006; Blank et al., 2008). Possibly, personality measures influence foreseeability and inevitability impressions more strongly than memory distortions, and associations between hindsight bias and personality measures are thus found mainly in the hypothetical design.

Age. The degree of hindsight bias furthermore depends on the participants' age (see Bayen et al., 2007, for an overview of hindsight bias across the lifespan). Both, young children and older adults show a stronger hindsight bias than younger adults. In the present section, findings on hindsight bias in children will be reviewed (see section 1.3. for a review on findings on adult age differences in hindsight bias).

Bernstein, Atance, Loftus, and Meltzoff (2004, Exp. 1) investigated hindsight bias in 3-, 4-, and 5-year old children and young adults with a visual hindsight bias task. Participants were asked to identify gradually clarifying pictures of degraded objects. Knowledge about object identity was manipulated within participants. The task was to either identify the object (control condition) or to estimate when a same-aged peer (a puppet named Ernie) would identify the known object (hindsight condition). Results showed that hindsight bias occurred in all four age groups, that is, identification points were on average later for control compared to hindsight conditions. Furthermore, hindsight bias decreased with increasing age. In a second, similar experiment, hindsight bias occurred again in all four age groups, yet remained relatively stable with increasing age.

Bernstein, Atance, Meltzoff, and Loftus (2007) examined the relationship between hindsight bias in preschool children and tasks measuring aspects of Theory of Mind (ToM).

ToM concerns children's understanding of the mental state of others and its impact on behavior, for example the attribution of false belief: Children younger than 4 years usually have difficulties in acknowledging that others can hold false beliefs[5]. Bernstein and his colleagues assumed that errors made in ToM tasks should be related to the magnitude of hindsight bias. Both tasks require the participant to understand that a person can hold a false belief and to understand that new knowledge can change previously held beliefs. In fact, Bernstein and his colleagues found a significant correlation between outcomes in the two tasks. Results also showed that ToM errors decrease significantly from age 3 to 5, whereas there is only little reduction in hindsight bias over the same time course.

Pohl, Bayen, and Martin (2010) examined hindsight bias in 9- and 12-year old children as well as young adults. Participants first had to answer 50 difficult general knowledge questions (OJs, e.g., "How many months are elephants pregnant?") and, after a retention interval, recall all of their initial estimates (ROJs). To half of the questions, the CJ was provided (experimental items, e.g., "The correct answer is 21 months."), while it remained unknown for the other half (control items). MPT analyses showed that all three age groups showed hindsight bias in the form of reconstruction bias. Additionally, in the group of 9-year olds, reconstruction bias was partly due to CJ adoptions. This age group also showed a significant recollection bias, whereas 12-year olds and young adults did not. Thus, the cognitive processes underlying hindsight bias differ substantially between children and adults.

Bernstein et al. (2011) investigated hindsight bias between 3 and 95 years of age. In their study both visual and verbal hindsight bias tasks were used. All age groups showed hindsight bias in both types of tasks. Furthermore, preschoolers showed hindsight bias in

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[5] In the "Sally-Anne" task (Baron-Cohen, Leslie, & Frith, 1985), a typical false-belief task, children watch how doll Sally places a marble into her basket. After Sally has left the room, doll Anne takes the marble out of the basket and places it into her box. When Sally returns, the experimenter asks the child where Sally will look for the marble. Children with a developed ToM will point to the former location (i.e., the basket), whereas children with underdeveloped ToM will point to the current location (i.e., the box). The critical time window to develop ToM is between 3 and 5 years of age (see Wellman, Cross, & Watson, 2001, for a meta-analysis).

the form of CJ adoptions, contrary to all other age groups. The probability of a recollection bias was small and did not differ across age groups.

In an anchoring study, Pohl and Haracic (2005) asked adults and children of different age groups (10, 12, and 14 years of age) to provide estimates to difficult general knowledge questions (e.g., "How many keys has an ordinary keyboard?"). The questions were accompanied by either high or low anchor values, supposedly answers of another person that were to be ignored. Pohl and Haracic found that estimates were higher with high anchors and lower with low anchors. Additionally, this anchor effect was smaller for adults compared to all three groups of children (but see Smith, 1999).

Taken together, research on hindsight bias in children revealed stronger hindsight bias in young children compared to young adults. Possibly, differences are due to a higher susceptibility to interference in children (see Bruck & Ceci, 1999; and Kail, 2002, for related paradigms). The hindsight-bias paradigm is a retroactive interference paradigm (Bayen et al., 2007; Erdfelder et al., 2007), with new information (the CJ) interfering with the retrieval of old information (the OJ). Pohl and Haracic (2005) argued that children's estimations are based on fewer knowledge elements, and associations between these elements are less differentiated. Accordingly, the impact of new information should be considerably higher in young children, leading to stronger hindsight bias.

However, some of the observed differences in hindsight bias between children and adults were due to qualitative rather than quantitative differences. Increased CJ adoption errors, elevated in young children (Bernstein et al., 2011; Pohl et al., 2010), may be caused by an underdeveloped ToM. That is, as young children are unable to imagine their own (or other's) naïve state of mind prior to learning the outcome (Birch & Bernstein, 2007), they erroneously think they had known the CJs all along. As this type of error is still increased in 9-year old children (Pohl et al., 2010), it may also reflect misconceptions about knowledge acquisition (e.g., Pressley, Levin, Ghatala, & Ahmad, 1987). Figure 3 summarizes core findings of research on hindsight bias, including manifestations, underlying cognitive processes, psychological functions, and important moderators.

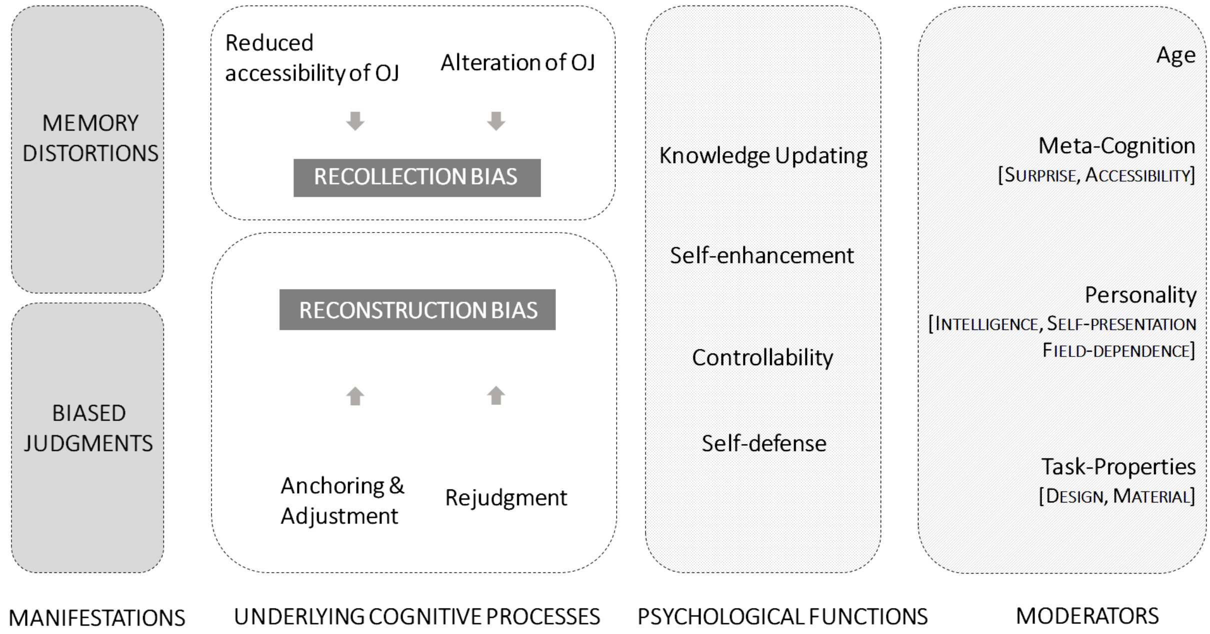

Figure 3. Core Findings of Research on Hindsight Bias.

1.3. Adult Age Differences in Hindsight Bias

Research on developmental characteristics of hindsight bias is even scarcer when it comes to aging. So far, two published studies investigated differences in hindsight bias between younger and older adults (Bayen et al., 2006; Bernstein et al., 2011).

In the Bayen et al. study (2006), memory hindsight bias of older adults (between 61 and 87 years of age) was compared to that of younger adults (between 17 and 28 years of age), using both a relative hindsight-bias index as well as the MPT model of hindsight bias. In Experiment 1, participants first had to answer 54 difficult general knowledge questions that required numerical estimates (OJ). After a retention interval, participants were to recall all of their OJs (ROJ). Half of the questions were accompanied by the CJ (experimental items), and the other half was not (control items). Results revealed that older adults showed higher mean relative hindsight-bias index scores than younger adults. As to the underlying cognitive processes determined with the MPT model, older adults showed recollection bias (as opposed to younger adults), lower overall recollection, and higher reconstruction bias than younger adults.

In Experiment 2, the CJ was not present during ROJ, but accessible in working memory. The procedure was similar to Experiment 1, except that CJs immediately preceded the ROJ and were then removed. Participants were instructed to memorize the CJs. Again, older adults showed higher mean relative hindsight-bias index scores than younger adults. Furthermore, older adults showed recollection bias (as opposed to younger adults), lower overall recollection, and higher reconstruction bias than younger adults.

Experiment 3 was designed to investigate boundary conditions of adult age differences in hindsight bias. The CJ was provided minutes before the ROJ (*delay* condition), and there was no instruction to encode the CJ. The effects reversed: Older adults' probability of a reconstruction bias was not significantly larger than zero, whereas that of younger adults was. Moreover, while older adults still had lower overall recollection probabilities, recollection bias disappeared as well. This reversal of effects can be explained with the difficulties in retrieval of information from episodic memory that older adults frequently exhibit. If the CJ is not accessible in working memory anymore, but must be retrieved from episodic memory in order to influence the ROJ, this leads to a smaller hindsight bias in older adults.

In the Bernstein et al. study (2011), older adults exhibited more hindsight bias than younger adults, irrespective of whether a verbal or a visual hindsight task was used. MPT model analyses revealed that in older adults recollection probabilities were lower, and the probability of a reconstruction bias was higher, compared to younger adults. Recollection for control items was better than for experimental items in all of the observed age groups, however, the difference was not significant for any group.

Taken together, findings suggest that older adults show a stronger hindsight bias than younger adults. Specifically, older adults show lower recollection probabilities and higher probabilities of a reconstruction bias.

1.4. Possible Explanations for Adult Age Differences in Hindsight Bias

1.4.1. Inhibitory Deficit

Adult age differences in hindsight bias may be due to an inhibitory deficit in older adults, as discussed in Bayen et al. (2006) and Bernstein et al. (2011). Inhibitory deficit (e.g., Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999) is moreover ascribed an important role for well-known age-related declines in episodic memory, working memory, problem solving, and attention (e.g., Craik & Salthouse, 2000; Craik & Salthouse, 2008).

Inhibition is the "basic cognitive suppression that contributes to task performance by keeping task-irrelevant information from entering and being maintained in working memory" (Harnishfeger, 1995, p. 178). It is one of the executive functions, with neuronal correlates in frontal and prefrontal brain regions. These regions are known to show a steeper neuronal loss with increasing age than other regions (e.g., Pfefferbaum, Sullivan, Rosenbloom, Mathalon, & Lim, 1998; Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003). Hasher and Zacks (1988; see also Lustig, Hasher, & Zacks, 2007) postulate in their influential inhibitory-deficit theory of cognitive aging that cognitive inhibition becomes less efficient with age, and that this inefficient inhibition underlies many of the well-documented age-related declines mentioned above.

Several studies have addressed adult age differences in inhibitory functions. Paradigms that have been proposed to investigate inhibition include the reading-with-distraction task (e.g., Connelly, Hasher, & Zacks, 1991), directed-forgetting tasks (e.g., Zacks, Radvansky, & Hasher, 1996), the garden-path-sentence completion task (e.g., Hartman & Hasher, 1991), and negative-priming tasks (e.g., Titz, Behrendt, Menge, & Hasselhorn, 2008). Age differences were found with all these paradigms, although not in every study or not unambiguously attributable to true declines in inhibitory functions.

Inhibitory-deficit theory is a useful starting-point for explaining age differences in hindsight bias. As mentioned earlier, the hindsight-bias paradigm is a retroactive interference paradigm, with new information (the CJ) interfering with the retrieval of old information (the OJ). Inhibitory processes presumably influence the magnitude of retroactive interference (e.g., Bayen et al., 2007; MacLeod, 2007), with efficient inhibition of the CJ leading to less interference.

According to Hasher and Zacks (1988), inhibition occurs at different stages of information processing. For the hindsight paradigm, two stages are of special interest, the *access function* and the *suppression function* of inhibition, as will be explained in turn.

Control of the access of irrelevant information to working memory is necessary in order to keep attention focused on relevant aspects of a task. That is, processing of irrelevant information must be avoided when it first occurs. In the hindsight-bias task, an efficient access function of inhibition would prevent access of the CJ to working memory and would therefore also prevent a biased recall of the OJ. If, however, the irrelevant information has gained access to working memory, it must be suppressed in order to avoid an influence of this irrelevant information on the processing of relevant information. In the hindsight task, an intact suppression function of inhibition would prevent a competition of relevant (OJ) and irrelevant (CJ) information in working memory, thus avoiding biased ROJs.

Assuming that aging is accompanied by a deficit in inhibitory functions, this deficit may be responsible for observed age differences in hindsight bias (Bayen et al., 2006; Bernstein et al., 2011), because either access of the CJ to working memory is not inhibited, or suppression of the CJ, once in working memory, is less effective in older adults.

1.4.2. Task-execution Strategies

Another reason for adult age differences in hindsight bias might be that different strategies are applied in completing the hindsight bias memory task. The CJ may gain access to working memory because of insufficient inhibition (cf. 1.4.1.), or, alternatively, people may apply a strategy to *intentionally* use the CJ in completing the task. Older adults may choose to look at the CJ more often than younger adults. They may either strategically seek access to the CJ because they think it positively influences their recall or reconstruction, or simply because they are more interested in it than younger adults. Thus, intentional CJ use may be strategic as to recall or reconstruct one's OJ, or, alternatively, participants may process the CJ for other reasons (e.g., curiosity).

Age differences in the intentional use of the CJ may exist because of cohort differences in the general use of information. New information and communication technologies provide easy access to information nowadays. Older adults may be more interested in learning the CJ during the experiment than younger adults, because older adults' opportunities to gain access to information are more limited. Furthermore, older adults may, to a larger extent than younger adults, misinterpret the CJ as environmental support for the recall of their OJ. Environmental support (Craik, 1986; Craik & Jennings, 1992) consists of information that is present in the memory environment during recall (as in a cued-recall compared to a free-recall task). It can serve as a compensation for deficient self-initiated processes or deficient processing resources. In the hindsight task, however, the CJ impairs memory for the OJ, or biases its reconstruction.

There is evidence that older and younger adults' strategy use differs with respect to various cognitive tasks (e.g., regarding the memorizing of paired associates, Dunlosky & Hertzog, 2001; the solving of arithmetic problems, Geary, Frensch, & Wiley, 1993; or computational estimation, Lemaire, Arnaud, & Lecacheur, 2004). Hence, there may also be age differences in intentional CJ use as a task-execution strategy in the hindsight-bias memory task.

1.4.3. Recall Ability

Another potential explanation for age differences in memory hindsight bias concerns poor memory for the original information. It has been discussed as a factor underlying susceptibility to interference (e.g., Belli, Windschitl, McCarthy, & Winfrey, 1992; Loftus, 1992). Older adults might thus be more prone to hindsight bias, because of their lower recall ability compared to younger adults (e.g., Verhaeghen, Marcoen, & Goossens, 1993), or, specifically, their poorer OJ memory (Bayen et al., 2006; Bernstein et al., 2011; Exp. 1 and 2 of this thesis).

In several hindsight experiments, manipulations of the *relative trace strength* (Hell et al., 1988) of the OJ compared to the CJ have been shown to influence the magnitude of hindsight bias. Manipulations included length of the retention interval (Erdfelder & Buchner, 1998; Nestler et al., 2010), repeated presentation of the CJ (Wood, 1978), having to provide reasons for the OJ (Hell et al., 1988), varying the time of CJ presentation (Hell et al., 1988), or being confronted again with the thoughts developed in foresight (Davies, 1987).

Note that poor memory does not preclude an explanation of inhibitory deficit. In fact, if the CJ gains access more likely, or it is insufficiently suppressed by older adults, this may contribute to poorer OJ memory, because the relative OJ trace strength becomes weaker. Thus, poor memory is not considered an alternative explanation to inhibitory deficit, but an additional explanation.

1.4.4. Other Possible Explanations

Another possible explanation for adult age differences in hindsight bias are source memory problems. Older adults may be less able to distinguish in memory between the OJ and the CJ, leading to adoptions of the CJ as their own OJ. Numerous studies have found that older adults exhibit difficulties in source memory tasks (see Zacks, Hasher, & Li, 2000, for a review). However, Bayen et al. (2006) found that CJ adoptions in the hindsight memory paradigm contribute only little to age differences in hindsight bias. With the CJ in sight during recall (Exp.1), the probability of CJ adoptions was very low and did not differ between younger and older adults. As in this case the CJ does not have to be memorized because it is presented in the retrieval environment, one would not expect source memory problems or age differences in source memory. A chance for source memory to influence hindsight bias exists, however, when the CJ is provided before the recall of the OJ and has to be retrieved from working memory, as in Exp. 2 and Exp. 3 (Bayen et al., 2006). In both experiments, age differences in CJ adoptions were found, although they were statistically significant only in Experiment 2, when there was an instruction to encode the CJ. The probability of a CJ adoption ranged between 9 and 11% for older adults, indicating that even under conditions that promoted source confusions, their probability was relatively small. In addition, age differences in hindsight bias were still present under conditions where source memory did not play a role (Exp. 1).

1.5. Research Questions

In the present thesis we investigated several explanations for adult age differences in hindsight bias. Specifically, we investigated

(1) whether adult age differences in CJ access exist and whether they can explain adult age differences in hindsight bias (Experiment 1),

(2) whether adult age differences in intentional CJ use exist and whether they can explain adult age differences in hindsight bias (Experiments 2 and 3), and

(3) whether adult age differences in recall ability can explain adult age differences in hindsight bias (Experiments 4 and 5).

In addition to traditional hindsight-bias measures, multinomial model-based analyses were applied to disentangle contributions of recollection bias and reconstruction bias to hindsight bias. Furthermore, with the help of the multinomial model, probabilities of CJ adoptions were estimated. However, they reflect true source memory problems only in cases, where the CJ is not present in the retrieval environment and were generally expected to be rare.

2. Empirical Part: Test of Potential Explanations

2.1. Experiment 1: The Role of Access Inhibition[6]

2.1.1. Overview

The first experiment had two main objectives. First, we wanted to replicate the finding that older adults show a stronger hindsight bias than younger adults, when the CJ is in sight during recall (Bayen et al., 2006, Exp.1). Second and most importantly, we wanted to investigate if age differences in one type of inhibitory control, namely access inhibition, are responsible for age differences in hindsight bias.

An objective and quantifiable measure of visual processing, and thus helpful for the investigation of visual access, is eye tracking. Two major types of eye movements are usually distinguished, namely high-velocity movements called saccades, and relatively still fixations where new information is acquired. We operationally defined the concept of access inhibition by means of fixation properties (cf. Kemper & McDowd, 2006). Although it is possible to dissociate eye location from attentional focus with certain paradigms (Posner, 1980), it can be assumed that there is a strong relationship between attentional focus and eye position in complex tasks such as reading. Thus, encoding of information can be directly assessed. This study was the first to record eye movements during the hindsight memory task. Specifically, we were interested in how young and older adults process the CJ during ROJ.

We expected effective access inhibition to be accompanied by shorter fixations and/or less frequent fixations to the task-irrelevant CJ information. Thus, older adults should fixate the CJs longer and more often than younger adults, if access inhibition declines with age. We additionally manipulated fixations to the CJ via task instructions. We expected that if participants are told to *ignore* the CJ, their fixations to the CJ as well as their hindsight bias

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[6] This chapter is a revised version of the unpublished manuscript „Hindsight Bias in Younger and Older Adults: The Role of Access Control" by Julia Groß and Ute J. Bayen, Heinrich-Heine-Universität Düsseldorf.

should be reduced, compared to conventional *free viewing* during the task. If older adults have difficulties with the inhibition of distracting information, an *ignore* instruction should be less helpful for them. Thus, compared to younger adults, we expected older adults to exhibit more and/or longer fixations and, hence, more hindsight bias.

2.1.2. Method

Participants. A power analysis with the G*POWER 3 program (Faul, Erdfelder, Buchner, & Lang, 2009) revealed that 30 participants per experimental condition are necessary to find the expected hindsight effect with a statistical power of .95. A total of 70 younger and 39 older adults participated in the present experiment. We excluded all individuals with a history of heart attack, stroke, brain trauma, emphysema, Parkinson's disease, drug or alcohol abuse, and depression or other psychiatric or neurological disorder in the past 6 months. We also excluded individuals with ophthalmic diseases, because of potential tracking problems. Individuals on medication that affects the central nervous system were also excluded from participation, because of potential effects on eye movements (e.g., prolongation of fixation duration). Thirteen younger adults and 11 older adults were excluded from further analyses due to tracking problems, either because of high offset values during calibration validation (3 young; 6 old), low-quality data despite sufficient validation values (9 young; 3 old), failure to comply with the calibration procedure (1 young; 1 old), or data loss during the experiment (1 old). Thus, data from 57 younger adults (44 of them female) and 28 older adults (17 of them female) were available for further analyses.

The younger adults were between 17 and 29 years old (M = 22.6, SE = 0.4) and received either course credit or monetary payment for their participation. The older adults were between 58 and 82 years old (M = 66.5, SE = 1.1), were recruited via newspaper advertisements, and received monetary payment. Mean years of formal education were 15.2 (SE = 0.3) for younger and 12.7 (SE = 0.6) for older adults (see results section *general knowledge* for an assessment of their current level of general education). All participants were native speakers of German and able to fluently read letters and numbers in 20-point font size on the 19-inch computer screen.

Apparatus. Eye movements were recorded from the dominant eye with a video-based stationary eye tracking system (SMI Hi-Speed) at a sample rate of 1250 Hz. Participants put their chin into a chin rest, so that the viewing distance was constant at 640 mm (25 in.). Both table and chin rest were height-adjustable to optimize tracking and to maximize participants' comfort level. We determined gaze position by using a 13-point calibration. Calibration and subsequent validation were repeated until an average offset value below 0.5° was accomplished.

Material was presented in Calibri typeface with a font size of 25. Participants' oral responses were recorded with a microphone attached to a headset.

Procedure. Participants took part in individual sessions. After giving informed consent[7], they were introduced to the eye tracking technology, and their dominant eye was determined. They were then seated comfortably in front of the computer screen. A short calibration procedure followed to ensure that tracking was possible. In the subsequent OJ phase, participants gave numerical responses to 80 difficult general-knowledge questions in the German language. We used difficult general knowledge questions that required exact numerical estimates (e.g., "How high is St. Peter's Basilica in Rome (in meters)?"). Questions were selected such that participants would be familiar with the topic of the material, but knew the correct answers only in rare cases. All questions are reported in the Appendix B. Questions were presented one at a time in random order. Participants gave oral responses. No eye movements were recorded during OJ. The space bar was used to go on through the trials.

In a 30-minute retention interval, participants completed a non-verbal puzzle task and a demographics and health questionnaire. Afterwards, participants went through the calibration and validation procedure again.

In the ROJ phase, participants received the same 80 questions in the same randomized order as in the OJ phase. They were instructed to recall all of their 80 OJs. Forty of the

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[7] Informed consent was obtained prior to each experiment conducted for this thesis.

items were presented as control items without CJ, the other 40 items were presented as experimental items with the CJ in sight during recall. Assignment of items to the control and experimental conditions was randomized by participant. Figure 4 shows an example of an experimental item. The participants were told that they would see the CJs for some of the questions. Up until this point, all of the participants went through the same procedure.

Fixations to the CJ were now manipulated via instructions. The *free-viewing* instruction corresponded to a standard hindsight-bias instruction that directs participants to recall their own estimates and also includes a suggestion to “not be distracted by the correct answer”. The *ignore* instruction was the same, but additionally instructed participants to “try to not look at the correct answer” as it would negatively influence their recall performance.

Design. The study design is shown in Table 1. Age was a between-subjects variable, and item type (control vs. experimental) a within-subjects variable. We manipulated CJ access both within participants as well as between participants in order to combine the benefits of within-subjects and between-subjects designs.

Table 1

Design of Experiment 1

	Young adults	Young adults	Older adults
	(*N* = 28)	(*N* = 29)	(*N* = 28)
ROJ block	IG-IG	FV-IG	FV-IG
1 (Items 1- 40)	ignore	free viewing	free viewing
2 (Items 41-80)	ignore	ignore	ignore

Notes. IG = ignore; FV = free viewing; ROJ = recall of the original judgment.

We randomly divided the younger adults into two groups. One group of younger adults (*N* = 29) and the group of older adults (*N* = 28) received the free-viewing instruction for the first 40 items and a subsequent ignore instruction for the second 40 items of the ROJ phase (FV-IG groups). We manipulated CJ access within participants, because we expected large interindividual differences in eye movements that might mask potential effects in a between-subjects design. A within-subjects design has the disadvantage that sequence effects may taint effects of the instructional manipulation. We, therefore, included another group of younger adults (N = 28) who received ignore instructions throughout the ROJ phase (IG-IG group) in order to also compare the effect of the manipulation between younger participants in the first block. Furthermore, the IG-IG group allowed us to test for potential sequence effects. That is, if there are no differences in fixations between the two ignore blocks in this group, we may trust that any between-block differences in the two FV-IG groups are due to the manipulation, and not due to fatigue or depletion.

2.1.3. Results

With a total of 85 participants and 80 items, 6800 OJ-ROJ-pairs were available for analyses. We excluded 30 cases, in which the OJ equaled the CJ (0.4%) and another 148 cases, in which either the OJ or the ROJ was missing (2.2%). Thus, for all hindsight-bias analyses, 6622 data points were available.

For eye movement analyses, only fixations to the CJ were measured; therefore, 3324 experimental items were available for the extraction of fixations from eye-movement raw data. Saccades and blinks were not included in our analyses, as we were interested in information intake, which occurs only during fixations. We allowed a minimum fixation duration of 40 ms and set a velocity threshold of 40° for the extraction of fixations.

At first, we will present results on general knowledge and OJ recollection. We will then describe the effects of the within- and the between-subjects manipulation on CJ fixations in the two younger-adult experimental groups. Next, we compare younger and older adults' fixation behavior. In the subsequent section, we compare hindsight bias in the two younger-adult experimental groups as well as between younger and older adults.

General knowledge. Older adults had less years of formal education than younger adults. This is typical in German samples (e.g., Mund, Bell, & Buchner, 2010; Pachur, Mata, &

Schooler, 2009), presumably because the post-war generation in Germany had fewer educational opportunities than young adults have nowadays. In order to exclude education as a confounding variable in our study, we calculated a more adequate measure of general education, namely the quality of the OJs in the hindsight task. If a participant's OJ is close to the CJ, we can assume that knowledge is higher, compared to when the OJ is far away from the CJ. We calculated the absolute difference of each single OJ to its corresponding CJ and, because of the different scaling of the items, divided this difference by the standard deviation of the OJ-CJ differences for that item. We thus define the quality of a judgment as

$$\frac{|OJ_{i,k} - CJ_k|}{SD_{|OJ-CJ|_k}} \tag{3}$$

where i denotes the participant, and k denotes the item. The smaller the score, the better a participant's general knowledge. The mean was 0.70 for younger adults (*SE* = 0.03) and 0.66 (*SE* = 0.03) for older adults, *t*(83) = 1.0, *p* = .342, *d* = 0.2. Therefore, we can conclude that our older participants had the same amount of knowledge concerning the experimental material as our younger participants, and, hence, that the difference in years of formal education did not result in a difference in the current actual educational level of the samples.

Yet, in addition to the analyses reported below, we conducted all analyses with mean years of formal education as a covariate. In none of the analyses was there a main effect of education or an interaction of education with the other variables. Unless noted otherwise, the pattern of results obtained with and without the covariate were the same.

Recollection. Younger adults recalled on average more OJs (*M* = 43%, *SE* = 1.7) than older adults (*M* = 33%, *SE* = 1.8), *t*(83) = 3.5, *p* = .001, *d* = 0.9. This is in line with the well-established finding of age differences in recall ability (for a meta-analysis, see Verhaeghen et al., 1993) and with previous results on age differences in OJ recollection in the hindsight memory design (Bayen et al., 2006; Bernstein et al., 2011).

Manipulation check: CJ fixations in younger Adults. We analyzed CJ fixations in the two younger-adult groups to test the hypothesis that our viewing manipulation had the intended effect. We used two dependent measures of eye fixations, namely CJ fixation duration, and number of fixated CJs. To obtain a measure of CJ fixation duration, we computed an index that relates mean CJ fixation duration to mean CJ *plus* text fixation duration. Figure 4 illustrates the two areas of interest (AOI). The relative index ranges between 0 (indicating 100% of fixations on the text and therefore 100% CJ ignoring) and 1 (indicating 100% of fixations on the CJ with no fixations on the text). We decided on this measure to exclude the possibility that results be biased, because older adults show generally longer fixations than younger adults in order to compensate for potential sensory deficits.

Figure 4. Example of an experimental item (How high is the St. Peter's Basilica in Rome (m)? Correct: 133. What was your OWN answer?), including the two areas of interest (AOI), text and CJ. One participant's eye movements are shown. The circles indicate fixations (the larger the circle, the longer the fixation duration).

Means and standard errors for relative CJ fixation duration in both younger-adult groups are shown in Figure 5. We carried out a 2 (experimental group: IG-IG vs. FV-IG) × 2 (ROJ block: 1 vs. 2) repeated-measures ANOVA on relative CJ fixation duration. The main effects of group, $F(1,55) = 14.9$, $p < .001$, $\eta_p^2 = .21$, and ROJ block, $F(1,55) = 79.1$, $p < .001$, $\eta_p^2 = .59$, were significant. As expected, we also found a significant group × ROJ block interaction, $F(1,55) = 53.2$, $p < .001$, $\eta_p^2 = .49$, indicating that the difference in CJ fixation duration between the first and second ROJ block was larger for the FV-IG experimental group.

In a next step, we carried out a 2 (experimental group: IG-IG vs. FV-IG) × 2 (ROJ block: 1 vs. 2) repeated-measures ANOVA on number of fixated CJs. Means and standard errors for number of fixated CJs are shown in Figure 6. As with the other fixation measure, we found a significant main effect of group, $F(1,55) = 8.0$, $p = .006$, $\eta_p^2 = .13$, a significant main effect of ROJ block, $F(1,55) = 108.8$, $p < .001$, $\eta_p^2 = .66$, as well as a significant group × ROJ block interaction, $F(1,55) = 65.3$, $p < .001$, $\eta_p^2 = .54$, which were all in line with our expectations.

Post-hoc comparisons revealed that both fixation measures differed significantly between the two blocks within the FV-IG group (fixation duration: $t(28) = 8.9$, $p < .001$, $d = 1.7$, and number of fixated CJs: $t(28) = 11.2$, $p < .001$, $d = 2.1$, respectively). Thus, more CJs were fixated during free viewing, and fixations were longer during free viewing, as intended.

Both fixation measures also differed significantly between the FV-IG and the IG-IG group in the first block (fixation duration $t(55) = 5.6$, $p < .001$, $d = 1.5$, and number of fixated CJs $t(55) = 6.5$, $p < .001$, $d = 1.7$, respectively). Thus, in both the within-subjects and the between-subjects comparison, the manipulation was successful.

However, participants in the IG-IG group had longer relative fixation durations in the first

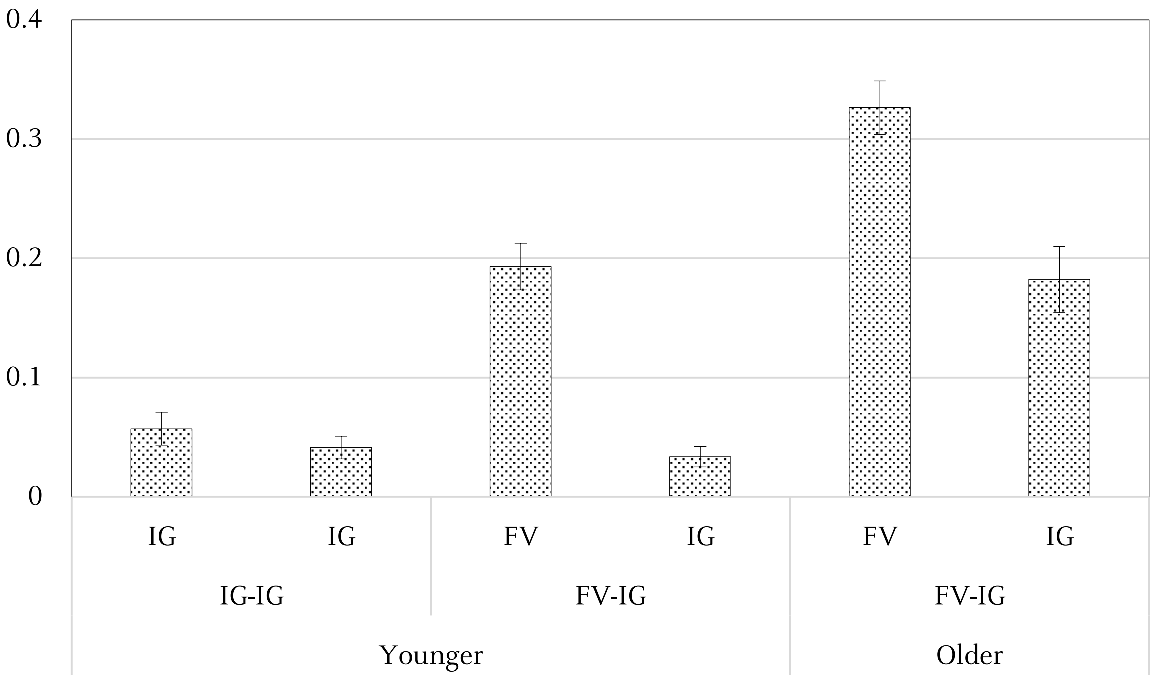

Figure 5. Mean relative CJ fixation duration as a function of viewing condition and age group. Error bars represent standard errors. IG = ignore; FV = free viewing.

IG block, $t(27) = 2.1$, $p = .050$, $d = 0.4$, and fixated on average more CJs in the first IG block, $t(27) = 2.2$, $p = .040$, $d = 0.4$. This decrease across blocks in the IG-IG group most likely indicates that ignoring the CJ can be practiced, and that fatigue or depletion are unlikely. Therefore, the difference between the two blocks in the FV-IG group is most likely due to the manipulation.

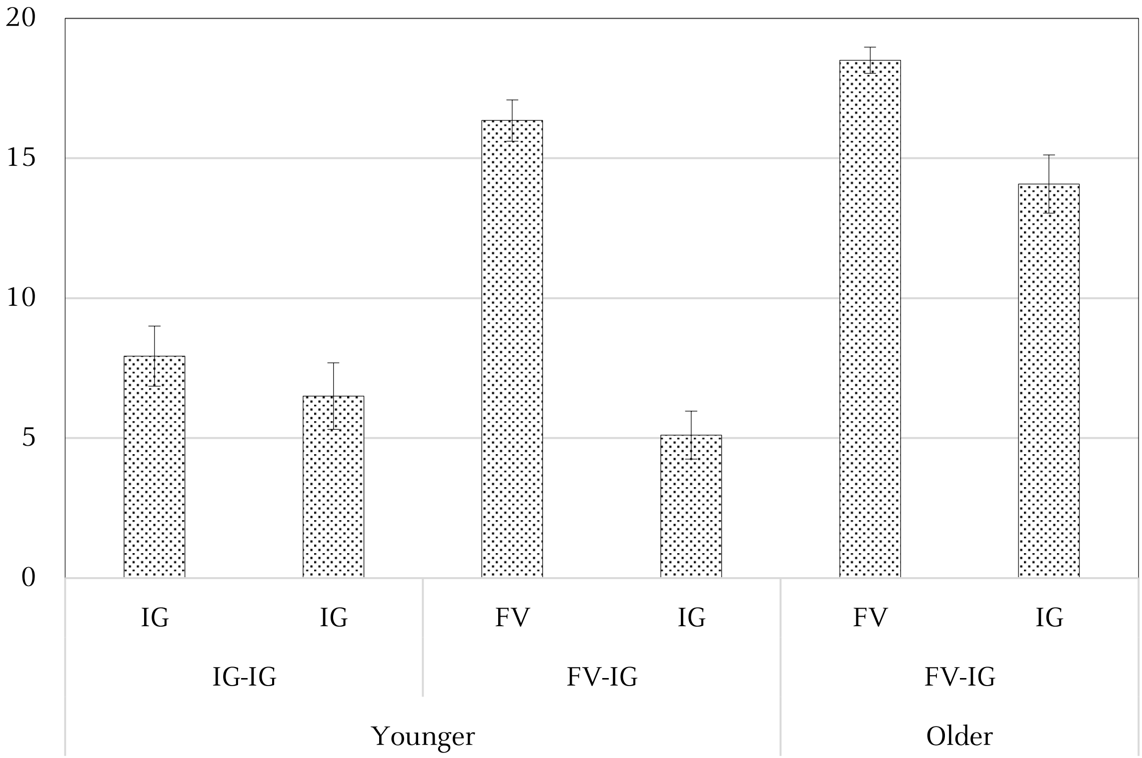

Figure 6. Mean number of fixated CJs as a function of viewing condition and age group. In each block, a total of 20 CJs was presented. Error bars represent standard errors. IG = ignore; FV = free viewing.

Age differences in CJ fixations. We compared CJ fixations in young and older adults in the FV-IG groups. To test the hypothesis that older adults fixated the CJs longer than younger adults, we conducted a 2 (age groups) × 2 (free viewing vs. ignore) repeated-measures ANOVA. Means and standard errors are shown in Figure 5. Relative CJ fixations were longer during free viewing than during ignoring, $F(1,55) = 119.8$, $p < .001$, $\eta_p^2 = .69$, and longer for older than for younger adults, $F(1,55) = 30.3$, $p < .001$, $\eta_p^2 = .36$. There was no interaction, $F(1,55) = 0.3$, $p = .581$, $\eta_p^2 = .01$.

Again, we were interested in how many of the presented CJs were fixated. Means and standard errors are shown in Figure 6. An ANOVA with age group and ROJ block confirmed a main effect of age group, $F(1,55) = 37.7$, $p < .001$, $\eta_p^2 = .41$, and a main effect of ROJ block, $F(1,55) = 132.1$, $p < .001$, $\eta_p^2 = .71$. There was also an interaction of age group and ROJ block, $F(1,55) = 25.0$, $p < .001$, $\eta_p^2 = .31$, indicating that ignore instructions did not help older adults as much as younger adults in reducing CJ fixations.

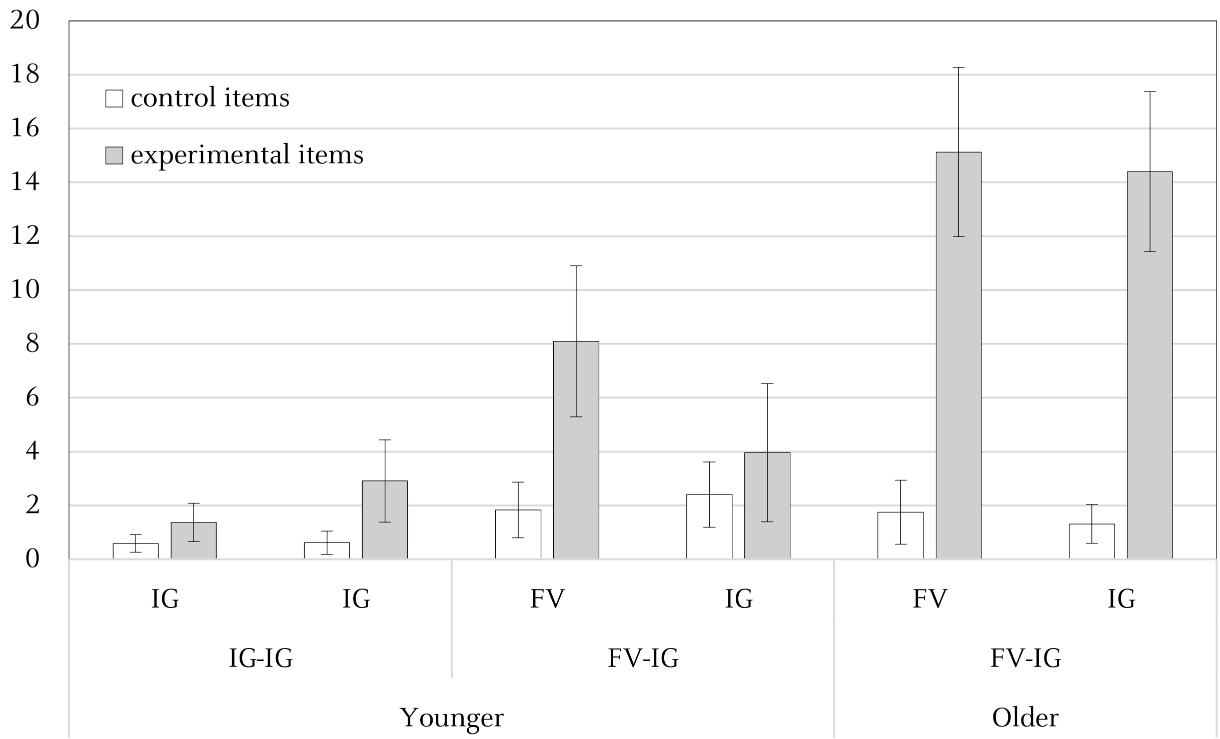

Figure 7. Mean hindsight-bias index scores for the three participant groups. Error bars represent standard errors. IG = ignore; FV = free viewing.

Hindsight bias in younger adults. To test whether our manipulation had an effect on the magnitude of hindsight bias in the two younger-adult groups, we first calculated the medians of the hindsight-bias index proposed by Hell et al. (1988, Equation 1), separately for experimental and control items. Means and standard errors for this measure are shown in Figure 7.

A 2 (item type: control vs. experimental) × 2 (experimental group: FV-IG vs. IG-IG) × 2 (ROJ block: 1 vs. 2) repeated-measures ANOVA with hindsight-bias index score as dependent measure revealed a significant main effect of item type only, $F(1,55) = 4.5$, $p = .038$, $\eta_p^2 = .08$. As expected, hindsight bias was larger for experimental items than control items. The expected item type × experimental group × ROJ block interaction fell short of statistical significance, $F(1,55) = 3.3$, $p = .075$, $\eta_p^2 = .06$. Single comparisons revealed, however, that only during free viewing hindsight bias occurred, that is, experimental items differed significantly from control items, $t(1,28) = 2.1$, $p = .044$, $d = 0.4$. No hindsight bias was found in any of the ignore conditions. Younger adults were thus able to ignore CJs to the point that no hindsight bias occurred.

Age differences in hindsight bias. We compared hindsight bias in young and older adults in the FV-IG groups. We performed a 2 (age group) × 2 (item type) × 2 (free viewing vs. ignore) repeated-measures ANOVA with the hindsight-bias index score as dependent measure. Means and standard errors are shown in Figure 7. Results revealed a significant main effect of item type, $F(1,55) = 25.7$, $p < .001$, $\eta_p^2 = .32$, a significant main effect of age group, $F(1,55) = 4.4$, $p = .040$, $\eta_p^2 = .08$, and a significant interaction of age group and item type, $F(1,55) = 7.6$, $p = .008$, $\eta_p^2 = .12$. That is, hindsight bias was larger in older than in younger adults[8]. However, no effect of viewing condition nor interaction with viewing condition emerged, indicating that hindsight bias was not dependent on the CJ viewing instruction.

Multinomial model-based analyses. We intended to perform analyses with the MPT model and therefore tallied frequencies of the 20 rank-order categories of OJ, CJ, and ROJ (10 control, 10 experimental) separately for each participant group. Raw frequencies are reported in Appendix A. As the G^2 statistic is not defined in cases of zero cells, we added a constant of +0.1 to each cell in each group for analyses. We performed MPT analyses with the multiTree program by Moshagen (2010). The model for each group has 10 degrees of

[8] Including years of formal education as a covariate led to non-significant effects of age group and item type. However, the expected age group × item type interaction remained significant, $F(1,53) = 5.1$, $p = .029$, $\eta_p^2 = .09$, indicating that hindsight bias was larger in older than in younger adults.

freedom. To avoid that small deviations from the model would be detected with high power, we determined alpha for the overall goodness-of-fit tests via a compromise power analysis with balanced α and β error risk. With a total of 2240 observations per participant group (28 participants × 80 items), alpha=beta=.06. We thus set alpha to .06 for overall model tests (see, e.g., Bayen et al., 2006, for similar alpha level adjustments). The critical G^2 value to reject the model is 17.71. G^2 exceeded the critical G^2 in all three participant groups, with $G^2_{\text{IG-IG, younger}} = 23.13$, $G^2_{\text{FV-IG, younger}} = 35.13$, and $G^2_{\text{FV-IG, older}} = 23.98$. Effect sizes of the distances between the model-predicted frequencies and observed frequencies were $w = .09$, $w = .12$, and $w = .09$, respectively ($w = .1$ indicates a small effect, Cohen, 1988). Exclusion of two items that did not meet symmetry criteria (cf. Bayen et al., 2006, Exp. 1) did not result in a better model fit. As hypothesis tests regarding parameters can be misleading in that case, we will not report parameter estimates.

2.1.4. Discussion

We examined the role of inhibitory control in adult age differences in hindsight bias. Specifically, we hypothesized that access inhibition as one type of inhibitory control should be easier for younger than for older adults, and that these age differences in access inhibition are related to age differences in hindsight bias. In the hindsight bias memory design, the CJ is task-irrelevant. Therefore, inhibiting access of the CJ should be helpful in producing unbiased ROJs. We operationally defined access as fixations to the CJ during ROJ. We included an access manipulation for both older and younger adults to test its influence on the amount of hindsight bias.

Our manipulation of CJ access was successful. Participants in both age groups looked to the CJ significantly more during free viewing than during ignoring. Between- and within-subjects manipulation of access produced comparable results.

In line with our expectations, older adults fixated more CJs and fixated them longer compared to younger adults. To ensure that our fixation measures were not biased by sensory deficits in older adults, we calculated a relative index of CJ fixation duration. With regard to the instructional manipulation, we discovered two interesting findings. First, when the instruction changed to ignoring the CJ, older adults reduced mean CJ fixation duration as effectively as younger adults. Second, however, older adults did not reduce the number of fixated CJs, when the instruction changed to ignoring. In fact, older adults processed most of the presented CJs in spite of ignore instructions. Both results, more and longer CJ fixations in older than younger adults during free viewing, and older adults being less able to inhibit the processing of the presented CJs, are evidence for an age-related deficit in access inhibition.

As to the question whether control of CJ access has an impact on hindsight bias, the results are mixed. Younger adults showed hindsight bias during free viewing, whereas they did not show hindsight bias with ignore instructions. This was in line with our expectations. In all ignore conditions, younger adults fixated less than half of the presented CJs. Thus, it is not surprising that we observed no hindsight bias in these conditions. It is also important to note that even during free viewing, younger adults' hindsight bias was rather small. The non-significance of the interaction effect for the two younger-adult groups is therefore most probably due to a floor effect.

In replication of Bayen et al. (2006), we found that older adults showed a larger hindsight bias than younger adults. However, older adults' hindsight bias was not dependent on the viewing instructions. This result was not in line with our expectation. Yet, the analyses of CJ fixations suggest an inhibitory deficit, with older adults less able to reduce the number of CJs they looked at. When they were told to ignore the CJ, they still fixated more than half of the presented CJs. It is, therefore, less surprising that they showed still quite an amount of hindsight bias after instructions to ignore the CJs. However, hindsight bias should have been reduced to some degree, compared to free viewing, if the relationship between CJ access and hindsight bias were a strong one.

We believe that increased access of the CJ information to working memory is partly responsible for adult age differences in hindsight bias. Yet, most probably, there are other processes that play a role as well. We hypothesized that age differences in hindsight bias are rooted in an age-related inhibitory deficit. As the hindsight memory paradigm is a retroactive interference paradigm, with the CJ producing interference to the OJ, some sort of distraction control via inhibition should be useful in recalling prior judgments without bias. Inhibitory control in this paradigm is possible by either inhibiting the access of the CJ to working memory or by suppressing its influence at a later stage of information processing, namely after the CJ has gained access to working memory. Thus, it is possible that in our study, in addition to the measured age differences in access control, possible lack of inhibitory suppression on the part of older adults may have also contributed to the observed age differences in hindsight bias. It is important to investigate the role of the suppression function of inhibition in future research on hindsight bias and aging.

Furthermore, difficulties with inhibitory control of CJ access is only one possible explanation for our findings related to CJ access. It is possible that older adults followed a different strategy in completing the hindsight memory task and *chose* to look at the CJ more often and longer. Possible strategic differences between age groups in completing the hindsight memory task are addressed in the following experiment.

2.2. Experiment 2: Intentional Use of the CJ (1)[9]

2.2.1. Overview

In Experiment 2, we investigated the influence of potential age differences in intentional CJ use as a task-execution strategy on age differences in hindsight bias and its underlying processes. Older and younger participants provided estimates to difficult general-knowledge questions during the OJ phase. After a retention interval, they received the same questions from the OJ phase in the ROJ phase. Items were presented as control items without CJ and experimental items with CJ. We sought to reveal participants' CJ use strategies by additionally including *choice items*. For each of these items, the participants decided whether or not they saw the CJ. They did so by deliberately pressing a key combination on the keyboard. We, thus, gave participants complete control over CJ processing for choice items, because we wanted to investigate the variance in hindsight

[9] This chapter is a revised version of the unpublished manuscript „Effects of Task-Execution Strategy on Hindsight Bias" by Julia Groß and Ute J. Bayen, Heinrich-Heine-Universität Düsseldorf.

bias that is due to intentional CJ use, not due to difficulties in inhibiting involuntary CJ processing. Importantly, CJ use for choice items should reflect how the CJs are processed for experimental items.

We further informed participants that they would see all CJs after the memory test to avoid that participants who chose to see many CJs during the ROJ phase did so out of mere curiosity. Thus, we assumed that participants would choose to see the CJs as a strategy to recall or reconstruct their OJ. To our knowledge, the inclusion of choice items is a new procedure that has not been used in previous hindsight-bias studies.

We expected to replicate adult age differences in hindsight bias. Furthermore, we expected older adults to show a higher relative frequency of requested CJs than younger adults, because we assume age differences in intentional CJ use. Most importantly, we expected a positive relationship between hindsight-bias magnitude and CJ-request strategy as measured by the relative frequency of requested CJs. Thus, age differences in intentional CJ use may be responsible for age differences in hindsight bias.

We used both, an overall hindsight bias index as well as the MPT model to investigate hindsight bias in this experiment. We expected task-execution strategy to be related to both recollection and reconstruction processes. Seeking strategic access to the CJ should result in lower recollection as well as higher reconstruction bias, because of competing OJ and CJ information in working memory. Further, we expected hindsight bias both for experimental items (compared to control items) and for requested choice items (compared to non-requested choice items). We had no specific hypothesis as to differences regarding the probability of CJ adoptions, as we expected them to be very low.

2.2.2. Method

Participants. A total of 48 younger and 47 older adults participated. We increased the number of participants, because less items were used to measure hindsight bias, as explained below. Exclusion criteria were a history of heart attack, stroke, brain trauma, emphysema, Parkinson’s disease, drug or alcohol abuse, and depression or other psychiatric or neurological disorder in the past 6 months.

The younger adults were between 19 and 32 years old (*M* = 21.6, *SE* = 0.4). Thirty-eight of them were female. Forty-three of them received course credit for their participation, and five volunteered without compensation. The older adults were between 58 and 82 years old (*M* = 67.4, *SE* = 0.8), were recruited via newspaper advertisements, and received monetary payment. Twenty-nine of them were female. Mean years of formal education were 14.1 (*SE* = 0.2) for younger and 14.0 (*SE* = 0.5) for older adults. All participants were native speakers of German and able to fluently read letters and numbers in 20-point font size on a 19-inch computer screen.

Procedure and design. Between one and four participants took part at a time, and testing was computer-based. Younger and older adults were tested in separate sessions. They were seated in individual computer booths, and the OJ phase began. After typing numerical answers to six practice questions, each participant answered 96 difficult general-knowledge questions which appeared one at a time on the computer screen. All 96 questions are listed in Appendix B. The OJs were self-paced. The order of the questions was randomized by participant.

During a 40-min retention interval, participants completed several unrelated tasks. During the ROJ phase, participants received the same 96 questions in the same randomized order as in the OJ phase. Participants were instructed to recall each of their 96 OJs. For 32 of the questions, they saw the CJ during the ROJ (experimental items); for 32 questions, they did not see the CJ (control items); and for 32 questions, they were given the choice to see or not to see the CJ during ROJ (choice items). Instructions included a suggestion to not be distracted by the CJ, but to recall one's own OJ. To reduce the probability that participants would choose to see the CJ out of mere curiosity (and not for strategic reasons), participants were also informed that all 96 CJs could be accessed at the end of the study.

A combination of the F5 and ENTER keys made the CJ visible. Choice items could be distinguished from other items by the information: "Solution: F5 + ENTER" ["Lösung: F5 + ENTER"]. As soon as participants typed in anything else but this combination, the opportunity to see the CJ ended. Assignment of items to item type was counterbalanced, such that across participants, each item appeared equally often as experimental, control, or choice item.

2.2.3. Results

Out of 9120 possible OJ-ROJ-pairs (95 participants × 96 items), 80 cases (0.9%) were excluded, in which the OJ equaled the CJ. Another 67 cases (0.7%) were excluded, because either the OJ or the ROJ was missing. A total of 8973 OJ-ROJ-pairs were thus available for further analyses.

As in Experiment 1, younger adults recalled on average more OJs (M = 37%, SE = 1.7) than older adults (M = 32%, SE = 1.7), $t(93)$ = 2.1, p = .036, d = 0.4. The mean quality of original judgments, following Equation 3, was 0.82 for younger adults (SE = 0.03) and 0.68 (SE = 0.02) for older adults, $t(93)$ = 3.6, p = .001, d = 0.8. Thus, older adults' OJs were significantly closer to the CJs than younger adults' OJs.

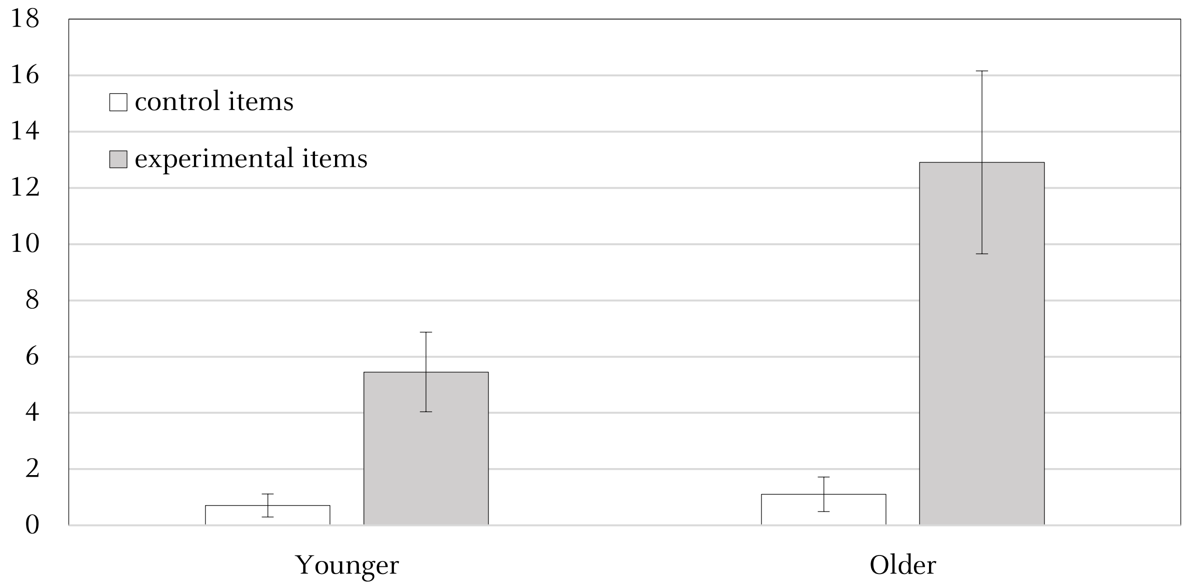

Figure 8. Mean hindsight-bias index scores for the three participant groups. Error bars represent standard errors.

Hindsight bias in younger and older adults. First, we calculated hindsight-bias index scores as proposed by Hell et al. (1988). Means and standard errors are shown in Figure 8. We performed a 2 (age group) × 2 (item type) repeated-measures ANOVA with the hindsight-bias index score as dependent measure. Results revealed a significant main effect of item type, $F(1,93) = 23.1$, $p < .001$, $\eta_p^2 = .20$, a significant main effect of age group, $F(1,93) = 4.4$, $p = .038$, $\eta_p^2 = .05$, and a significant interaction of age group and item type, $F(1,93) = 4.2$, $p = .043$, $\eta_p^2 = .04$. Thus, hindsight bias was larger in older compared to younger adults, as expected.

In the group of younger adults, the comparison of hindsight bias between requested choice items (*M* = 14.9, *SE* = 5.5) and not-requested choice items (*M* = 0.9, *SE* = 4.9) fell short of statistical significance, $t(31) = 2.0$, $p = .059$, $d = 0.4$. In the group of older adults, hindsight bias for requested choice items (*M* = 25.8, *SE* = 9.1) and not-requested choice items (*M* = 14.9, *SE* = 15.9) did not differ, $t(37) = 0.6$, $p = .566$, $d = 0.1$.

For analyses with the MPT model, we tallied frequencies for the 20 rank-order categories (10 for control, 10 for experimental items), separately for older and younger adults. The model has five degrees of freedom for each age group. A compromise power analysis revealed that with a total of 3072 observations (48 participants × 64 items), alpha=beta=.01. The critical G^2 to reject the model is thus 15.09. Results of overall goodness-of-fit tests and parameter tests for both age groups are shown in Table 2.

Model fit was acceptable for both age groups. Model-predicted frequencies and observed frequencies differed with effect sizes of $w = .04$ (younger adults) and $w = .05$ (older adults). The probability of reconstruction bias when the OJ could not be recalled (parameter *b*) was estimated at .31 (*SE* = .04) for younger adults and at .45 (*SE* = .04) for older adults. Younger adults' recollection parameters were estimated at .37 (*SE* = .01) for control items (r_C) and .36 (*SE* = .01) for experimental items (r_E). Model fit did not decrease significantly when r_C and r_E were set equal; thus, there was no indication of recollection bias in younger adults. Older adults' recollection parameters were estimated at .35 (*SE* = .01) for control items (r_C) and .31 (*SE* = .01) for experimental items (r_E). Contrary to younger adults, older adults did show a significant recollection bias. The estimated probability of a CJ adoption was .03 (*SE*

= .01) for younger adults and differed significantly from the estimated probability of a CJ adoption for older adults of .10 (*SE* = .02).

Table 2

Results of Overall Goodness-of-Fit Tests and Parameter Tests for both Age Groups

	G^2		df
Overall model tests			
Younger adults	6.3		5
Older adults	6.5		5
	ΔG^2		Δdf
Tests across age groups			
b constant across groups	6.1	*	1
r_C constant across groups	1.6		1
r_E constant across groups	10.9	*	1
c constant across groups	9.8	*	1
Tests within group: Younger adults			
$b = 0$	38.8	*	4
$r_C = r_E$	0.4		1
$c = 0$	5.7	*	1
Tests within group: Older adults			
$b = 0$	126.9	*	4
$r_C = r_E$	6.7	*	1
$c = 0$	71.7	*	1

Note. G^2 = likelihood ratio goodness-of-fit statistic; r_C and r_E = OJ recollection probabilities for control and experimental items, respectively; b = probability of a biased reconstruction given a failure to recall the OJ; c = probability of a CJ adoption, given a biased reconstruction. * significant with alpha = .05.

We used the 32 choice items to determine a CJ-request score for each participant, defined as the proportion of choice items for which a participant chose to see the CJ. CJ request proportion ranged between 0 and 1, with a mean of .48 (*SE* = .04). As expected, older adults requested significantly more CJs (*M* = .60, *SE* = .05) than younger adults (*M* = .37, *SE* = .06, $t(93) = 2.9$, $p = .005$, $d = 0.6$).

We investigated the relationship between CJ use and hindsight-bias index scores the following way. First, we subtracted control-item index scores from experimental-item index scores to receive a single hindsight-bias measure. Next, we regressed hindsight difference scores on CJ-request score, separately for the age groups. Three younger and 2 older participants were excluded, because their standardized residuals exceeded three times the interquartile range and were thus considered extreme outliers (Tukey, 1977). We found CJ use to be positively correlated with hindsight bias in younger adults ($r = .415$, $p = .006$), but not in older adults ($r = -.221$, $p = .145$).

To investigate the relationship between CJ use and hindsight bias with the MPT model, we split participants in both age groups at the age-group specific median of CJ-request frequency into *CJ users* and *CJ non-users*. We tallied frequencies for the rank-order categories separately for control versus experimental items, older and younger adults, as well as for CJ users versus CJ non-users. As there were zero cells, we added a constant of +0.1 to each cell. Frequencies are listed in Appendix C. Results are shown in Table 3 (younger adults) and Table 4 (older adults).

Effect sizes of the distances between model-predicted frequencies and observed frequencies were $w = .08$ (young CJ users) and $w = .09$ (young CJ non-users), respectively. In line with the positive correlation between hindsight-bias index scores and CJ requests in younger adults, we found reconstruction bias parameter *b* to be significantly greater for young CJ users ($b_{\text{users}} = .41$, *SE* = .06) compared to young CJ non-users ($b_{\text{non-users}} = .20$, *SE* = .07). Interestingly, the probability of a biased reconstruction did not differ significantly from zero in young CJ non-users. The probabilities of a CJ adoption were .04 (*SE* = .02) for CJ users and .004 (*SE* = .02) for CJ non-users.

Table 3

Results of Overall Goodness-of-Fit Tests and Parameter Tests for User Groups Within Younger Adults

	G^2		df
Overall model tests			
CJ users	10.6		5
CJ non-users	13.7		5
	ΔG^2		Δdf
Tests across user groups			
$b_{users} = b_{non\text{-}users}$	5.5	*	1
$r_{E\ users} = r_{E\ non\text{-}users}$	3.2		1
$r_{C\ users} = r_{C\ non\text{-}users}$	3.4		1
$c_{users} = c_{non\text{-}users}$	1.6		1
Tests within user groups: CJ users			
$b = 0$	38.4	*	4
$r_C = r_E$	0.1		1
$c = 0$	7.8	*	1
Tests within user groups: CJ non-users			
$b = 0$	6.9		4
$r_C = r_E$	0.2		1
$c = 0$	0.0		1

Note. G^2 = likelihood ratio goodness-of-fit statistic; r_C and r_E = OJ recollection probabilities for control and experimental items, respectively; b = probability of a biased reconstruction given a failure to recall the OJ; c = probability of a CJ adoption, given a biased reconstruction. * significant with alpha = .05.

Table 4

Results of Overall Goodness-of-Fit Tests and Parameter Tests for User Groups Within Older Adults

	G^2		df
Overall model tests			
CJ users	6.3		5
CJ non-users	5.8		5
	ΔG^2		Δdf
Tests across user groups			
$b_{users} = b_{non\text{-}users}$	0.1		1
$r_{E\ users} = r_{E\ non\text{-}users}$	1.4		1
$r_{C\ users} = r_{C\ non\text{-}users}$	2.2		1
$c_{users} = c_{non\text{-}users}$	7.0	*	1
Tests within user groups: CJ users			
$b = 0$	76.5	*	4
$r_C = r_E$	3.0		1
$c = 0$	47.3	*	1
Tests within user groups: CJ non-users			
$b = 0$	53.2	*	4
$r_C = r_E$	3.8		1
$c = 0$	23.4	*	1

Note. G^2 = likelihood ratio goodness-of-fit statistic; r_C and r_E = OJ recollection probabilities for control and experimental items, respectively; b = probability of a biased reconstruction given a failure to recall the OJ; c = probability of a CJ adoption, given a biased reconstruction. * significant with alpha = .05.

Within the group of older adults, model-predicted frequencies deviated from observed frequencies with effect sizes w = .06 (older CJ users) and w = .06 (older CJ non-users). The probability of a biased reconstruction, parameter *b,* did not differ between CJ users (b_{users} = .43, SE = .05) and CJ non-users ($b_{non\text{-}users}$ = .46, SE = .05). The probability of a CJ adoption was .14 for CJ users (SE = .03) and .06 for CJ non-users (SE = .02). Although present in the whole sample of older adults, no recollection bias was found in either user group.

2.2.4. Discussion

This study investigated intentional CJ use as a potential strategy for generating ROJs in hindsight memory tasks and as a potential variable for explaining age differences in hindsight bias. Only when the CJs are actually processed, hindsight bias can occur. The inclusion of choice items can therefore tell us how participants execute the ROJ task. Moreover, age differences in CJ processing may explain age differences in hindsight bias.

We assumed that participants chose to see the CJ as a strategy to recall or reconstruct their OJ. Furthermore, we assumed that participants who frequently chose to see the CJ for choice items also used the CJ more for experimental items and would thus show stronger hindsight bias, compared to participants who chose to see CJs less often or not at all. Moreover, we expected age differences in CJ use to explain age differences in hindsight bias. Age differences in CJ use are a potential alternative explanation for age differences in CJ access (cf. Exp. 1): Older adults may *choose* to look at the CJ more often than younger adults.

In younger adults, frequency of CJ requests explained 17% of the variance in hindsight bias. Thus, younger participants who requested more CJs for choice items also showed larger hindsight bias on the standard items. Furthermore, the probability of reconstruction bias was approximately twice as high for young CJ users compared to young CJ non-users, indicating that the CJ-request strategy greatly influenced reconstruction processes. In fact, young CJ non-users' reconstruction bias was not different from zero. The effect on recollection, on the other hand, was rather small, and there was no recollection bias in either user group.

Contrary to younger adults, we found no correlation between CJ requests and hindsight bias in older adults. Thus, older participants who requested more CJs for choice items did not show larger hindsight bias on standard items. Reconstruction bias did not differ between older users and non-users.

In both age groups, the probabilities of CJ adoptions were higher in CJ users than in CJ non-users. Thus, CJ use increases the probability of a CJ adoption. However, probabilities of a CJ adoption were very low overall (see also Bayen et al., 2006; Erdfelder & Buchner, 1998). Differences in CJ adoptions thus contributed only little to differences in hindsight bias.

Results support an alternative explanation to age differences in access inhibition: Older adults requested significantly more CJs (60%) than younger adults (37%). Thus, more and longer CJ fixations in older compared to younger adults in Experiment 1 may have been due to a deliberate process instead of inhibitory deficit. However, it remains open whether the results of Experiment 1 can be fully explained by age differences in intentional CJ use: Even when explicitly asked to ignore the CJ (*ignore* condition), older adults showed considerably more and longer fixations than younger adults.

In the present experiment, younger adults' intentional use of the CJ mainly affected reconstruction processes. This is in line with previous studies showing that hindsight bias in the memory design is primarily a result of biased reconstruction (e.g., Bayen et al., 2006; Dehn & Erdfelder, 1998; Erdfelder & Buchner, 1998).

Hindsight bias for choice items (i.e., comparison of index scores for requested vs. not-requested choice items) fell short of statistical significance for younger adults and was not present in older adults. However, per participant, only 32 items were available in total for this comparison (vs. 64 for the standard items), and large variability in the frequency of CJ requests made reliable measurement difficult.

Note that participants were informed that the CJs to all of the questions could be accessed at the end of the study. Thus, number of requested CJs for choice items should reflect a task-execution strategy, and not mere curiosity. However, one could argue that participants who rarely requested the CJ for choice items may just have been motivated to leave the experiment early. If this was the case, these *hurried* participants should have taken less time for the other items as well. A supplementary analysis of the reaction times revealed, however, that CJ users and CJ non-users did not differ significantly in how much time they took in total for ROJs of experimental and control items (Younger adults: $M_{\text{users}} = 6.6$ minutes, $SE = 0.3$; $M_{\text{non-users}} = 6.7$ minutes, $SE = 0.4$, $t(46) = 0.4$, $p = .728$, $d = 0.1$, older adults: M_{users} = 12.0 minutes, SE = 0.7; $M_{\text{non-users}}$ = 12.2 minutes, SE = 0.6, $t(47) = 0.2$, p = .831, d = 0.1). We, therefore, believe that when participants requested to see the CJ for a choice item, it was indeed an expression of a task-execution strategy. Taken together, this study revealed that CJ use as a task-execution strategy may be a key variable in explaining differences in hindsight bias in younger adults, while it may be of less importance in explaining hindsight bias in older adults.

2.3. Experiment 3: Intentional Use of the CJ (2)

2.3.1. Overview

Experiment 3 was designed to further explore CJ use as a task-execution strategy. There were two main goals. The first goal was to replicate the finding that CJ use explains substantial variance of hindsight bias in younger adults. Furthermore, Experiment 2 left open whether CJs were indeed requested as a strategy to recall or reconstruct the OJs, as expected. It was thus our second goal to investigate participants' reasons to follow a CJ-request or a CJ non-request strategy.

2.3.2. Method

Participants. Eighty-one young adults participated in Experiment 3. We increased the number of participants, because we wanted to find a potential effect of CJ use on recollection parameters with adequate power. Power analyses revealed that 120 participants would have been necessary to find the expected effects with a statistical power of .80. For economic reasons, however, we decided on a total of 81 participants.

Participants were between 18 and 31 years old (M = 20.9, SE = 0.4) and 66 of them were female. They received course credit for their participation. All participants were native speakers of German and able to fluently read letters and numbers in 20-point font size on a 19-inch computer screen.

Materials. We used the same 96 difficult general knowledge questions as in Experiment 2. Furthermore, we created a questionnaire that prompted for CJ-request reasons after the experiment. Participants were to indicate whether the specified reasons applied as CJ-request reasons or not on a 5-point scale ranging from 1 ("does not apply at all") to 5 ("does fully apply", consult Appendix D for the complete questionnaire).

Procedure and design. The procedure was identical to that of Experiment 2. Only young adults participated, thus it was a 1 × 3 (itemtype: control, experimental, choice) within-subject design.

2.3.3. Results

Out of 7776 possible OJ-ROJ-pairs (81 participants × 96 items), 57 cases (0.7%) were excluded, in which the OJ equaled the CJ. Another 81 cases (1.0%) were excluded, because either the OJ or the ROJ was missing. A total of 7638 OJ-ROJ-pairs were thus available for further analyses.

Hindsight bias. A dependent-sample *t* test revealed that hindsight bias index scores were higher for experimental items (M = 6.5, SE = 1.7) than control items (M = 0.8, SE = 0.3, $t(80)$ = 3.3, p = .002, d = 0.4), indicating that hindsight bias occurred. Requested choice items (M = 16.4, SE = 3.9) and not-requested choice items (M = 5.0, SE = 7.1) did not differ, $t(52)$ = 1.4, p = .154, d = 0.2.

Results of MPT analyses for the total sample are shown in Table 5. A compromise power analysis revealed, that with a total of 5184 observations (81 participants × 64 items), alpha=beta=.001. The critical G^2 value to reject the model is 20.51. Model fit was acceptable with 15.0 < 20.51. The effect size of the distance between model-predicted frequencies and observed frequencies was w = .05. Reconstruction bias parameter b was estimated at .35 (SE = .03) and differed significantly from zero. Recollection of control items, r_C, was estimated at .36 (SE = .01), recollection of experimental items, r_E, was estimated at .35 (SE = .01). There was no recollection bias. The probability of a CJ adoption was estimated at .03 (SE = .01).

Table 5

Results of Overall Goodness-of-Fit Tests and Parameter Tests for the Total Sample and User Groups

	G^2		df
Overall model tests			
Total sample	15.0		5
CJ users	10.7		5
CJ non-users	6.8		5
	ΔG^2		Δdf
Tests within total sample			
$b = 0$	90.6	*	4
$r_C = r_E$	0.7		1
$c = 0$	13.1	*	1
Tests across user groups			
$b_{\text{users}} = b_{\text{non-users}}$	0.1		1
$r_{E\ \text{users}} = r_{E\ \text{non-users}}$	18.8	*	1
$r_{C\ \text{users}} = r_{C\ \text{non-users}}$	8.5	*	1
$c_{\text{users}} = c_{\text{non-users}}$	1.3		1
Tests within user groups: CJ users			
$b = 0$	54.2	*	4
$r_C = r_E$	1.8		1
$c = 0$	5.8	*	1
Tests within user groups: CJ non-users			
$b = 0$	41.2	*	4
$r_C = r_E$	0.0		1
$c = 0$	7.8	*	1

Note. G^2 = likelihood ratio goodness-of-fit statistic; r_C and r_E = OJ recollection probabilities for control and experimental items, respectively; b = probability of a biased reconstruction given a failure to recall the OJ; c = probability of a CJ adoption, given a biased reconstruction. * significant with alpha = .05.

CJ use and hindsight bias. On average, to 41% (*SE* = 4.2) of the choice items, CJs were requested. We regressed hindsight difference scores on CJ-request score. One participant was excluded because the standardized residual exceeded three times the interquartile range and was thus considered an extreme outlier. We found no correlation between frequency of CJ-requests and hindsight bias (r = -.036, p = .578).

Additionally, we investigated the relationship between CJ use and hindsight bias with help of the MPT model. We split the participants according to the median CJ-request score (*Mdn* = .31) into CJ users and CJ non-users. Raw frequencies are reported in Appendix E. A constant of +0.1 was added to each cell because of zero cells. According to compromise power analyses, with a total of 2560 observations (40 participants × 64 items), alpha=beta=.03. The critical G^2 to reject the model is thus 12.4. Model-predicted frequencies deviated from observed frequencies with effect size w = .05 (CJ non-users) and w = .06 (CJ users). Results of the overall goodness-of-fit tests and parameter tests are shown in Table 5.

Contrary to the results of Experiment 2, the estimates of reconstruction bias parameter b did not significantly differ between CJ users and CJ non-users (b_{users} = .34, *SE* = .04 vs. $b_{\text{non-users}}$ = .36, *SE* = .05). The probability of a recollection of control items, r_C, was estimated at .33 for CJ users (*SE* = .01) and differed significantly from that of CJ non-users, which was estimated at .39 (*SE* = .01). The probability of a recollection of experimental items, r_E, was estimated at .31 for CJ users (*SE* = .01) and also differed significantly from that of CJ non-users, which was estimated at .39 (*SE* = .01). Probabilities of CJ adoptions were low in both users groups (c_{users} = .02, *SE* = .01, vs. $c_{\text{non-users}}$ = .04, *SE* = .01).

Post-experiment questionnaire. Results of the post-experiment questionnaire are shown in Table 6. On average, participants disapproved of item 1 and 3 (i.e., CJs were requested because the solution helps to recall/reconstruct the judgment) and approved of item 2 and 4 (i.e., CJs were requested because the solution impedes recalling/reconstructing the judgment). Correlations indicate that the impression of a negative impact of the CJs on the accuracy of ROJs was a reason to *not* request CJs. However, the impression of a positive impact of the CJs on the accuracy of the ROJs was not a reason to request CJs.

Contrary to the assumptions of an exclusively strategic CJ use, participants in the present experiment highly approved of item 5 (checking accuracy of OJ) and 7 (interest/curiosity).

Table 6

Results of the Post-Experiment Questionnaire

	CJ-request reason	*M* (*SE*)	*ρ* CJ use	
1	Solution helps recalling the judgment	1.96 (0.14)	.146	
2	Solution impedes recalling the judgment	3.76 (0.17)	- .421	*
3	Solution helps reconstructing the judgment	2.04 (0.15)	.149	
4	Solution impedes reconstructing the judgment	3.86 (0.15)	- .299	*
5	Check accuracy of own judgment	3.91 (0.17)	.693	*
6	Requesting solution as desirable behavior	2.25 (0.16)	- .097	
7	Interested in solutions/Curiosity	3.86 (0.18)	.777	*
8	No reason to request solutions, as they can be consulted at the end of the study	2.04 (0.15)	- .245	*

Note. *ρ* CJ use = Spearman's rank correlation coefficient of specified CJ-request reason with CJ-request score. *significant with alpha = .05

2.3.4. Discussion

In Experiment 3 we attempted to further explore the role of CJ use as a task-execution strategy. According to Experiment 2, CJ use differs between older and younger adults, yet does not cause adult age differences in hindsight bias. However, as of its large impact on younger adults' hindsight bias, we thought CJ use to be a promising variable for the explanation of hindsight bias in young adults. We therefore conducted a replication of

Experiment 2 with young adults only. Additionally, we included a post-experiment questionnaire to prompt for CJ-request reasons.

The experiment revealed several interesting findings. First, we could not replicate a relationship between CJ use and hindsight-bias magnitude. Reconstruction bias was equally large for CJ users and CJ non-users. Results are thus contradicting the results of Experiment 2. Second, however, CJ non-users showed a recollection advantage for both, experimental and control items, replicating the descriptive trend of Experiment 2. Third, and contrary to our expectations, participants requested CJs mainly out of curiosity as well as the desire to check if one's OJ was close to the CJ rather than due to strategic reasons. Moreover, participants' knowledge about the biasing effect of the CJ led them to *not* request the CJs. As CJs were, on average, not used as a strategy to recall one's OJ, this indicates that CJ use most probably led to worse OJ recollection in the present experiment, instead of that poor recollection led to strategic CJ use.

Taken together, the results of Experiment 2 suggest that CJ use cannot explain adult age differences in hindsight bias. However, CJ use explained substantial variance in younger adults' hindsight bias. Specifically, CJ use affected both, the probabilities of a reconstruction bias and OJ recollection. Contrary, in Experiment 3 - a replication of Experiment 2 with younger adults only – there was no difference in reconstruction bias between CJ users and CJ non-users, yet a considerable recollection advantage for CJ non-users.

As to the reasons for CJ use, we cannot be sure whether the two samples differed. Different reasons for CJ use may have caused different results. However, participants were introductory psychology students in both experiments, and all of them received the same compensation (i.e., course credit). In our opinion, thus, there is no indication for a systematic difference between the samples. Therefore, the diverging results of Experiments 2 and 3 concerning the relationship between CJ use and hindsight bias in young adults highlight the importance of the replicability of results and thus indicate that more research is needed on this issue.

2.4. Experiment 4: Role of Recall Ability (1)[10]

2.4.1. Overview

It is well established that the average ability to recall information from episodic memory is lower in older than younger adults (e.g., Balota, Dolan, & Duchek, 2000; Verhaeghen et al., 1993). Accordingly, in previous studies on hindsight bias and aging (Bayen et al., 2006, Bernstein et al., 2011, Experiment 1 and 2 of this thesis), younger adults recalled on average more of their OJs than older adults. Their lower recall ability may make older adults more susceptible to hindsight bias than younger adults. Since their OJ-memory trace is weaker, the CJ may have a greater influence (cf. Hell et al., 1988, relative trace strength hypothesis). A weaker OJ memory, relative to the CJ, may thus result in stronger hindsight bias in older adults (see Loftus, 1992, for a similar explanation pertaining to the misinformation effect)

In one approach to investigate the role of recall ability in adult age differences in hindsight bias, we compared hindsight bias between younger and older adults in both the memory design and the hypothetical design of hindsight bias. As the hypothetical design does not include a memory task, recall ability cannot influence judgments. Consequently, if recall ability plays a role for age differences in hindsight bias in the memory design, age differences should be larger in the memory compared to the hypothetical design. If, however, recall ability does not play a role in age differences in hindsight bias, we would expect equal age differences in both hypothetical and memory hindsight bias. To our knowledge, this is the first study to investigate adult age differences in hindsight bias in the hypothetical design.

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[10] The chapters 2.4. and 2.5. are revised versions of the unpublished manuscript „Adult Age Differences in Hindsight Bias: The Role of Recall Ability" by Julia Groß and Ute J. Bayen, Heinrich-Heine-Universität Düsseldorf.

2.4.2. Method

Participants. A total of 45 younger and 45 older adults participated in Experiment 4. Younger adults were between 19 and 31 years old (M = 21.3, SE = 0.3) and received either course credit or monetary payment for their participation. The older adults were between 58 and 81 years old (M = 68.7, SE = 0.8), were recruited via newspaper advertisements, and received monetary payment. Exclusion criteria were the same as in Experiment 2.

Mean years of formal education were 14.1 years (SE = 0.2) for younger and 14.1 years (SE = 0.8) for older adults. All participants were native speakers of German.

Materials. Materials were presented in paper-pencil format (Calibri typeface in 12-point font size). The items were 80 German almanac-type assertions taken from the study by Musch (2003)[11]. Of the 80 items, 40 were false (e.g., “Basel is the largest city in Switzerland.”), and 40 were true (e.g., “Of all animals, ants have the highest ratio of brain-to bodyweight.”). Each assertion was accompanied by a 21-point scale, with the end-points marked as *certainly true* and *certainly false*. Assertions are listed in Appendix F.

Design and procedure. Age was a between-subjects variable, and type of hindsight task (memory vs. hypothetical) a within-subject variable. We created two test versions, using Musch’s (2003) assignment of items to Sets A and B, as these sets showed to be equally difficult in his study. We used Set A (40 items, 20 true) as the memory-item set for half of the participants, and Set B (40 items, 20 true) as their hypothetical item set. For the other half of the participants, the set-task combination was reversed.

Half of the memory items were used as experimental items; that is, the CJ was revealed to the participants before ROJ; the other half was used as control items. The item sets were randomly split into CJ Version 1 and CJ Version 2, each consisting of 10 true and 10 false items. All of the hypothetical items came along with the CJ.

[11] We thank Jennifer Campbell, Lynn Hasher, and Jochen Musch for making their items available.

We created eight different test versions, resulting from crossing item set (A vs. B as memory-item set), CJ version (1 vs. 2), and task order (memory vs. hypothetical first). The eight test versions were approximately counterbalanced across participants. Twenty younger adults received Set A as the memory item set (vs. 22 older adults). Twenty-one younger adults received CJ Version 1 (vs. 22 older adults). Twenty-eight younger adults had memory instructions first (vs. 26 older adults).

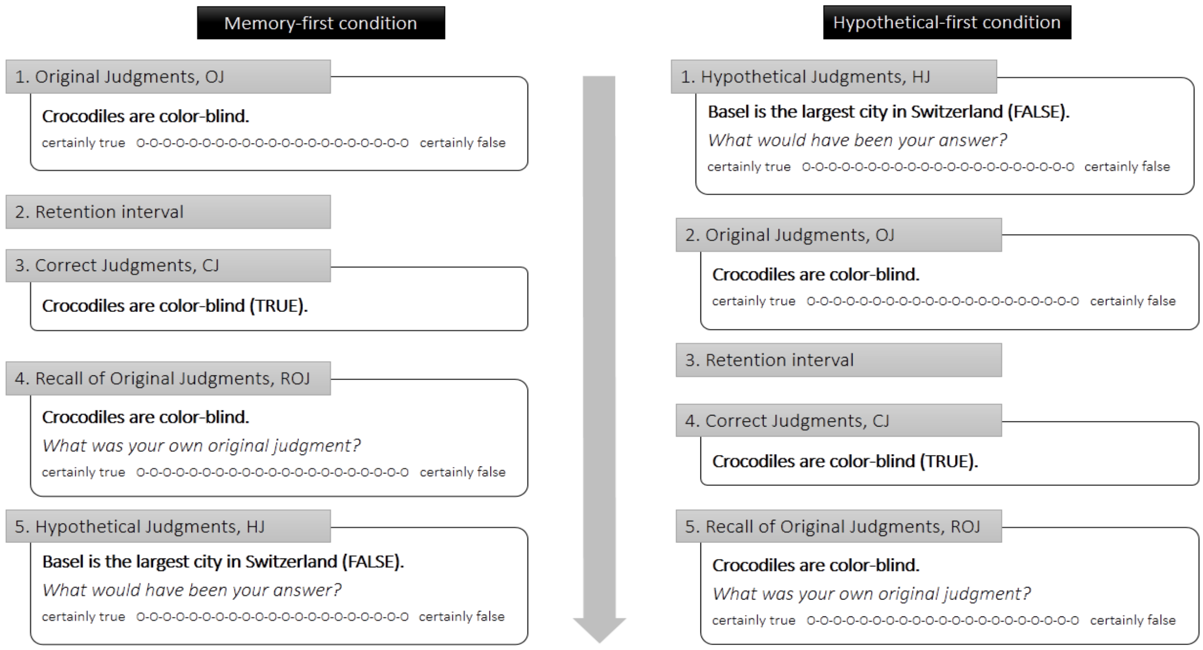

Figure 9. Task-order conditions in Experiment 4, including examples.

Participants were tested in groups of 5 to 19. Within each group, all participants received the same task order. The two task-order conditions, memory-first and hypothetical-first, are illustrated in Figure 9. Two experimenters were present during testing. Each task appeared in a small booklet that was handed out by the experimenters. Instructions appeared both on the cover page of the booklets and on presentation slides. They were simultaneously read out aloud by an experimenter.

Participants were given 15 minutes each for the OJ, ROJ, and HJ parts. During OJ, participants were to indicate their confidence about whether the statement was true or false on the 21-point rating scale (cf. Fig. 9). The retention interval was 25 minutes long, during which participants completed several unrelated questionnaires. Participants had five minutes to memorize the 20 CJs[12]. For the ROJ part, participants were to recall as accurately as possible their own original answers. For the HJ part, statements appeared along with the CJ and participants were to indicate what they *would have said*, had they not seen the answer. Test sessions lasted approximately 75 minutes.

2.4.3. Results

Items were re-coded in one direction (with rating 21 = CJ) to simplify analysis. Older adults knew more CJs (M = 7.8, SE = 0.9) than younger adults (M = 3.2, SE = 0.6, $t(74.4) = 4.3$, $p < .001$, $d = 0.9$), measured as how many assertions were correctly answered during OJ and correctly recalled during ROJ (OJ = CJ = ROJ). Sets A and B were equally difficult ($M_{A,OJ}$ = 12.1, SE = 0.2 and $M_{B,OJ}$ = 11.7, SE = 0.2, $t(88) = 1.4$, $p = .154$, $d = 0.3$).

Correct recollections in the memory task. To measure correct recollections, we related number of correctly recalled items (OJ = ROJ) to the number of to-be-recalled items. We assume that if a participant knows the correct solution, no recall process is initiated. Thus, to-be-recalled items are those that were not known by the participants (i.e., not OJ = ROJ = CJ). Surprisingly, there was no age difference in rate of correct recollections. It was 24.1% (SE = 1.3) for younger adults and 25.2% (SE = 2.2) for older adults, $t(70.7) = 0.4$, $p = .692$, $d = 0.1$.

Memory hindsight bias. For each participant, we calculated the median of the hindsight-bias index proposed by Hell et al. (1988), separately for experimental and control items. Means and standard errors for this measure as a function of age group are shown in Figure 10. A repeated-measures ANOVA with item type (experimental vs. control) as within-subject variable and age group (older vs. younger adults) as between-subjects variable revealed a significant main effect of age group, $F(1,88) = 9.5$, $p = .003$, $\eta_p^2 = .10$, a significant main effect of item type, $F(1,88) = 14.7$, $p < .001$, $\eta_p^2 = .14$, and a significant

[12] We decided to let participant memorize the CJs instead of presenting CJs simultaneously with the ROJ task, as we wanted to make sure the CJs were processed by all of the participants. It is known from informal observations that during paper-pencil tests, some participants cover the CJs with their hands.

interaction between age group and item type, $F(1,88) = 6.9$, $p = .010$, $\eta_p^2 = .07$. Thus, memory hindsight bias was larger for older than for younger adults[13].

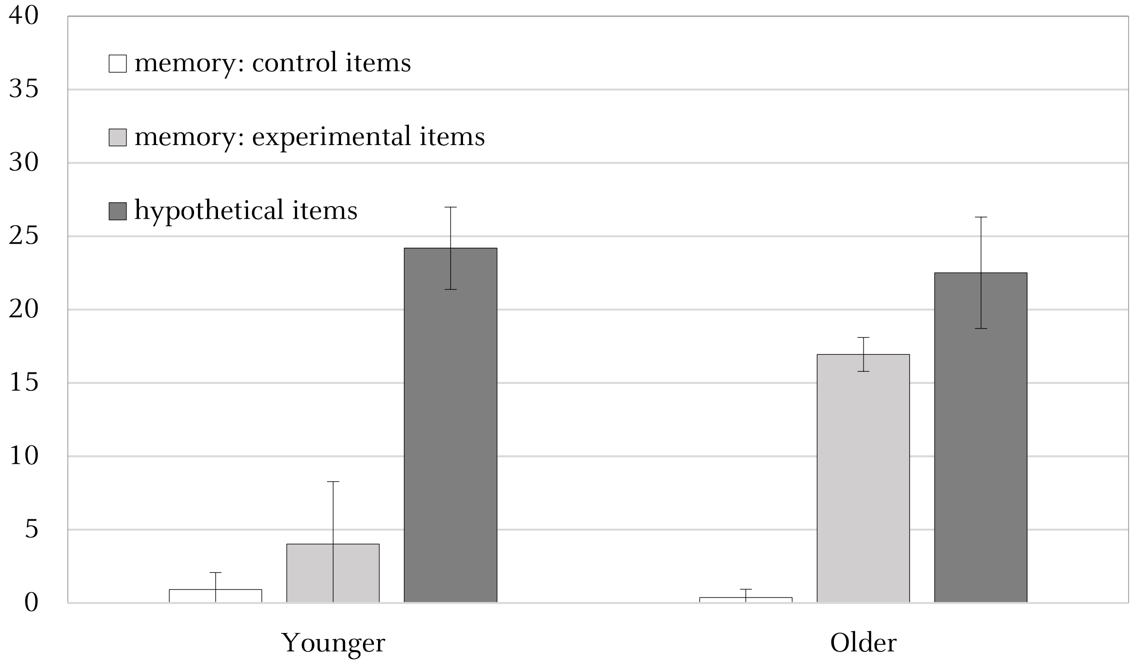

Figure 10. Hindsight-bias index scores as a function of hindsight task instruction and age group. Error bars represent standard errors.

Hypothetical hindsight bias. For the hypothetical index, we used Hell et al.'s (1988) measure as well. As Sets A and B were equally difficult, we used OJs to the memory item set as the within-subject control for the hypothetical hindsight-bias score. We calculated means of HJs (experimental) and OJs (control) for each participant[14], and then applied the hindsight-index equation:

$$\frac{\overline{OJ} - \overline{HJ}}{\overline{OJ} - CJ} \times 100 \quad (4)$$

[13] Data in the present experiment cannot be analyzed with the MPT model of hindsight bias. As the CJs are the end-points of the rating scale, to some rank order categories there are no possible answers.

[14] Contrary to the memory design, an HJ does not have a corresponding OJ. Therefore, to measure hindsight bias, means of all OJs and all HJs were calculated prior to applying the equation.

Means and standard errors of hypothetical hindsight bias as a function of age group are shown in Figure 10. Both younger and older adults showed hypothetical hindsight bias (Young: $t(44) = 8.0$, $p < .001$, $d = 1.2$; older: $t(44) = 6.4$, $p <.001$, d = 0.9). There was no difference between the groups, $t(88) = 0.0$, $p = .725$, $d = 0.1$.

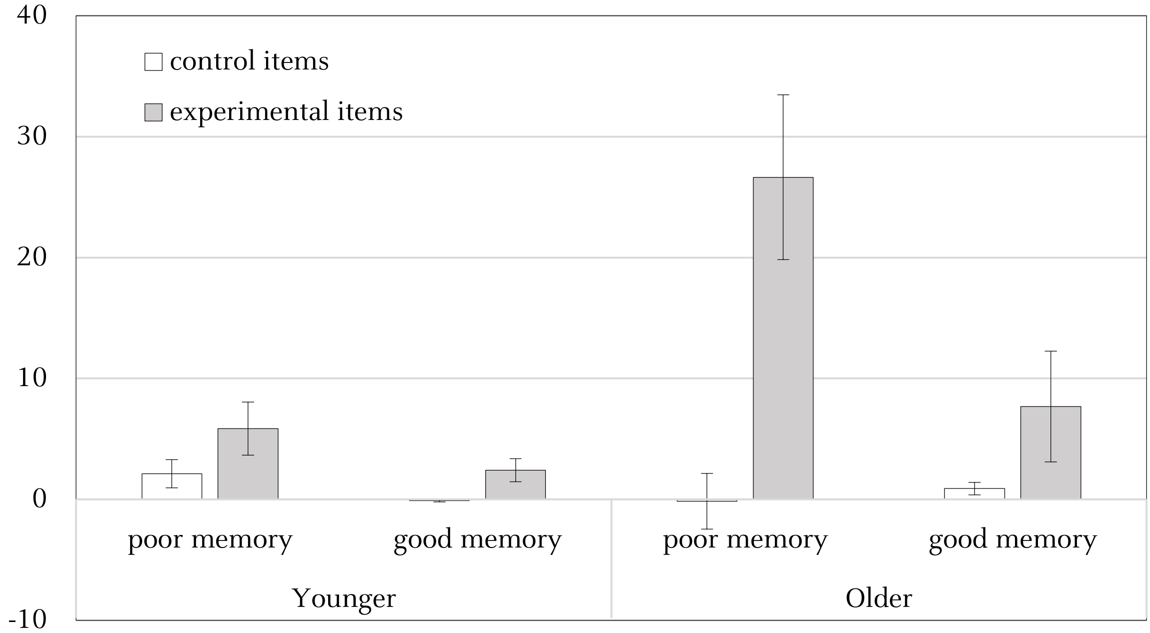

Figure 11. Memory hindsight-bias index scores as a function of item type, age group, and recall group in Experiment 4. Error bars represent standard errors.

Recall ability and memory hindsight bias. We hypothesized that older adults' larger memory hindsight bias is related to their worse OJ recall ability. Although we did not find mean OJ recall differences between the age groups, OJ recall could still be crucial. Additional analyses revealed a negative correlation between OJ recall and memory hindsight bias in the group of older adults, $r = -.342$, $p = .021$. Moreover, older adults showed a larger variance in their recall performance than younger adults ($Var_{older} = 226.1$ vs. $Var_{younger} = 76.5$, $F(1,88) = 8.3$, $p = .005$). Therefore, to further elucidate the relationship between recall ability and memory hindsight bias, we split both age groups according to their median OJ recall score ($Mdn_{older} = 22.5$ vs. $Mdn_{younger} = 25.0$). We conducted a repeated-measures ANOVA with item type (experimental vs. control) as within-subject variable, age group (young vs. older) and recall group (good vs. poor) as between-subjects variables, and memory hindsight-bias score as the dependent variable. Means and standard errors are shown in Figure 11.

We found a significant main effect of age group, $F(1,86) = 10.6$, $p = .002$, $\eta_p^2 = .11$, a significant main effect of item type, $F(1,86) = 16.1$, $p < .001$, $\eta_p^2 = .16$, and a significant main effect of recall group, $F(1,86) = 9.5$, $p = .003$, $\eta_p^2 = .10$. Furthermore, there were significant interactions between item type and age group, $F(1,86) = 7.6$, $p = .007$, $\eta_p^2 = .08$, as well as between item type and recall group $F(1,86) = 4.6$, $p = .035$, $\eta_p^2 = .05$. The three-way interaction between item type, age group, and recall group fell short of statistical significance, $F(1,86) = 3.6$, $p = .061$, $\eta_p^2 = .04$. The results suggest that age differences in memory hindsight bias may only exist for participants poor in recall, whereas they may not for good recall performers. Thus, it seems that in the present experiment, age effects in hindsight bias may have been caused by those older adults who showed poor recall performance.

2.4.4. Discussion

Older adults outperformed younger adults in Experiment 4 with regard to how many answers to the assertions they knew. This is in line with the literature on developmental characteristics of crystallized intelligence (as opposed to fluid intelligence, e.g., Christensen, 2001; Horn & Cattell, 1967; Staudinger, Cornelius, & Baltes, 1989). In prior aging studies on memory hindsight bias, general-knowledge questions requiring exact numerical estimates were used (Bayen et al., 2006; Bernstein et al., 2011). Contrary to the present experiment, age differences in knowledge presumably did not become apparent in prior studies, as correct answers were known only in very rare cases, as intended.

Knowledge differences in the present study in turn may have contributed to the finding that older and younger adults' OJ recall rates were virtually equal, because the high proportion of correct answers by older adults reduced their absolute number of to-be-recalled OJs. Thus, by knowing more answers, older adults had to recall less OJs, and therefore the recall was presumably easier for them.

However, we were able to replicate larger memory hindsight bias for older compared to younger adults. An analysis on the link between age, recall performance, and hindsight bias revealed that age differences in hindsight bias were most likely caused by those older adults who performed poorly on the OJ recall test. The three-way interaction fell short of significance, however, a post-hoc power analysis revealed that approximately twice as many participants would have been necessary to find the effect with sufficient power. Furthermore, variance in OJ recall was larger in older adults, with best-performing older adults exceeding best-performing younger adults in OJ recall (Max_{older} = 66.7% vs. $Max_{younger}$ = 42.5%).

Hypothetical hindsight bias did not differ between age groups. Thus, the memory component of the task seems crucial to bring about adult age differences in hindsight bias.

2.5. Experiment 5: Role of Recall Ability (2)

2.5.1. Overview

In Experiment 5, we investigated the effects of retention on hindsight bias and its underlying processes. Specifically, we used a retention-interval manipulation to lower younger adults' OJ recall performance.

In prior studies, manipulations regarding the relative trace strength of the OJ compared to the CJ resulted in hindsight-bias differences. Larger hindsight bias occurred when the CJ was repeatedly presented (Wood, 1978), when it was presented before OJ recollection instead of immediately after OJ generation (Hell et al., 1988), and when the retention interval was longer (Erdfelder & Buchner, 1998; Nestler et al., 2010). Smaller hindsight bias resulted when participants were confronted with the thoughts made in foresight (Davies, 1987) and when participants had to justify their OJs (Hell et al., 1988).

A longer retention interval should thus lead to poorer OJ recall. If recall ability is crucial for adult age differences in hindsight bias, a longer retention interval should lead to larger hindsight bias, compared to a short retention interval. In the present experiment, we compared younger adults with a long retention interval to both older and younger adults with a short retention interval. If age differences in OJ recall are essential for age differences in hindsight bias, then younger adults with a long retention interval who show poorer OJ recall should have stronger hindsight bias than younger adults with a short retention interval and thus better OJ recall.

By applying multinomial modeling, effects of retention on recollection and reconstruction processes can be disentangled. Specifically, we expected recollection parameters, r_C and r_E, to be smaller with a) long retention (e.g., Hell et al., 1988) and b) in older adults (cf. Bayen et al., 2006; Bernstein et al., 2011), compared to young adults with a short retention interval. Most importantly, we expected reconstruction bias parameter *b* to be larger for older adults and young adults with a long retention interval, compared to young adults with a short retention interval.

2.5.2. Method

Participants. A total of 87 younger and 41 older adults participated in Experiment 5. Exclusion criteria were the same as in Experiment 2 and 4. The younger adults were between 18 and 30 years old (M = 20.6, SE = 0.3) and received either course credit or monetary payment for their participation. The older adults were between 60 and 82 years old (M = 71.6, SE = 0.9), were recruited via newspaper advertisements, and received monetary payment.

Mean years of formal education were higher for younger adults (M = 13.2, SE = 0.2) than older adults (M = 12.2, SE = 0.4, $t(49.6)$ = 2.8, p = .005, d = 0.5). However, older adults had higher MWT-B vocabulary (Lehrl, 1999) scores (M = 32.5, SE = 0.3) than younger adults (M = 27.8, SE = 0.4, $t(121.8)$ = 10.0, p < .001, d = 1.7). There was no difference in the quality of original judgments, following equation 3, between younger adults (M = 0.76, SE = 0.2) and older adults (M = 0.74, SE = 0.4, $t(126)$ = 0.5, p = .640, d = 0.1). All participants were native speakers of German.

Design and procedure. Younger adults were randomly assigned to either a long-retention-interval (RI) group (N = 46) or a short-RI group (N = 41). Older adults received a short RI (N

= 41). Group (young-short, young-long, older-long) was thus a between-subjects variable. Item type (experimental vs. control) was a within-subject variable.

The procedure for the three groups is shown in Table 7. Between one and five participants took part at a time, with all participants tested simultaneously being in the same group. Testing was computer-based.

Table 7

Task Order for the Three Participant Groups

Participant group		Time 1		Time 2 (46h later)
Older adults	(short RI)	OJ	ROJ	-
Younger adults	(short RI)	OJ	ROJ	filler task
Younger adults	(long RI)	OJ	filler task	ROJ

Note. RI = retention interval; OJ = original judgment; ROJ = recall of original judgment.

First, participants were made familiar with the keyboard via six semi-difficult practice questions. All of the participants then answered the 96 difficult general-knowledge questions used in Experiments 2 and 3 one at a time at their own pace (OJ). Order of items was randomized by participants.

After the OJ phase, the long-RI group completed two short unrelated filler tasks on spatial imagination and was then sent home. Both groups with a short RI (younger-short, older-short) instead completed a demographics-and-health questionnaire and several other paper-pencil tasks (e.g., a riddle on German proverbs) for a total of 20 minutes (short RI). Afterwards, they had to recall all of their 96 OJs (ROJ part) one at a time in the same randomized order. Half of the items were previously randomly assigned to appear as experimental items (with the CJ in sight during recall); the other half were control items (with no CJ provided). After the ROJ phase, both short-RI groups were sent home.

Exactly 46 hours later, both younger-adult groups (short-RI, long-RI) came back for the second part of the experiment. The long-RI group now completed the paper-pencil tasks for a total of 20 minutes, followed by the ROJ part. The short-RI group completed the two filler tasks on spatial imagination. We required the short-RI younger-adult group to come back for a second testing session, because we did not want the young-adult groups to differ in terms of motivation and compensation.

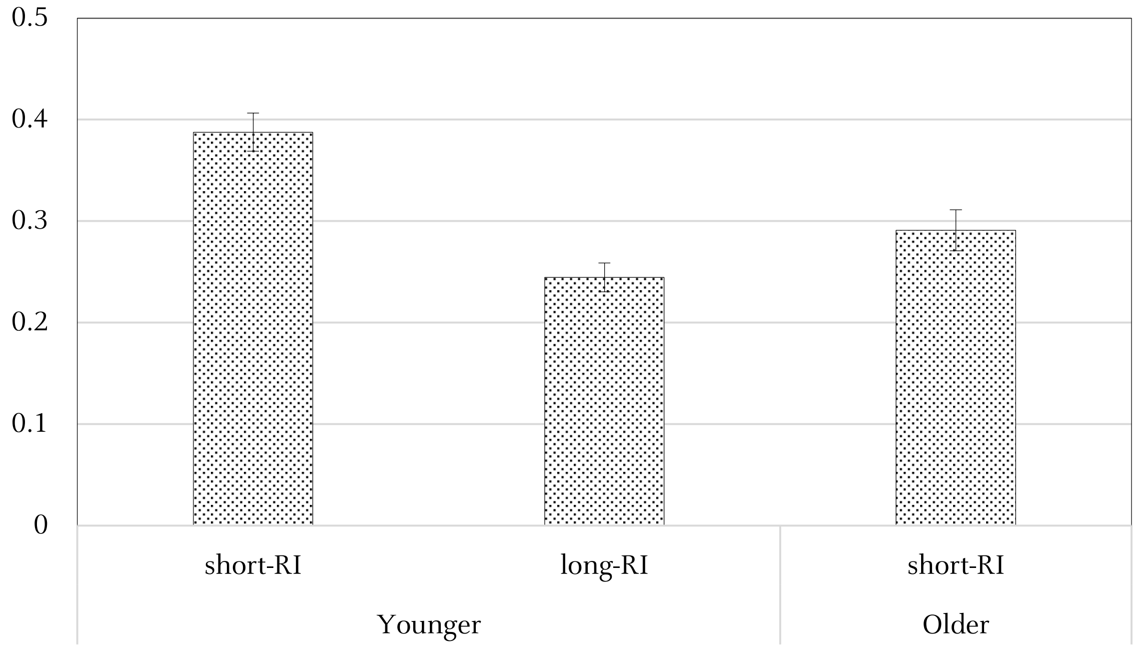

Figure 12. Mean OJ recall as a function of participant group. RI = retention interval. Error bars indicate standard errors.

2.5.3. Results

A total of 128 participants and 96 items resulted in 12,288 OJ-ROJ pairs. In 93 cases (0.76%), the OJ equaled the CJ. Older adults hit the CJ in 33 cases, compared to 60 cases for younger adults. We excluded these rare cases from analyses. In eight cases, the ROJ was missing (0.07%), leaving 12,187 observations for analyses.

Manipulation check. An ANOVA on mean OJ recall rates showed an effect of group, $F(2,125) = 17.1$, $p < .001$, $\eta_p^2 = .22$. Means and standard errors are shown in Figure 12. Post-hoc comparisons revealed a significant difference between younger and older adults with a short RI, $t(80) = 3.5$, $p = .001$, $d = 0.8$. Furthermore, the young-short and young-long groups differed significantly, $t(85) = 6.2$, $p < .001$, $d = 1.3$, indicating that the RI-manipulation had the intended effect. The young-long and old-short groups did not differ, $t(73.7) = 1.9$, $p = .065$, $d = 0.4$.

Hindsight bias. As in the previous experiments, we calculated median hindsight-bias index scores separately for experimental and control items, to receive an overall measure of hindsight bias. Mean index scores and standard errors are shown in Figure 13.

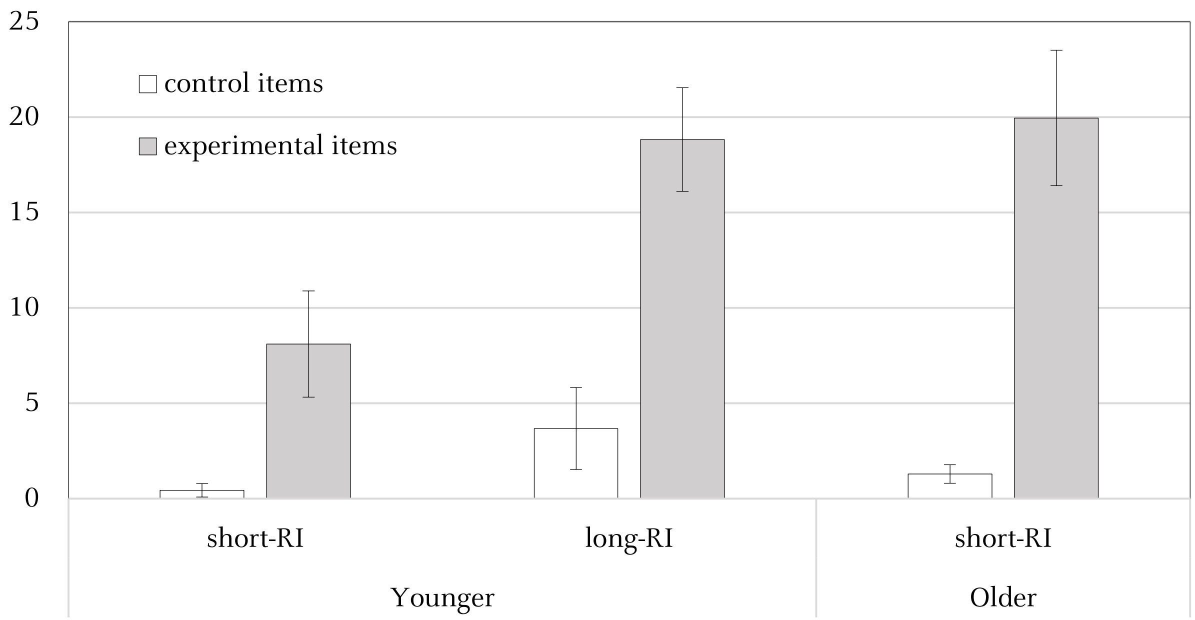

Figure 13. Hindsight-bias index scores as a function of item type and participant group. RI = retention interval. Error bars represent standard errors.

A repeated-measures ANOVA with item type as within-subject variable and group as between-subjects variable revealed a significant main effect of item type, $F(1,125) = 76.2$, $p < .001$, $\eta_p^2 = .38$, a significant main effect of group, $F(2,125) = 4.0$, $p = .020$, $\eta_p^2 = .06$, and a significant interaction between item type and group, $F(2,125) = 4.0$, $p = .020$, $\eta_p^2 = .06$.

To receive a single hindsight-bias measure, we subtracted hindsight-bias index scores of control items from those for experimental items. Hindsight bias was larger for short-RI older adults compared to short-RI younger adults, $t(74.4) = 2.6$, $p = .010$, $d = 0.6$, thus replicating stronger hindsight bias in older compared to younger adults. Hindsight bias was also larger for long-RI younger compared to short-RI younger adults, $t(85) = 2.2$, $p = .032$, $d = 0.5$, indicating an effect of retention on hindsight bias. The young-long and old-short groups did not differ, $t(73.3) = 0.9$, $p = .392$, $d = 0.2$.

Multinomial model-based analyses. For analyses with the MPT model, we tallied frequencies of the 20 rank-order categories (10 control, 10 experimental) separately for each participant group. Raw frequencies are reported in Appendix G. According to compromise power analyses, with a total of 4416 observations per group (46 participants × 96 items), alpha=beta=.002. The critical G^2 is thus 18.90. Model fits were acceptable with $G^2 = 5.9$ (short-RI, young), $G^2 = 7.1$ (long-RI, young), and $G^2 = 8.4$ (short-RI, older), respectively. Model-predicted frequencies deviated from observed frequencies with effect sizes of $w = .04$ (short-RI, young), $w = .04$ (long-RI, young), and $w = .05$ (short-RI, older), respectively.

Overall goodness-of-fit tests as well as parameter tests are shown in Table 8. Each participant group showed reliable reconstruction bias (parameter b). Estimates of reconstruction bias for the three participant groups are shown in Figure 14. Reconstruction bias was larger in short-RI older adults than in short-RI younger adults ($p = .020$), replicating earlier findings on age differences in reconstruction bias (Bayen et al., 2006). Parameter b did not differ between short-RI older adults and long-RI younger adults ($p = .492$). Descriptively, short-RI younger adults had a lower probability of reconstruction bias than long-RI younger adults; however, the difference fell short of statistical significance ($p = .080$).

Table 8

Results of Overall Goodness-of-Fit Tests and Parameter Tests for the Participant Groups

	G^2		df
Overall model tests			
Older adults, short RI	8.4		5
Younger adults, short RI	5.9		5
Younger adults, long RI	7.1		5
	ΔG^2		Δdf
Tests across age groups: effects of aging (younger, short-RI; older, short-RI)			
b constant across groups	5.4	*	1
r_C constant across groups	43.9	*	1
r_E constant across groups	35.5	*	1
c constant across groups	7.6	*	1
Tests across age groups: similar recollection (younger, long-RI; older, short-RI)			
b constant across groups	0.5		1
r_C constant across groups	16.7	*	1
r_E constant across groups	8.3	*	1
c constant across groups	2.9		1
Tests across conditions: effects of retention (younger, short-RI; younger, long-RI)			
b constant across groups	3.1		1
r_C constant across groups	118.2	*	1
r_E constant across groups	80.8	*	1
c constant across groups	17.4	*	1
Tests within group: Older adults, short-RI			
$b = 0$	131.6	*	4
$r_C = r_E$	8.8	*	1
$c = 0$	17.0	*	1

Table 8 (continued)

Results of Overall Goodness-of-Fit Tests and Parameter Tests for the Participant Groups

Tests within group: Younger adults, short-RI			
$b = 0$	79.2	*	4
$r_C = r_E$	13.5	*	1
$c = 0$	30.4	*	1
Tests within group: Younger adults, long-RI			
$b = 0$	117.4	*	4
$r_C = r_E$	3.4		1
$c = 0$	2.9	*	1

Note. RI = retention interval; G^2 = likelihood ratio goodness-of-fit statistic; r_C and r_E = OJ recollection probabilities for control and experimental items, respectively; *b* = probability of a biased reconstruction given a failure to recall the OJ; *c* = probability of a CJ adoption, given a biased reconstruction. * significant with alpha = .05.

Recollection estimates are shown in Figure 14. Both short-RI older and younger adults showed reliable recollection bias, $r_E < r_C$ ($p = .003$, and $p < .001$, respectively), whereas the comparison fell short of statistical significance for long-RI younger adults ($p = .064$). Recollection bias was equally large in all groups, as there were no interactions (*p*s > .475 for single comparisons).[15]

As expected, probabilities of CJ adoptions were generally low. Short-RI younger adults' probability was highest (.067), and differed significantly from both, short-RI older adults (.025, $p = .006$) and long-RI younger adults (.010, $p < .001$).

[15] We thank Morten Moshagen for his help with modeling interactions with the MPT model.

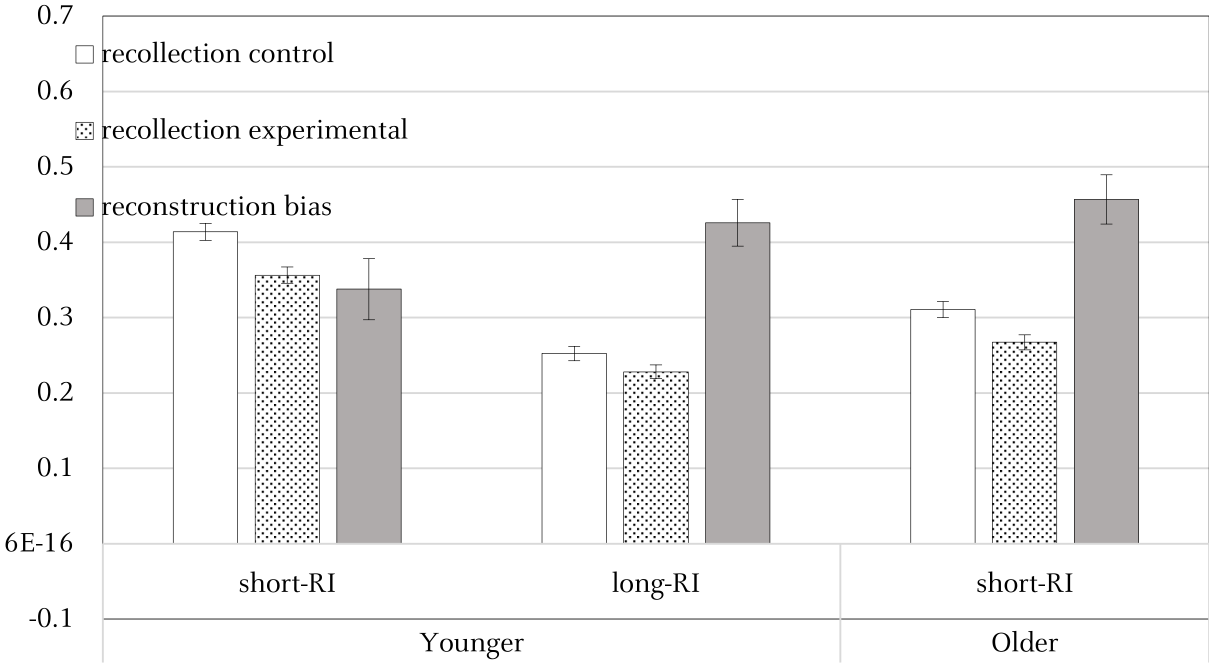

Figure 14. Probability of recollection of the OJ and of reconstruction bias as a function of participant group. Error bars represent standard errors.

2.5.4. Discussion

In Experiment 5, we manipulated the retention interval between OJ and ROJ in order to investigate the influence on age differences in hindsight bias. We compared younger adults with a 46-hour retention interval to both younger and older adults with a 20-minute retention interval. Traditional and MPT model analyses were consistent in their essential findings. The results indicate an effect of retention and thus OJ recall ability on hindsight bias. Recall rates in older adults with short RI and younger adults with long RI were similar, and hindsight bias did not differ between these groups. Thus, recall ability is a key variable in explaining adult age differences in hindsight bias. However, it may not be the only contributing factor, as long-RI younger adults recalled even fewer OJs (24%) than older adults (29%), but did not show stronger hindsight bias than older adults.

Retention affected both recollection and reconstruction. That is, when younger adults' recollection parameters were lowered via long retention, reconstruction bias was stronger.

This is in line with previous ideas (Hell et al., 1988; Loftus, 1992) that the weaker the original memory, the more susceptible one is to interference from new information.

A similar idea was expressed by Brainerd and Reyna in their *fuzzy-trace* framework (2002; see also Reyna & Mills, 2007). They proposed that multiple representations are encoded and stored in parallel, and that those representations differ in their degree of precision: *verbatim* representations are specific and surface-based, while *gist* representations are rather vague and meaning-based. Unless the task demands otherwise, participants will have a fuzzy-processing preference, that is, they will use the gist representation to support their judgments and choices. As the ability to encode a precise verbatim representation decreases with increasing age, reconstructive processes increase to compensate for a decline in verbatim recall (see Brainerd & Reyna, 2004, for empirical evidence). The results of Experiment 5 are thus in line with this framework: In older adults as well as in young adults with a long retention interval, we found both, decreased recall ability and increased reconstruction bias.

Pohl (2007) addresses the issue of recall ability from a methodological point of view. Especially when using a composite measure of hindsight bias (e.g., the relative hindsight-bias index; Hell et al., 1988), the degree of hindsight bias is heavily influenced by the amount of correct recollections (or more precisely: cases of OJ = ROJ), as these cases translate into zero bias. Thus, a difference in overall hindsight bias could result from differences in overall recall ability alone.

The present results showed that a poorer overall recall ability facilitates biased reconstructions. Recall ability did not influence recollection bias, as it was found to be equally large in all participant groups.

The long retention interval led to poorer recall in younger compared to short-RI older adults. However, hindsight bias was the same in both groups. Therefore, recall ability is a key variable in explaining adult age differences in hindsight bias, however, it may not be the only one. There thus appears to be more than one cause for adult age differences in hindsight bias.

2.6. General Discussion

2.6.1. Overview of the Results

The present thesis was concerned with adult age differences in hindsight bias. It revealed once more that hindsight bias is a robust and easy-to-replicate phenomenon. In all five experiments hindsight bias was demonstrated. Moreover, four experiments compared hindsight bias between younger and older adults, and in these four experiments older adults showed reliably larger memory hindsight bias than younger adults. Thus, results of Bayen et al. (2006) and Bernstein et al. (2011) were replicated.

Experiment 1 was designed to investigate the role of age differences in access inhibition for age differences in hindsight bias. Eye movements, namely fixations, to the task-irrelevant CJ were measured and used as an indicator for CJ access. Additionally, CJ access was manipulated via task instructions. Results revealed that older adults had trouble inhibiting CJ access. Even with explicit ignore instructions, older adults fixated on average more than half of the presented CJs. Accordingly, their hindsight bias was still large and not different from hindsight bias in a conventional free-viewing condition. Younger adults, in contrast, were more effective in inhibiting CJ access, both with conventional instructions and even more with instructions to ignore the CJ. In fact, younger adults did not show hindsight bias under ignore instructions. Yet, the effect of viewing instructions on hindsight bias was not statistically significant. Taken together, there is evidence that older adults are less effective in their access inhibition than younger adults and that CJ access plays a role for age differences in hindsight bias. This role, however, is not a prominent one. Furthermore, it is possible that differences in CJ access were masked by differences in inhibitory suppression, or are the result of differences in intentional CJ processing.

In Experiment 2 we therefore investigated the role of intentional CJ processing as a task-execution strategy for age differences in hindsight bias. In addition to experimental and control items, participants were given the choice to look at the CJ for choice items. As expected, older adults requested CJs more frequently than younger adults. The proportion of requested CJs was taken as an indicator of CJ processing for experimental items. As a consequence, we expected a positive relationship between CJ use and the degree of hindsight bias. In the group of younger adults, CJ use explained 17% of the variance in hindsight bias. Young CJ users showed a probability of a reconstruction bias amounting to that of older adults, whereas young CJ non-users' probability of a reconstruction bias was statistically not different from zero. However, older adults' CJ use was unrelated to their hindsight bias magnitude, indicating that CJ use explains hindsight bias in younger, but not in older adults.

Experiment 3 was designed to further elucidate the role of intentional CJ use as a task-execution strategy for hindsight bias in young adults. According to Experiment 2, CJ use presumably does not cause adult age differences in hindsight bias. Yet, we thought it to be a fairly interesting variable due to its large impact on hindsight bias in the group of young adults. We therefore ran a replication of Experiment 2 with young adults only. We furthermore added a post-experiment questionnaire to prompt for CJ-request reasons. Unfortunately, results of Experiment 2 were not replicated: CJ use was unrelated to hindsight bias. Moreover, reconstruction bias was equally large for CJ users and CJ non-users. Moreover, and contrary to our expectations, CJs were mainly used out of curiosity as well as to check the accuracy of one's OJs. Thus, CJs were generally not requested as a strategy to recall or reconstruct one's judgment. However, CJ non-users showed a recollection advantage for both, experimental and control items. In combination with the finding that CJs were, on average, not used as a strategy to recall one's OJ, this indicates that CJ use leads to worse OJ recollection instead of vice-versa.

Experiment 4 was the first to investigate hypothetical hindsight bias in older adults. As there is no recall task-component in the hypothetical design, recall ability cannot influence hindsight bias. In line with our expectations we found no age difference in the hypothetical design. This points to a key role of the recall task-component for age differences in hindsight bias. However, we found no age differences in actual recall in the memory design, yet age differences in memory hindsight bias. Further analyses clarified that those older adults with poor OJ recall were most likely responsible for larger memory hindsight bias in older compared to younger adults.

Experiment 5 followed a different approach towards the investigation of recall performance and its impact on hindsight bias. Older adults with a short retention interval (20 minutes) were compared to both, younger adults with a short retention interval (20 minutes) and younger adults with a long retention interval (46 hours). As expected, the long retention interval for young adults led to poorer OJ recall. Mean OJ recall was virtually equal to that of older adults. As presumed, the probability of a biased reconstruction was virtually equal as well, indicating that a lower overall recall ability in older adults most probably increases the biasing effect of the CJ.

2.6.2. Methodological Aspects

General issues in cognitive aging research. We excluded those from participation with medical or mental health problems that are associated with cognitive limitations (e.g., heart attack, stroke, brain trauma, or current depression). The probability of a suchlike problem increases with increasing age. Thus, without the applied exclusion criteria, age differences could be inflated by health differences due to confounding. Consequently, we can be sure that in the present experiments, age differences are unaffected by health issues. Presumably, however, our older participants were therefore also a highly selective sample (i.e., healthier than their average peers), and results may therefore lack external validity (see, e.g., Poon, Krauss, & Bowles, 1984, for a discussion on subject selection in cognitive aging studies).

Just like in the published studies on age differences in hindsight bias (e.g., Bayen et al., 2006; Bernstein et al., 2004; Bernstein et al., 2011), we chose a cross-sectional approach towards the investigation of adult age differences. Thus, we cannot draw inferences about the true development or true change of hindsight bias across adulthood. Furthermore, differences between age groups may as well be due to cohort differences. Subsequent research should therefore consider whether true changes in the degree of hindsight bias can be observed in longitudinal designs, and whether age differences (observed in cross-sectional designs) and age changes (observed in longitudinal designs) differ in their magnitude.

Another important issue and potential confounder in cognitive aging research is education. Young and older adults must not differ with regard to their education in order to draw meaningful conclusions about the exclusive effect of age on cognition. In Germany, the older adults from the post-war generation had fewer educational opportunities than young adults have nowadays. Therefore, young adults typically have received more years of formal education than older adults (Experiment 1 and 5, but see Experiment 2 and 4), however, this may not be indicative of the actual level of education. In the present thesis we therefore additionally calculated a more adequate measure of general education, namely the quality of the OJs in the hindsight task. We argued that this measure is a more valid index of the participants' current education. Older adults' OJs in Experiment 2 were closer to the CJs compared to young adults' and of equal quality in Experiment 1 and 5. Importantly, age differences in hindsight bias were found in all of the experiments. We can therefore be sure that differences in education were not responsible for the observed age differences in hindsight bias.

Testing took up to 1 hour and 45 minutes per session. We cannot rule out that older adults were more fatigued by the long sessions than young adults. However, we attempted to rule out confounding effects of time of day by testing participants at their age-group specific peak time. Following May, Hasher, & Stoltzfus (1993), older participants perform best in the morning, thus sessions were scheduled only between eight and 12 o'clock for all of the experiments with age-group comparisons (Experiments 1, 2, 4, and 5). Young adults were tested mainly in the afternoon. However, exceptions were made in Experiment 1 (due to single testing and thus economic reasons) and Experiment 5 (due to narrow time windows for the 46h-interval).

External validity. Hindsight bias has been shown in numerous domains and with a variety of different material (see Hawkins & Hastie, 1990, and Pohl, 2007, for overviews). Findings on adult age differences in hindsight bias, however, have so far been restricted to difficult general knowledge questions (Bayen et al., 2006; Bernstein et al., 2011; Exp. 1, 2, and 5), assertion-type questions (Exp. 4), and visual material (Bernstein et al., 2011). Further research should therefore attempt to generalize findings to other domains and material. Furthermore, age differences in hindsight bias could be investigated in more naturalistic settings to evidence their ecological validity.

2.6.3. Conclusions and Outlook

The results of Experiment 1 of the present thesis support an inhibitory deficit view of aging (Hasher & Zacks, 1988; see also Hasher et al., 1999): Inhibiting access of the CJ to working memory was more difficult for older than for younger adults. However, according to inhibitory deficit theory, the access function of inhibition is only one inhibitory function. Once the CJ has gained access to working memory, it needs to be suppressed in order to avoid biased ROJs. Thus, age differences in the ability to suppress the CJ may have masked effects of CJ access in Experiment 1. Further research should therefore focus as well on the impact of suppression. Since technological improvements allow visual displays to change contingently with the viewer's eye position (called gaze-contingent displays, GCD), information intake (i.e., access) can be controlled and held constant. Therefore, conclusions about the suppression function of inhibition can be drawn from experiments in which access of information is the same for older and younger adults.

An alternative explanation for higher CJ access in older than in younger adults are differences in intentional CJ use. It is possible that older adults choose to look at the CJ more often, instead of being obliged to do so because of an inhibitory deficit. However, in Experiment 1 age differences in CJ access were also present with explicit ignore instructions. We further assume that our participants were compliant with instructions, and therefore believe that this alternative explanation is rather unlikely. To conclude, there is an effect of age differences in CJ access on age differences in hindsight bias in; its size, however, is small.

The results of Experiment 2 and 3 are somewhat puzzling. Whereas there was a considerably large effect of CJ use on younger adults' reconstruction bias in Experiment 2 (while effects on recollection fell short of statistical significance), there was a considerably large effect on recollection in Experiment 3 (while there was no effect on reconstruction bias). One possibility for the contradicting findings is that there were differences in motivation to request CJs between the sampled participants. We would not expect CJ use to influence reconstruction if it occurred mainly due to curiosity and the desire to check one's OJs, as successful inhibitory processes may prevent an influence of CJ on ROJs. However, we *would* expect CJ use to influence reconstruction, if it occurred mainly due to strategic reasons, that is, to recall or reconstruct one's OJ.

There is no indication, however, that the samples differed in their reasons for CJ use. Both samples were introductory psychology students who received course credit for their participation. It thus remains open up to this point, whether CJ use is an important variable for the explanation of hindsight bias. There seems to be, however, an effect of CJ use on recollection. This effect fell short of statistical significance in the smaller sample of Experiment 2; it was significant, however, with the larger sample of Experiment 3. Thus, there may have been a power issue in Experiment 2.

In various other cognitive tasks, older and younger adults follow different strategies (e.g., Dunlosky & Hertzog, 2001; Geary et al., 1993; Lemaire et al., 2004). Thus, we assumed that CJ use as a strategy that has received little attention so far could be important both for hindsight bias and age differences therein. While younger and older adults indeed follow a different strategy, these differences do not affect age differences in hindsight bias. To conclude, further research on the issue of CJ use is needed. However, age differences in CJ use can be ruled out as an explanation for age differences in hindsight bias.

Experiment 4 was the first to investigate hindsight bias in older adults with a hypothetical design. When there is no instruction to recall an earlier given judgment, age differences in hindsight bias disappear. Thus, recall instructions seem to be crucial to bring adult age differences about.

Results of Experiment 5 support results of Experiment 4. The poorer OJ memory of older adults makes them more susceptible to hindsight bias. Results are thus in line with the idea of *relative trace strength* (Hell et al., 1988): The weaker the OJ memory trace (compared to the CJ), the larger the impact of the CJ. Loftus (1992) stated that participants are "particularly prone to having their memories modified when the passage of time allows the original memory to fade" (p. 121). As older adults' original memories fade with a more rapid pace, they are more susceptible to the influence of the CJ.

Results on age differences in recall ability should always be considered in the light of possible effects of stereotype threat (Steele & Aronson, 1995). Stereotype threat refers to the finding that individuals of a stereotyped group perform more poorly on a task, when the stereotype is salient during the task. Anxiety that one will confirm a negative stereotype will have disruptive effects on task performance (Steele & Aronson, 1995). That is, older adults may show worse recall performance when negative age-related stereotype content is activated (e.g., memory loss, forgetfulness, fading skills). In a study by Rahhal, Hasher, and Colcombe (2001), adult age differences in recall of newly learned information were only present, when instructions emphasized the memory task-component, compared to a memory-neutral instruction. Thus, older adults in Experiment 5 may have been worse in their OJ recall compared to younger adults with a short retention interval, because the standard hindsight bias recall instruction activated negative age-related stereotypes. The same logic can be applied to recall differences in Experiment 1 and 2. Further research on age differences in hindsight bias could therefore attempt to use implicit instead of explicit hindsight bias measures and hence estimate the impact of negative aging stereotypes on recall differences in hindsight bias and aging studies. Furthermore, one could implicitly prime positive stereotype content before ROJ. Such a priming procedure may effectively reduce age differences in recall (cf. Hess, Hinson, & Statham, 2004; Levy, 1996), and thus also age differences in hindsight bias.

Possibly, the experience of participating in a laboratory experiment at the young-adult populated university may suffice to induce negative aging stereotypes. Research on age differences in prospective memory performance has shown that there is an age-related detriment in laboratory studies (e.g., Zimmermann & Meier, 2006), but an age-related benefit in naturalistic studies (e.g., Henry, MacLeod, Phillips, & Crawford, 2004). This paradoxical finding may partly be due to differential activation of age-related stereotype content. Thus, further research should investigate whether age differences in hindsight bias still exist in more naturalistic settings.

Irrespective of whether age differences in recall are due to a true age-related decline in recall ability or due to the activation of negative age-related stereotypes, they seem to be the most important cause of adult age differences in hindsight bias. Yet, most likely there are multiple influences.

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Appendix A: Raw Frequencies for the Rank Order Categories in Experiment 1

	Younger adults IG-IG				Younger adults FV-IG				Older Adults FV-IG			
	IG		IG		FV		IG		FV		IG	
	Con.	Exp.	Con.	Exp.	Con.	Exp.	Con.	Exp.	Con.	Exp.	Con.	Exp.
ROJ<OJ<CJ	61	58	67	57	57	42	62	52	69	41	64	44
ROJ=OJ<CJ	153	128	135	130	127	125	138	138	116	81	113	86
OJ<ROJ<CJ	45	72	64	78	59	79	62	76	58	106	68	104
OJ<ROJ=CJ	0	0	1	0	1	0	0	0	0	0	3	0
OJ<CJ<ROJ	25	21	25	17	17	36	24	26	24	32	26	37
CJ<OJ<ROJ	66	56	60	45	78	54	57	55	79	45	56	49
CJ<ROJ=OJ	99	96	101	112	99	99	114	103	86	73	94	75
CJ<ROJ<OJ	65	83	56	80	90	85	80	84	73	113	83	110
CJ=ROJ<OJ	0	2	0	0	2	1	1	2	1	1	1	0
ROJ<CJ<OJ	21	21	38	28	35	41	31	33	41	55	42	42

Note. IG = ignore; FV = free viewing; Con. = control items; Exp. = experimental items; ROJ = recall of original judgment; OJ = original judgment; CJ = correct judgment. As the G^2 statistic is not defined in cases of zero cells, we added a constant of +0.1 to each cell in each group for the analyses.

Appendix B: General Knowledge Questions used in Experiment 1, 2, 3, and 5

No.	Question	Unit	Solution
1	Wie lang ist die Elbe?	(km)	1091
2	Wieviele Sternbilder sind offiziell anerkannt?		88
3	Wann wurde Heinrich von Kleist geboren?		1777
4	Wieviele Nr.-1-Alben hatten die Beatles in den USA?		19
5	Wie lang ist die Strecke München-Athen?	(km)	1480
6	Wie lang ist der Suez-Kanal?	(km)	167
7	Wie hoch ist der Eiffelturm?	(m)	300
8	Wann besuchte Albert Einstein zum ersten Mal die USA?		1921
9	Wie alt wurde Mahatma Gandhi?	(Jahre)	78
10	Wann wurde Leonardo da Vinci geboren?		1452
11	Wie lang ist das Flugzeug Boing 747 SP?	(m)	56
12	Wie hoch ist der Fudjiyama?	(m)	3776
13	Wann wurde das erste Spiegelteleskop gebaut?		1616
14	Wie lang ist die Sphinx in Gizeh?	(m)	74
15	Wann starb Karl der Große?		814
16	Wie hoch ist der Rheinfall bei Schaffhausen?	(m)	23
17	Wie lang kann ein Blauwal werden?	(m)	33
18	In welchem Jahr wurde die Parkuhr erfunden?		1935
19	Wie hoch ist das Brandenburger Tor?	(m)	26

20	Wieviele Meter über dem Meeresspiegel liegt die Ortsmitte von Ulm?	(m)	478
21	Wieviel Primzahlen gibt es im Intervall von 1 bis 1000?		168
22	Wieviele Einwohner hatte Hannover am 01.01.2009?		524951
23	Wie lang ist der Panamakanal?	(km)	82
24	Wie lang ist die Strecke Tokio - Hongkong (Luftlinie)?	(km)	2935
25	Wie lang ist die Themse?	(km)	346
26	Wie weit ist Frankfurt (a.M.) von Berlin entfernt?	(km)	420
27	Wieviele Meter über dem Meeresspiegel liegt die Ortsmitte von Kaiserslautern?	(m)	240
28	Wie hoch ist die Freiheitsstatue mit Sockel?	(m)	93
29	Bei welcher Temperatur schmilzt Blei?	(°C)	327
30	Wie hoch ist der höchste Berg auf dem Mond?	(m)	1738
31	Wieviele Tage ist eine Elefantenkuh im Durchschnitt trächtig?	(Tage)	631
32	Was für einen Durchmesser hat die Erde?	(km)	12757
33	Wie lang ist die Strecke Münster-Berlin?	(km)	390
34	In welcher Rekordzeit wurde 2007 der Montblanc bestiegen?	(h)	4
35	Wann entstand der Text des Deutschlandliedes?		1841
36	Wie lang ist der Rhein?	(km)	1320
37	Wie alt wurde Martin Luther King?	(Jahre)	39
38	Wann wurde der Heißluftballon erfunden?		1783
39	Wieviel Gramm wiegt ein Tennisball?	(g)	57
40	In welchem Jahr ereignete sich die Meuterei auf der Bounty?		1789

41	Wieviele Arten der Kleidervögel gibt es?		21
42	In welchem Jahr wurde das Patent für die drahtlose Telegraphie angemeldet?		1899
43	Wieviele afrikanische Staaten gibt es?		53
44	Wieviele Kriminalromane schrieb Agatha Christie?		67
45	Wie schnell kann ein Gepard rennen?	(km/h)	112
46	Wieviele Kalorien haben zehn Gummibärchen (30g)?		98
47	Wann begann der Hundertjährige Krieg?		1337
48	Wie breit ist der Bodensee an seiner breitesten Stelle?	(km)	14
49	Wieviele Buchstaben hat die arabische Schrift?		28
50	Wieviele mm lang ist ein 50-Euro Schein?	(mm)	140
51	Wie lang ist die Strecke der Transsibirischen Eisenbahn?	(km)	9288
52	Wieviele Theaterstücke hat Shakespeare geschrieben?		33
53	Wie hoch ist der Schiefe Turm von Pisa?	(m)	54
54	Wann wurde mit der Wellensittich-Züchtung begonnen?		1846
55	Wann gab es in Deutschland den ersten Farbfilm?		1936
56	Wieviele Saiten hat eine Doppelpedalharfe?		47
57	Der wievielte Präsident der USA war Richard Nixon?		37
58	Wann wurde die erste Autobahn eingeweiht?		1921
59	Wie viele Muschelarten gibt es in Deutschland?		32
60	Wann fand in Frankreich die letzte Hinrichtung statt?		1977
61	Wieviele Meter pro Sekunde kann ein Regentropfen fallen?		8

62	Wieviele bewohnte ostfriesische Inseln gibt es?		7
63	Wie tief ist der Chiemsee an seiner tiefsten Stelle?	(m)	73
64	Wann wurde Louisiana ein Bundesstaat der USA?		1812
65	Wann wurde Astrid Lindgren geboren?		1907
66	Wie groß ist die Insel Borkum?	(km^2)	31
67	Wieviele Suren hat der Koran?		114
68	Wie hoch ist die Peterskirche (Petersdom) in Rom?	(m)	133
69	Wie hoch war einst die Cheops-Pyramide?	(m)	147
70	Wie lang ist ein Jahr auf dem Merkur (in Erdentagen)?		88
71	Wie lang ist der Amazonas?	(km)	6448
72	Wann wurde der erste Briefkasten aufgestellt?		1633
73	In welchem Jahr wurde Antonio Vivaldi geboren?		1678
74	Wann wurde die erste Herztransplantation beim Menschen durchgeführt?		1967
75	Wie hoch ist die höchste Erhebung im Ural?	(m)	1894
76	Wie hoch ist die höchste auf der Erde gemessene Lufttemperatur?	(°C)	58
77	Wieviele Opern schrieb W. A. Mozart?		21
78	Wann ist die Mona Lisa von Leonardo da Vinci entstanden?		1503
79	In welchem Jahr wurde der Planet Uranus entdeckt?		1781
80	Wieviele Mio. Kubikkilometer Wasser fasst der atlantische Ozean?		350
81	Wieviele Knochen hat ein Mensch?		214
82	In welchem Jahr wurde die Coca Cola Company gegründet?		1892

83	Mit wievielen Stecknadeln ist ein zum Verkauf gefaltetes Herrenoberhemd fixiert?		7
84	In welchem Jahr starb Queen Victoria?		1901
85	Wie hoch ist der Olymp?	(m)	2911
86	Wie viele Menschen kamen 2004 durch das Seebeben im Indischen Ozean ums Leben?		230000
87	In welchem Jahr gewann Gao Xingjian den Literaturnobelpreis?		2000
88	Wann wurde Mark Twain geboren?		1835
89	In welchem Jahr erschien Homo Faber von Max Frisch?		1957
90	In welchem Jahr wurde das Taj Mahal fertig gestellt?		1648
91	In welchem Jahr fand die erste Rallye Monte Carlo statt?		1911
92	Wie lang ist die Donau?	(km)	2845
93	Wie hoch ist der Hoover-Staudamm?	(m)	180
94	Wie hoch ist der Stuttgarter Fernsehturm?	(m)	211
95	Wie lang ist die kürzere Seite einer internationalen Postkarte?	(mm)	105
96	Wie schwer konnte ein Tyrannosaurus Rex werden?	(kg)	6800

Note. Questions 1-80 were used in Experiment 1; questions 1-96 were used in Experiments 2, 3, and 5.

Appendix C: Raw Frequencies for the Rank Order Categories in Experiment 2

	Younger adults				Older adults			
	CJ users		CJ non-users		CJ users		CJ non-users	
	Con.	Exp.	Con.	Exp.	Con.	Exp.	Con.	Exp.
ROJ<OJ<CJ	98	59	95	83	115	61	80	60
ROJ=OJ<CJ	150	137	128	154	135	133	120	104
OJ<ROJ<CJ	89	118	100	109	88	126	84	128
OJ<ROJ=CJ	1	3	2	0	2	17	0	7
OJ<CJ<ROJ	37	50	41	40	32	38	40	49
CJ<OJ<ROJ	102	64	91	69	113	79	109	51
CJ<ROJ=OJ	116	126	177	143	150	124	11	96
CJ<ROJ<OJ	106	157	94	125	93	155	97	134
CJ=ROJ<OJ	2	7	0	2	0	17	0	6
ROJ<CJ<OJ	48	43	34	39	46	40	46	60

Note. CJ = correct judgment; Con. = control items; Exp. = experimental items; ROJ = recall of original judgment; OJ = original judgment. As the G^2 statistic is not defined in cases of zero cells, we added a constant of +0.1 to each cell in each group for the user-group analyses.

Appendix D: Post-Experiment Questionnaire Experiment 3

Vielen Dank für Ihre Teilnahme!

Zum Schluss möchten wir Sie bitten, noch einige kurze Fragen zur Studie zu beantworten.

Am Ende der Studie sollten Sie sich an Ihre eigene Schätzung erinnern. Dazu konnten Sie bei einigen Fragen selbst entscheiden, ob Sie die Lösung sehen möchten oder nicht.

Bei den Fragen, wo Sie selbst entscheiden konnten (F5 + ENTER):

1. Haben Sie sich die Lösungen angesehen?

☐ ja, (fast) immer (75-100%) ☐ ja, oft (50-75%) ☐ ja, manchmal (25-50%)

☐ ja, aber nur ganz selten (<25%) ☐ nein, nie

2. Aus welchen Gründen haben Sie sich entschieden, die Lösung anzusehen bzw. nicht anzusehen?

	Trifft gar nicht zu	**Trifft kaum zu**	**Weder noch**	**Trifft etwas zu**	**Trifft sehr gut zu**
Ich konnte mich an meine eigene Schätzung nicht erinnern und habe vermutet, dass die Lösung mir dabei hilft, mich zu erinnern.	☐	☐	☐	☐	☐
Ich hatte den Eindruck, dass die Lösung mich darin beeinträchtigt, meine eigene Schätzung zu erinnern.	☐	☐	☐	☐	☐
Ich konnte mich an meine eigene Schätzung nicht erinnern und habe einen Anhaltspunkt gesucht, um meine eigene Schätzung zu rekonstruieren.	☐	☐	☐	☐	☐
Ich hatte den Eindruck, dass die Lösung mich darin beeinträchtigt, meine eigene Schätzung zu rekonstruieren.	☐	☐	☐	☐	☐
Ich wollte prüfen, wie gut meine eigene Schätzung war.	☐	☐	☐	☐	☐

	Trifft gar nicht zu	Trifft kaum zu	Weder noch	Trifft etwas zu	Trifft sehr gut zu
Ich hatte den Eindruck, es ist gewünscht, sich die Lösungen anzuschauen.	☐	☐	☐	☐	☐
Ich habe die Lösungen angeschaut, weil sie mich interessiert haben/Ich war neugierig.	☐	☐	☐	☐	☐
Da alle Lösungen am Ende eingesehen werden können, gab es für mich keinen Grund diese während der Aufgabe anzuschauen.	☐	☐	☐	☐	☐
sonstiger Grund:	☐	☐	☐	☐	☐

3. War Ihnen bewusst, dass Sie alle Lösungen am Ende beim Versuchsleiter einsehen können?

☐ ja ☐ nein

Vielen Dank!

Appendix E: Raw Frequencies for the Rank Order Categories in Experiment 3

	Younger adults			
	CJ users		CJ non-users	
	Con.	Exp.	Con.	Exp.
ROJ<OJ<CJ	180	129	143	94
ROJ=OJ<CJ	241	206	253	244
OJ<ROJ<CJ	148	245	134	175
OJ<ROJ=CJ	1	4	2	6
OJ<CJ<ROJ	75	67	59	74
CJ<OJ<ROJ	189	125	174	119
CJ<ROJ=OJ	200	202	231	243
CJ<ROJ<OJ	202	256	162	207
CJ=ROJ<OJ	0	2	3	7
ROJ<CJ<OJ	81	79	66	73

Note. CJ = correct judgment; Con. = control items; Exp. = experimental items; ROJ = recall of original judgment; OJ = original judgment. As the G^2 statistic is not defined in cases of zero cells, we added a constant of +0.1 to each cell in each user groups for the user-group analyses.

Appendix F: General Knowledge Assertions used in Experiment 4

Set A Questions:

No.	Assertion	Solution
1	Die ursprüngliche Religion Koreas ist der Shintoismus.	False
2	Die erste deutsche Eisenbahn fuhr 1835.	True
3	St. Petersburg wurde von Peter dem Großen gegründet.	True
4	Kaffee wurde nach der Äthiopischen Provinz Kaffa benannt.	True
5	Die Fläche der BRD beträgt etwa 350.000 Quadratkilometer.	True
6	Ultraviolette Strahlung ist in der Lage, Bakterien zu töten.	True
7	Die meisten Völker in Ost- und Südostasien haben eine starke Abneigung gegen Milch.	True
8	Ein Maulwurf kann in einer Nacht einen Tunnel von mehr als 80 Meter Länge graben.	True
9	Der Nil ist kürzer als 5000 km.	False
10	Der Pförtnermuskel des menschlichen Körpers befindet sich am Mageneingang.	False
11	Die am häufigsten in der Bibel erwähnten Tiere sind Löwen.	False
12	Whiskey ist ein Branntwein aus Gerste oder Mais.	True
13	Krokodile sind farbenblind.	True
14	Der Louvre in Paris ist das größte Museum der Welt.	False
15	In Brasilien fahren 10% aller Pkw mit Ethanol.	True

16	Im Sommer wird es in Alaska nicht wärmer als 10° Celsius	False
17	Die ersten olympischen Spiele der Neuzeit fanden in Rom statt.	False
18	Der Wels ist mit bis zu 3 Metern der größte Süßwasserfisch Europas.	True
19	Eine Sonnenfinsternis dauert maximal 17 Minuten.	False
20	Die Erde ist der einzige Planet in unserem Sonnensystem, der genau einen Mond hat.	True
21	Der Aachener Dom steht auf der UNESCO-Liste der Kulturdenkmäler.	True
22	Memphis war einmal die Hauptstadt von Ägypten.	True
23	Neugier ist eine der sieben Todsünden.	False
24	Es ist umso leichter, die Schallmauer zu durchbrechen, je tiefer man fliegt.	False
25	Die Waldfläche in Nordrhein-Westfalen beträgt mehr als 20% der Gesamtfläche.	True
26	China verbraucht weniger als zehn Prozent der weltweiten Stromproduktion.	False
27	Im Körper eines Erwachsenen befinden sich mehr als 300 Kilometer Blutgefäße.	False
28	In Deutschland leben mehr als eine Million Menschen in Ein-Zimmer-Wohnungen.	False
29	Der äquatoriale Radius des Mars entspricht in etwa dem der Erde.	False
30	Deutschland ist der viertgrößte Weinproduzent der Erde.	False
31	Der Elch war bis ins 18. Jahrhundert in Deutschland heimisch.	True
32	Perlen lösen sich in Alkohol auf.	False
33	In Deutschland leben auf einem km² durchschnittlich weniger als 150 Menschen.	False
34	J.S. Bach hatte mehr als zehn Kinder.	True
35	Die Landfläche der USA entspricht ungefähr der von Australien.	True

36	Julius Caesar wurde im Jahre 98 v.Chr. ermordet.	False
37	Der Bodensee ist 539 km^2 groß.	True
38	Der Rote Halbmond ist ein internationales Schutzzeichen des Sanitätsdienstes.	True
39	Der Buchdruck wurde im Jahre 1527 erfunden.	False
40	Den Zeitraum, in dem der Homo Heidelbergensis gelebt hat, bezeichnet man als Jura.	False

Set B Questions:

No.	Assertion	Solution
1	In Deutschland beenden pro Jahr über 70.000 Menschen ihre Schullaufbahn ohne Hauptschulabschluss.	True
2	Die Zugspitze ist 2962 m hoch.	True
3	Basel ist die größte Stadt der Schweiz.	False
4	Der südlichste Punkt der Vereinigten Staaten ist Kalae, Hawaii.	True
5	Russland gewann in den Jahren 1896 bis 1996 die meisten olympischen Medaillen.	False
6	Lenin starb an einer seltenen Form der Lungenentzündung.	False
7	China war das erste Land, in dem Papiergeld benutzt wurde.	True
8	Die Donau ist der längste Strom Europas.	False
9	Die Grippeepidemie zum Ende des ersten Weltkriegs tötete mehr als 18 Millionen Menschen.	True
10	Mark Twains „Tom Sawyer“ durfte nach dem Erscheinen in vielen Bibliotheken der USA nicht an Kinder oder sogar gar nicht ausgeliehen werden.	True

11	Die Gesamtlänge des deutschen Eisenbahnnetzes beträgt mehr als 92.000 km.	False
12	Die Sahara bedeckt mehr als 20.000 Quadratkilometer.	False
13	In Deutschland sind mehr als doppelt so viele Männer wie Frauen erwerbstätig.	False
14	Antoine Saint-Exupéry überflog als erster den Atlantik in Ost-West-Richtung.	False
15	Kopenhagen war 1998 Kulturhauptstadt Europas.	False
16	Die Rocky Mountains erstrecken sich in nördliche Richtung bis Alaska.	True
17	Der erste amerikanische „Goldrausch“ fand in South Carolina statt.	False
18	Bei Temperaturen in der Nähe des absoluten Nullpunktes ändern sich die magnetischen Eigenschaften vieler Stoffe.	True
19	Mehr als ein Viertel aller Ausländer in Nordrhein-Westfalen sind jünger als 18 Jahre.	True
20	Hohe Gaben von Vitamin A können zu Sehstörungen und Schwindelgefühlen führen.	True
21	„Lindenstraße“ ist die international erfolgreichste deutsche Fernsehserie.	False
22	1998 ist die Einwohnerzahl Nordrhein-Westfalens gesunken.	True
23	Die Volksrepublik China wurde 1947 gegründet.	False
24	Der Atlantische Ozean ist im Durchschnitt tiefer als der Pazifik.	False
25	Das Autokennzeichen von Finnland ist „FI“.	False
26	In Deutschland gibt es mehr Ledige als Verheiratete.	False
27	Sylt ist die zweitgrößte deutsche Insel.	False
28	Kühe haben 3 Mägen.	False
29	Ostern ist am Sonntag nach dem ersten Frühlingsvollmond.	True

30	Salz war noch bis ins 19. Jh. das offizielle Zahlungsmittel in vielen Gegenden Nordafrikas.	True
31	Ernest Hemingway erhielt für „Der Alte Mann und das Meer“ den Pulitzer-Preis.	True
32	Nach dem chinesischen Kalender ist 1999 das Jahr der Ameise.	False
33	Ameisen haben das höchste Verhältnis zwischen Gehirn- und Körpergewicht.	True
34	West ist die in Deutschland meistverkaufte Zigarettenmarke.	False
35	Lithium ist das leichteste aller Metalle.	True
36	Die Menschheit begann vor etwa 20.000 Jahren mit der Landwirtschaft.	False
37	In Deutschland sind mehr als 40.000.000 Kraftfahrzeuge zugelassen.	True
38	Martin Luther King erhielt den Friedensnobelpreis.	True
39	Ernest Hemingway beging 1961 Selbstmord.	True
40	Der Ursprung des Wortes „Hinduismus“ ist das indische Wort für „Gesetz“.	True

Appendix G: Raw Frequencies for the Rank Order Categories in Experiment 5

	Young Short-RI		Young Long-RI		Older Short-RI	
	Con.	Exp.	Con.	Exp.	Con.	Exp.
ROJ<OJ<CJ	216	167	325	168	248	157
ROJ=OJ<CJ	429	339	299	261	315	246
OJ<ROJ<CJ	226	324	322	444	262	322
OJ<ROJ=CJ	2	15	6	9	3	11
OJ<CJ<ROJ	105	90	162	198	106	163
CJ<OJ<ROJ	224	150	326	217	288	153
CJ<ROJ=OJ	387	358	267	246	295	279
CJ<ROJ<OJ	266	390	326	465	283	474
CJ=ROJ<OJ	3	17	6	5	3	9
ROJ<CJ<OJ	102	96	156	178	141	137

Note. RI = retention interval; Con. = control items; Exp. = experimental items; ROJ = recall of original judgment; OJ = original judgment; CJ = correct judgment.

Eigenständigskeitserkärung

Die hier vorliegende Dissertation habe ich eigenständig und ohne unerlaubte Hilfsmittel angefertigt. Sie wurde in dieser oder ähnlicher Form bei noch keiner anderen Institution eingereicht. Es fanden bisher keine erfolglosen Promotionsversuche statt.

Düsseldorf, im Februar 2013

Julia Groß