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The Multifold Relationship Between Memory and Decision Making: An Individual-Differences Study

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Several judgment and decision-making tasks are assumed to involve memory functions, but significant knowledge gaps on the memory processes underlying these tasks remain. In a study on 568 adults between 25 and 80 years of age, hypotheses were tested on the specific relationships between individual differences in working memory, episodic memory, and semantic memory, respectively, and 6 main components of decision-making competence. In line with the hypotheses, working memory was positively related with the more cognitively demanding tasks (Resistance to Framing, Applying Decision Rules, and Under/Overconfidence), whereas episodic memory was positively associated with a more experience-based judgment task (Recognizing Social Norms). Furthermore, semantic memory was positively related with 2 more knowledge-based decision-making tasks (Consistency in Risk Perception and Resistance to Sunk Costs). Finally, the age-related decline observed in some of the decision-making tasks was (partially or totally) mediated by the age-related decline in working memory or episodic memory. These findings are discussed in relation to the functional roles fulfilled by different memory processes in judgment and decision-making tasks.

Keywords: judgment and decision making, decision-making competence, working memory, cognitive aging, individual differences

Among the more promising research developments in the field of judgment and decision making is the attempt to ground judgment and decision-making processes in findings and models derived from memory research, tracing complex cognitive tasks back to their basic cognitive roots to improve the understanding of how individuals perform these tasks. Indeed, memory can play an important role in several aspects of judgment and decision-making tasks (for reviews, see, e.g., Alba, Hutchinson, & Lynch, 1991; Dougherty, Gronlund, & Gettys, 2003; Tomlinson, Marewski, & Dougherty, 2011; Weber, Goldstein, & Barlas, 1995), and the age-related decline observed in some aspects of memory functioning (Park, 2000; Park et al., 2002, 1996; Salthouse, 2004) can mediate part of the age-related changes in decision-making abilities. However, the investigation of the role of memory functions in decision making has been scattered and nonsystematic, leaving various knowledge gaps about which memory functions underlie specific decision-making tasks and limiting theoretical integration between memory and decision research. The study presented in

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this article aims to fill some of these gaps through a systematic analysis of the relationships between individual differences in memory processes and individual differences in various aspects of decision-making competence, guided by a functional view of memory processes in decision making.

In the next section, the theoretical background of the research will be presented, followed by the specific hypotheses of the study, which refer to the contribution of different memory processes to six main components of decision making, measured by the Adult Decision-Making Competence battery (Bruine de Bruin, Parker, & Fischhoff, 2007). Next, the methodological aspects of the research and the rationale of its four-step data analysis procedure will be described, followed by the results of structural equation modeling for each of these steps. Finally, the discussion will focus on the implications of the results for the functional roles fulfilled by different memory processes in judgment and decision-making tasks.

Theoretical Background and Hypotheses

Working Memory, Executive Control, and Decision Making

Existing empirical evidence suggests that working memory processes support judgment and decision-making tasks requiring extensive processing and thoughtful evaluation of information about options, while the same processes seem less relevant to tasks that can be successfully completed by using less demanding strategies. Dual-task studies showed that participants tend to rely on simpler judgment and evaluation strategies or emotion-based choice processes under high concurrent cognitive load (e.g., De Neys, 2006; De Neys & Verschueren, 2006; Hinson, Jameson, & Whitney, 2003; Hinson & Whitney, 2006; Shiv & Fedorikhin, 1999), with working-memory resources being necessary to articulate a preference or judgment based on a more thoughtful consideration of the options and associated information (e.g., Evans, 2008; Stanovich & West, 2008). Moreover, individual-difference studies observed that participants with greater working memory capacity provide less subadditive probability judgments (Dougherty & Hunter, 2003) and that participants with better performance in executive functioning tests obtain better results in cognitively-demanding judgment and decision-making tasks (Del Missier, Mäntylä, & Bruine de Bruin, 2010, 2012; Parker & Fischhoff, 2005). Additionally, studies on individual differences highlighted age-related declines only in cognitively taxing judgment and decision-making tasks that are more closely associated with fluid intelligence measures (Bruine de Bruin, Parker, & Fischhoff, 2007, 2012; Mäntylä, Del Missier, et al., 2012).

Working memory processes seem to be much less involved when the decision task can be carried out by using simple and effortless strategies (see also Evans, 2008, 2009; Glöckner & Witteman, 2010; Hogarth, 2005; Stanovich, 2009), by relying on acquired experience and knowledge (e.g., Bruine de Bruin, Parker, & Fischhoff, 2012; Fisk & Rogers, 2000; Hess, Osowski, & Leclerc, 2005; Meyer & Pollard, 2004; Peters, Hess, Auman, & Västfjäll, 2007; Stanovich & West, 2008) or on emotion-related processes (e.g., Bechara, Damasio, Tranel, & Anderson, 1998; Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; MacPherson, Phillips, & Della Sala, 2002). Accordingly, age-related declines have not been observed in less cognitively demanding decision tasks or when experience and knowledge can exert a significant positive role (see Bruine de Bruin, Parker, & Fischhoff, 2012; Mather, 2006; Peters et al., 2007).

Following previous investigations, in the present study we expect to observe selective positive relations between individual differences in working memory and performance in the three more cognitively demanding Adult Decision-Making Competence battery (A-DMC) tasks (Resistance to Framing, Applying Decision Rules, Under/Overconfidence). The task-specific instantiations of this hypothesis will be articulated below.

Long-Term Declarative Memory and Decision Making

Although only a limited number of studies have investigated the relationship between declarative long-term memory processes and judgment and decision-making task, existing evidence seems to support the idea that episodic memory processes and memory sampling/assessment of past experiences may underlie performance in some decision tasks, while the correct accomplishment of other decision tasks may depend on the availability and accessibility of appropriate semantic knowledge.[1]

In particular, a series of studies have been successful in corroborating, by simulation or empirical research, the hypothesis that judgments and decisions are, in some circumstances, expressed on the basis of memory sampling or cued recall processes (e.g., Fiedler & Juslin, 2006; Lange, Thomas, & Davelaar, 2012; Stewart, Chater, & Brown, 2006; Thomas, Dougherty, Sprenger, & Harbison, 2008), and that judgments of frequency rely on strategies supported by different types of long-term memory processes and representations (Brown, 1995, 1997, 2002; Haberstroh, 2008). As we will explain in the next section, we hypothesize that episodic memory processes are selectively involved in performing the Recognizing Social Norms tasks of the A-DMC battery, which relies on judgments of frequency based on accumulated experience.

Studies on the role of knowledge in decision making have posited, and in some cases showed, that knowledge is helpful to avoid economic and probabilistic biases (e.g., Fennema & Perkins, 2008; Larrick, Morgan, & Nisbett, 1990; Stanovich & West, 2008). Moreover, some investigations highlighted the positive association between self-protective HIV/AIDS knowledge and successful self-reported self-protective behavior (Bruine de Bruin, Downs, Fischhoff, & Palmgren, 2007) and between financial knowledge and financial behaviors (Bruine de Bruin et al., 2010; Parker, Bruine de Bruin, Yoong, & Willis, 2012), although the positive role of knowledge and expertise in decision making continues to be debated and the results seem to vary with the domain and the task (e.g., Shanteau, 1992; Shanteau & Stewart, 1992).[2] Relying on these results and on more task-specific considerations (see the next section), we hypothesize that performance in two

[1] The actual influence of retrieved memories and knowledge on judgments and decisions depends also on the processing strategy adopted by the decision maker, as various studies have shown (e.g., Hastie & Park, 1986; Karlsson, Juslin, & Olsson, 2008; Marewski & Schooler, 2011; Stanovich & West, 2008).

[2] In some cases, performance may even suffer if acquired knowledge supports a biased response, as shown by the developmental research on some judgment biases that seem to depend on social knowledge (De Neys & Vanderputte, 2011; Jacobs & Klaczynski, 2002).

A-DMC tasks requiring background semantic knowledge (Consistency in Risk Perception, Resistance to Sunk Costs) are related to individual differences in semantic memory.

A Study on the Memory–Decision Making Relationship: Aims and Hypotheses

As the preceding review makes clear, a number of studies have examined the role of memory in decision making. However, these studies employed diverse research paradigms and decision tasks and generally relied on a rather narrow and task-specific theoretical perspective. Although the results have been promising and some regularities emerged, an integrated and comprehensive functional account of the memory-decision making relationships is still missing and it is still unclear which memory processes are relevant for several important kinds of decision-making tasks. Moreover, until recently, a severe limitation to individual-difference studies has been by unavailability of valid and reliable instruments for measuring individual differences in decision-making competence (Bruine de Bruin, Del Missier, & Levin, 2012; Bruine de Bruin, Parker, & Fischhoff, 2007; Del Missier et al., 2012). Fortunately, the recent development and validation of new instruments, like the Adult Decision-Making Competence battery (henceforth A-DMC; Bruine de Bruin, Parker, & Fischhoff, 2007), helped to overcome this limitation (see also Finucane & Guillon, 2010).

The study presented in this article aimed to fill the abovementioned knowledge gaps through a systematic investigation of the relationships between individual differences in memory processes and individual differences in important components of decision-making competence. The research has been carried out within the *Betula* project (Nilsson et al., 2004, 1997; Rönnlund & Nilsson, 2006; see http://w3.psychology.su.se/betula/en/), a 25-year longitudinal research project on aging and memory that has been recently extended to include the study of decision-making competence (Mäntylä, Del Missier, et al., 2012). In particular, the present study examined the relationships between individual differences in semantic, episodic, and working memory on one side, and six important aspects of decision-making competence on the other side. Individual and age-related differences in memory have been assessed with multiple tasks previously employed in the *Betula* project, while the six aspects of decision-making competence, measured through A-DMC battery, involved the ability to resist framing effects, the correct application of decision rules, calibration of confidence in knowledge, the ability to recognize social norms, the ability to resist sunk costs, and consistency in risk perception. A description of these A-DMC tasks is provided in the method section and the whole battery is available on-line (http://sds.hss.cmu.edu/risk/ADMC.htm).

Here, we describe our specific hypotheses about the involvement of different memory processes in each aspect of decision-making competence (see also Table 1) and summarize task-specific pre-existing empirical support. Our specific hypotheses stem from the general idea that diverse memory processes may functionally support decision making in different ways. Generalizing from existing evidence, we assume that working memory will support those decision-making tasks in which a successful performance requires more extensive processing and manipulation of information. Semantic memory should instead play a more important role in decision tasks that require background knowledge, whereas episodic memory is expected to support performance in decision tasks that are based on the evaluation of past experiences. Hence, the present study tested the general hypothesis of a multifold functional relationship between memory and decision making.

Resistance to Framing. This A-DMC task measures the individual's ability to resist normatively irrelevant variations in how the decision problem is presented. For example, a medical treatment should be evaluated as similarly attractive whether it is described as 95% effective or 5% ineffective, and relative preferences between a sure thing and a risky option should be independent of whether the options are framed as gains or losses. The task includes attribute framing problems and risky-choice framing problems (Levin, Gaeth, Schreiber, & Lauriola, 2002; Levin, Schneider, & Gaeth, 1998), which are presented in positive/negative or gain/loss versions, respectively (see the materials section for further details). Various theoretical accounts of framing effects exist (for reviews, see Gonzalez, Dana, Koshino, & Just, 2005; Keren, 2011; Kühberger, 1997), but several explanations share the idea that the ability to resist framing effects involves blocking an intuitive and relatively rough evaluation of the options, affected by the superficial appearance and valence of the problem description, and expressing a more thorough evaluation of the objective features of the options (see, e.g., De Martino, Kumaran, Seymour, &

Table 1
Summary of Hypotheses

Decision-making task	Working memory	Episodic memory	Semantic memory	Relation with age and mediation/suppression
Resistance to Framing	+			Negative Working memory mediation
Applying Decision Rule	+			Negative Working memory mediation
Under/Overconfidence	+			Negative Working memory mediation
Recognizing Social Norms		+		Positive, after controlling for episodic memory mediation
Resistance to Sunk Costs			+	Positive
Consistency in Risk Perception			+	No significant relation

Note. The plus sign indicates a positive expected relationship between performance in the specific decision-making task (in the row) and individual differences in specific memory processes (in the column).

Dolan, 2006; Kahneman & Frederick, 2007; Levin & Gaeth, 1988; Levin et al., 1998; McElroy & Seta, 2003). As the previous summary of the literature makes clear, these cognitive operations require working memory and executive control resources. In line with this view, previous A-DMC studies have shown that Resistance to Framing is positively related with a general composite measure of executive control in a sample of adolescents (Parker & Fischhoff, 2005) and with the updating/inhibition dimension of executive control beyond fluid intelligence (Del Missier et al., 2012). Bruine de Bruin, Parker, and Fischhoff (2012) showed that the observed age-related decline in Resistance to Framing can be mediated by a correspondent decline in fluid intelligence. The hypothesis for the present study is that individual differences in Resistance to Framing will be positively related with individual differences in tests of working memory performance. Moreover, a negative correlation is expected between Resistance to Framing and age, which should be at least partially mediated by a corresponding age-related decline in working memory.

Applying Decision Rules. Research on decision-making strategies has shown that individuals use different choice heuristics in different circumstances (Bettman, Luce, & Payne, 1998; Payne & Bettman, 2004). The ability in the application of decision strategies is essential in multiattribute choice, where multiple options vary along multiple attributes, and where the accurate application of different rules offers adaptive advantages (Payne, Bettman, & Johnson, 1993). The Applying Decision Rules task in the A-DMC battery assesses the ability to correctly apply various decision rules. The application of decision strategies is assumed to depend on working memory if these strategies require computations, comparisons, and aggregation of values (e.g., Payne et al., 1993). Moreover the application of decision rules may also require inhibiting information that is irrelevant or no longer relevant (Del Missier et al., 2010). Past work on A-DMC has shown that performance in the Applying Decision Rules task is positively related with measures of inhibition and working memory updating (Del Missier et al., 2010, 2012). Additionally, Applying Decision Rules was the only significant predictor of ADHD status in a study that employed other tasks involving decision making, like the Balloon Analogue Risk Task and the Iowa Gambling Task (Mäntylä, Still, Gullberg, & Del Missier, 2012). Performance in this task was also negatively related with age (Bruine de Bruin, Parker, & Fischhoff, 2007; Mäntylä, Del Missier, et al., 2012), with this relation being possibly mediated by fluid intelligence, which declines with age (Bruine de Bruin, Parker, & Fischhoff, 2012). Thus, we expect that Applying Decision Rules will be positively related with individual differences in working memory and negatively related with age, and that the negative relation with age will be at least partially mediated by a corresponding age-related decline in working memory.

Under/Overconfidence. The Under/Overconfidence A-DMC task measures calibration in judgments of confidence, which is a critical metacognitive ability to effective decision making. Overconfidence can lead to inappropriate risky behavior, while underconfidence can lead to inappropriate hesitation and inaction (for brief reviews, see, e.g., McGraw, Mellers, & Ritov, 2004; Parker et al., 2012). In particular, the Under/Overconfidence task presents true/false factual statements, asking participants to judge if each statement is true or false and, immediately afterward, to express their degree of confidence in each answer on a scale ranging from 50% (*just guessing*) to 100% (*absolutely sure*). The performance score is 1 minus the absolute value of the difference between (mean) confidence and knowledge (percent correct) across all items. The overconfidence often observed in this type of task has been explained in various ways (see Griffin & Brenner, 2004). According to a prominent explanation, people show a tendency to focus on the reasons confirming (rather than disconfirming) the answers they gave (Koriat, Lichtenstein, & Fischhoff, 1980). Thus, the ability to "defocus" attention and take into account disconfirming evidence should promote less overconfident judgments (cf. Brenner, Koehler, & Tversky, 1996; Hoch, 1985; Koriat et al., 1980). This process is assumed to be cognitively-intensive and, according to some scholars and previous results, it may involve working memory (Dougherty & Hunter, 2003; Mäntylä, Del Missier, et al., 2012; Sprenger & Dougherty, 2006; Stanovich, 2009). However, individual-differences studies on the Under/Overconfidence task have provided varying results, possibly due to differences in predictors and samples. Adolescents' performance on this task was positively associated with a general measure of executive functioning (Parker & Fischhoff, 2005), while this positive correlation was found only for some measures of executive functioning in young adults (Del Missier et al., 2012). Moreover, Bruine de Bruin, Parker, and Fischhoff (2007) did not find a significant correlation between performance in Under/Overconfidence and age, whereas Mäntylä, Del Missier, et al. (2012) observed a significant negative correlation. The hypothesis for the present study, grounded in the abovementioned account of the Under/Overconfidence A-DMC task, is that performance will be positively related with working memory measures and negatively related with age. Moreover, the negative correlation with age will be at least partially mediated by a corresponding age-related decline in working memory.

Recognizing Social Norms. This ADMC task measures the accuracy of perceived social norms, by comparing the actual social norms of a group of peers with the social norms estimated by the single members of the group (who are asked to estimate the percentage of peers approving of sometimes engaging in different negative behaviors, such as stealing). An accurate perception of social norms is important for effective real-word decision making and the perception of social norms is assumed to play a role in decision-related phenomena (Parker & Fischhoff, 2005). Previous studies have shown that performance on this task is not related to measures of executive functioning (Del Missier et al., 2012; Parker & Fischhoff, 2005) and that it is not negatively related to age (Bruine de Bruin, Parker, & Fischhoff, 2007; Mäntylä, Del Missier, et al., 2012). Performance in the Recognizing Social Norms task, as in other frequency-estimation tasks, may require appropriate factual background about the behaviors that have to be judged (for similar arguments, see Bruine de Bruin, Parker, & Fischhoff, 2012), perhaps in the form of accumulated memory traces of social behaviors or generic impressions derived from the accumulation of memory traces (Brown, 1995, 1997, 2002). Knowledge that something is more or less unacceptable from a moral viewpoint is not the central issue in this task. Similarly, working memory resources may not be fundamental in a frequency-related task that may not require explicit retrieval of instances, due to the recurrence and similarity of the stored information (i.e., social behaviors of given types; cf. Brown, 2002). Hence, the hypothesis of the current study is that performance in this

A-DMC task will not be related with individual differences in working memory or semantic memory, but positively related with individual differences in episodic memory, which capture the ability to encode events or episodes. A better ability to encode instances of inappropriate behaviors will allow participants to estimate more accurately the relative frequency of these behaviors at a later time (for the role of perceived experience on social norms, see, e.g., Cialdini, Kallgren, & Reno, 1991), through non-enumeration and non-numerical strategies (see, e.g., Brown, 1995, 1997, 2002; Conrad, Brown, & Cashman, 1998; Haberstroh, 2008), and, consequently, to estimate more accurately the related social norms. An additional hypothesis is that, after the negative indirect influence of age through the decline of episodic memory is controlled for, age will have a direct positive influence on the ability to estimate social norms due to age-related changes in social skills and competence, because older adults may have better social skills (Hess et al., 2005; Peters et al., 2007) that can be useful in estimating social norms (Bruine de Bruin, Parker, & Fischhoff, 2012).

Resistance to Sunk Costs. This A-DMC task measures the capacity to discontinue failing commitments despite having invested unrecoverable financial and time costs. Decision makers are often unable to ignore unrecoverable or "sunk" costs and therefore continue failing commitments into the future (Arkes & Blumer, 1985). This has been explained by assuming that decision makers do not want to waste time or money already invested in a course of action (cf. Baron, 2008; Hastie & Dawes, 2001), and thus they go on with the existing course of action even if taking a new one would be the better choice, although various other explanations have been proposed (see Strough, Karns, & Schlosnagle, 2011). Researchers have hypothesized that knowledge of the principle that unrecoverable costs need to be ignored can help in avoiding sunk costs (e.g., Bruine de Bruin, Parker, & Fischhoff, 2012; Fennema & Perkins, 2008; Larrick et al., 1990), while previous experiences with sunk costs do not necessarily immunize individuals who have not acquired a sufficient awareness of the principle. Additionally, performance on Resistance to Sunk Costs was not found to be significantly related to executive functioning (Del Missier et al., 2012; Parker & Fischhoff, 2005). Thus, the hypothesis for the present study is that performance in Resistance to Sunk Costs will be positively related to individual differences in semantic memory. Given that the Betula data set currently does not include direct measures of task-specific knowledge, performance in semantic memory tests will be used as a proxy.[3] Previous studies also observed a positive correlation between age and the capacity to resist sunk costs (Bruine de Bruin, Parker, & Fischhoff, 2012; Mäntylä, Del Missier, et al., 2012; Strough, Mehta, McFall, & Schuller, 2008), explaining this finding with older adults' greater tendency to avoid focusing on painful unrecoverable past costs in the attempt of maintaining a positive emotional state (Strough et al., 2008; Strough, Karns, & Schlosnagle, 2011; Strough, Schlosnagle, & DiDonato, 2011). In line with previous studies, a positive correlation between age and Resistance to Sunk Costs is expected.

Consistency in Risk Perception. Congruency of individual's probabilistic judgments with basic probability principles is an essential prerequisite of proper risk assessment. The A-DMC Consistency in Risk Perception task asks participants to judge the probability of various events (e.g., getting into a car accident while driving; driving accident-free) happening in different time frames (in the next year, in the next 5 years) in order to evaluate the consistency of these judgments (see the Materials section for a more detailed description). This task seems to require cognitive flexibility, given that performance is positively related to individual differences on the shifting facet of executive functioning, but does not seem to strongly involve working memory updating (Del Missier et al., 2010, 2012). In addition, research on this task did not observe significant age-related changes (Bruine de Bruin, Parker, & Fischhoff, 2007; Mäntylä, Del Missier, et al., 2012). The hypothesis for the present study is that performance in this task will not be related to working memory and that it will be related to semantic memory, because knowledge of probability rules supports performance in probability-based tasks (see, e.g., Reyna & Brainerd, 2008; Stanovich & West, 2008). Episodic memory is not expected to play a significant positive role, because a good performance in this task is essentially based on "rational" probabilistic assessments of consistency, constrained by knowledge of probability principles, and not on sampling of event-related episodic experiences. As with the Resistance to Sunk Costs task, in the absence of specific measures of knowledge, the degree of general knowledge as measured by semantic memory tests will be used as a proxy. In line with previous studies, a correlation between age and Consistency in Risk Perception is not expected (considering also that a connection between age and acquisition of the principles of probability is not very likely in adulthood: cf. Stanovich & West, 2008).

The Betula Study on Memory and Decision Making

In order to test the just-stated hypotheses (see Table 1), a sample of participants in the Betula Prospective Cohort Study (Nilsson et al., 2004, 1997) completed the Swedish version of the A-DMC battery, together with multiple tests of working memory, semantic memory, and episodic memory.

Method

Participants and procedure. Participants belonged to the fifth test wave of the Betula Study. The data collection was completed in Umeå, which is a medium-sized town with approximately 110,000 inhabitants in a northern region of Sweden. The Betula project uses a stratified random sampling strategy. At the recruitment stage, participants were screened for dementia, sensory impairments, mental retardation, and a native tongue other than Swedish (for further details concerning sampling, recruitment, and inclusion criteria see Nilsson et al., 1997). Participants underwent an extensive health assessment at the first test occasion. One week later, 1,047 participants completed a battery of cognitive tests including episodic, semantic, and working memory. The two sessions lasted for about two hours each.

These participants received also the Swedish version of the A-DMC questionnaire and were asked to complete it at home and

[3] As pointed out in the discussion section, further studies could include measures of task-specific knowledge in order to provide a stronger test of the knowledge-related hypotheses advanced in the present article.

then to return it by postal mail. The A-DMC questionnaire presents detailed written instructions before each task and provides examples showing how to complete the items of the more complex tasks. Participants were asked to complete the A-DMC battery alone and without external aids, closely following the pre-specified order of the tasks (see Materials for more details).

Five hundred and seventy eight participants (55%) returned the questionnaire with at least 80% of all items completed. The remaining participants were considered to have dropped out (45%).[4] The final sample included 568 adults (26% in the 25–55 age range, 51% in the range 56–70, and 22% in the range 71–80) balanced for gender (49% males and 51% females).[5]

Materials.

Decision-making measures. Decision-making competence was assessed by using the Swedish-language version of the A-DMC battery, which underwent previous back-translation and validation, and showed psychometric properties similar to those of the original instrument (Mäntylä, Del Missier, et al., 2012). As with the original A-DMC (Bruine de Bruin, Parker, & Fischhoff, 2007), the Swedish version consists of six decision tasks: Resistance to Framing, Applying Decision Rules, Under/Overconfidence, Recognizing Social Norms, Resistance Sunk Cost, and Consistency in Risk Perception. The A-DMC tasks were administered in the original fixed order: (1) positive-item versions of Resistance to Framing, (2) Recognizing Social Norms questions to assess social norms, (3) Under/Overconfidence, (4) Applying Decision Rules, (5) Consistency in Risk Perception, (6) Resistance to Sunk Costs, (7) negative-item versions of Resistance to Framing, and (8) Recognizing Social Norms questions asking for estimates of other people's social norms. This order maximized the distance between related tasks (i.e., Resistance to Framing and Recognizing Social Norms).

Resistance to Framing. This task includes seven risky-choice framing problems and seven attribute framing problems. Each risky-choice problem is presented in pairs of formally equivalent gains and losses, and asks to evaluate a sure-thing option vs. a risky choice. For example, a risky-choice framing problem describes a pesticide threatening the lives of 1,200 endangered animals. The gain version poses a choice between (A) saving 600 endangered animals for sure and (B) a 75% chance that 800 animals will be saved, and a 25% chance that no animals will be saved. The corresponding loss version presents a choice between (A) losing 600 animals for sure and (B) a 75% chance that 400 animals will be lost, and a 25% chance that 1,200 animals will be lost (Schneider, 1992). Responses are given on a 6-point scale (1 = *definitely would choose A*; 6 = *definitely would choose B*), intentionally omitting a midpoint to force the expression of a preference between the two options. Each attribute framing problem asks participants to rate positive and negative descriptions of normatively equivalent options. For example, participants rated on a 6-point scale (1 = *very low*; 6 = *very high*) the quality of ground beef, described as 80% lean in the positive version and as 20% fat in the negative version (Levin & Gaeth, 1988). The positive frames and negative frames appear in separate sets with different item orders and are separated by other A-DMC tasks. Performance is measured by the mean absolute difference between ratings for the loss and the gain versions across items.

Applying Decision Rules. In this task, participants are presented with 10 different multi-attribute decision problems involving choices between fictitious DVD players with different features (such as picture quality). For each problem, participants are asked to select one or more options according to a different decision rule (lexicographic, satisficing, equal weights, etc.; see Payne et al., 1993) from a table showing numeric ratings of features. Each rule is presented by providing participants with a short written description of the procedure or criteria to be applied in the specific problem. Scores represent the proportion of responses across items that reflect normatively correct answers that would have been obtained from an errorless application of the prescribed decision rules.

Under/Overconfidence. This task presents 34 true/false statements about various general topics. Participants are asked to indicate whether each statement is true or false and to assess their confidence in their answer on a scale ranging from 50% (*just guessing*) to 100% (*absolutely sure*). Under/Overconfidence equals one minus the absolute difference between mean confidence and percentage correct across items (so that higher scores reflect better performance).

Recognizing Social Norms. Participants first judge whether "it is sometimes OK" to engage in each of 16 undesirable behaviors (e.g., to steal under certain circumstances). Later in the test battery, participants estimate how many "out of 100 people your age" would endorse each behavior. The former set of responses is used to compute the percentage of participants who endorsed each behavior (the actual social norms), the latter is used to assess the participant's perception of social norms. For each participant, performance is measured by the rank-order correlation (from −1 to 1) between the percentage of endorsements (actual social norms) and the estimated percentage of endorsements (perceived social norms) across the 16 behaviors.

Resistance to Sunk Costs. This tasks comprises 10 problems describing a situation in which someone could go on with a prior course of action that is failing (thus honoring sunk costs) or move to a new course of action. For each problem, participants are asked to provide a 1–6 rating to indicate their relative preference for the "sunk cost" option (= 1) versus the normatively correct option to discontinue the investment (= 6). Performance is measured by the average of the ratings across the 10 items, with higher ratings expressing greater Resistance to Sunk Costs.

Consistency in Risk Perception. For 10 different events, participants are asked to judge the probability of each happening in 1 year and in 5 years. Judgments of probability are expressed by ticking a graduated ruler ranging from 0% (no chance) to 100% (certain). Consistency is then evaluated by assessing the congruency of pairs of judgments with three principles: (i) the judged probabilities of the same event in different time frames should be consistent (e.g., the probability of getting in a car accident could not be greater in 1 year than in 5 years), (ii) the judged probability of a subset event cannot exceed that of its superset event (e.g., the probability "of dying in a terrorist attack during the next year"

[4] No significant attrition effect was observed for years of education, $t(1013) = 1.41$, $p = .16$. The dropouts were 43% males and 57% females, percentages that were only slightly different from the returnees' ones (albeit the difference was marginally significant: $p = .053$). A slight difference was observed also for age: returnees were, on average, 2 years older than dropouts, $t(1045) = 2.5$, $p = .01$ (63 vs. 61 years).

[5] Ten participants older than 80 were discarded.

cannot be greater than the probability of dying "from any cause—crime, illness, accident, and so on—during the next year"), and (iii) the judged probabilities of complementary events should add up to 100% (e.g., probability of moving "your permanent address to another state some time during the next year" and probability of keeping "your permanent address in the same state during the next year"). Performance is assessed by the proportion of consistency checks (on a total of 20) successfully passed by participants' probabilistic judgments.

Memory tests. The memory tests used in the present study were part of the larger cognitive test battery of the Betula project and they always appeared in the same fixed order throughout all test occasions. The order of the tests was as follows: vocabulary, recall of sentences, cued recall of nouns, word fluency, recognition of nouns, general knowledge, n-back, and reading span (with other tests interspaced). The order was fixed because counterbalancing was not achievable, considering the large number of tests and the forecasted loss of participants across Betula waves due to death, dementia, or other kinds of illness.

Working memory: Reading span. The reading span test evaluates working memory capacity through a computerized verbal span task, jointly tapping storage and processing functions (Daneman & Carpenter, 1980). The version of the task used in the present study involves multiple trials requiring the participant to decide whether a sentence displayed on a computer screen is semantically congruent or not and to memorize a sequence of single words presented in between sentences (see also Engle, Tuholski, Laughlin, & Conway, 1999). In the present study, participants performed three trials at each of four different levels of cognitive load corresponding to a successive increase in storage demands from two to five items (i.e., number of words to be memorized in a trial). The performance scores of serial recall at the end of each trial provide the basis for the evaluation of working memory capacity, which consists in the proportion of words recalled in correct serial order across the four different trials and levels.

Working memory: n-back. The ability to update working memory contents is assessed by a computerized version of the n-back paradigm (e.g., Owen, McMillan, Laird, Laird, & Bullmore, 2005). In the Betula T5 version of this test, forty single words are displayed sequentially on a computer screen and the participants are required to maintain the two most recent words and their temporal order in working memory to indicate whether the current word is the same as the one presented two items earlier or not. If the participant thinks that the current word matches the "2-back" word actively held in working memory she/he has to respond by pressing a "yes" key, otherwise she/he should press a "no" key. The test phase is preceded by two rounds of 15 practice items. Good performance on the 2-back task depends on continuous updating of the contents of working memory and efficient removal or suppression of no-longer relevant memory representations. The proportion of correct responses is used as the performance score.

Episodic memory: Recall of sentences. In this test (Nilsson et al., 1997; Rönnlund & Nilsson, 2006), participants are presented with two lists of 16 verb-noun sentences, each denoting a simple action (e.g., lift the book). For one list, participants are requested to enact each sentence, using the specified object. The other list is studied without enactment. A free recall test of the sentences follows after each list. The mean value of correctly recalled sentences (including the correct verb and noun) from the two lists is used as the dependent variable.

Episodic memory: Cued recall of nouns. This task is a category cued recall of nouns from the list of previously-presented words (Nilsson et al., 1997; Rönnlund & Nilsson, 2006). The nouns of the two study lists of the recall of sentences task belong to eight semantic categories (e.g., fruits, musical instruments, body parts, kitchen tools). Immediately after the free recall of sentences, participants are provided with these categories, and they are told that category cues might help to remember the nouns. The mean number of nouns recalled from the enacted and non-enacted list is the measure used in the analyses.

Episodic memory: Recognition of nouns. Thirty minutes after the free recall test, the participants are presented with 32 nouns. Of these, 8 are from the enacted study list and 8 from the non-enacted study list, and the remaining 16 are non-studied words (8 distracters per list, two for each category). Participants have to indicate, (by saying "Yes" or "No"), the items they recognize. The mean number of hits minus false alarms for each list is used as the dependent variable.

Semantic memory: Letter fluency. Participants generated as many words with an initial letter A as possible in one minute. The total number of correctly-generated words is used as performance score (Nilsson et al., 1997; Rönnlund & Nilsson, 2006).

Semantic memory: General knowledge. This test consist of 26 general knowledge questions (e.g., "What is the capital city of Ethiopia?"), with four possible answers out of which the correct one has to be chosen (Rönnlund & Nilsson, 2006). The performance score for this task is the number of correct answers.

Semantic memory: Vocabulary. The vocabulary test is a 30-item multiple-choice synonym test (SRB; Dureman, 1960). Participants' task is to select a synonym of the target word from among five alternatives. Seven minutes are allotted for test completion. The total number of correctly identified synonyms is the performance score (Nilsson et al., 1997; Rönnlund & Nilsson, 2006).

Results

The results will be presented in four steps, following the corresponding stages of data analysis. In the first step, a structural equation model of memory variables has been estimated. This represents a measurement model of memory functions that has been used in all subsequent stages. In the second stage, structural models have been estimated in order to test the specific hypotheses on the relationship between individual differences in memory functions and different facets of decision-making competence (cf. Table 1). In the third stage, the influence of age on different aspects of memory functioning has been assessed, by relying again on the measurement model estimated in the first stage. In the fourth and final stage, the models estimated in stages two and three have been combined, thus assessing simultaneously the effects of memory on decision making and the effects of age on both memory and decision making, in order to understand whether memory variables mediate the effects of age on different aspects of decision making. The approach of separating measurement models (stage 1) from structural models (stages 2 to 4) is often followed in structural equation modeling, because it assures that a structural model

Table 2
Descriptive Statistics for All the Measures Used in the Study

Measure	*N*	Range	*M*	Minimum	Maximum	*SD*	Skewness	Kurtosis	Reliability
Decision making									
Resistance to Framing[a]	568	0–5	3.91	2.36	4.93	0.52	−0.40	−0.16	.59
Under/Overconfidence	568	0–1	.89	.41	1.00	.08	−1.05	1.67	.62
Applying Decision Rules	564	0–1	.73	.27	1.00	.16	−0.32	−0.59	.83
Consistency in Risk Perception	568	0–1	.79	.30	1.00	.12	−0.50	0.30	.57
Recognizing Social Norms	559	−1 to 1	0.59	−0.22	0.89	0.21	−1.09	1.29	.78/.90[b]
Resistance to Sunk Costs	568	1–6	4.59	2.00	6.00	0.66	−0.44	0.16	.48
Working memory									
Reading span	520	0–1	0.35	0.00	1.00	0.20	0.70	−0.06	NA[c]
n-back[d]	525		0.98	0.00	1.57	0.20	0.07	3.44	.76
		(0–1)	(0.81)	(0.00)	(1.00)	(0.11)	(−2.23)	(11.4)	
Episodic memory									
Recall of sentences	568	0–16	7.56	1.50	14.00	2.35	0.05	−0.39	.63/.62[e,f]
Recognition of nouns	568	0–8	6.09	0.50	8.00	1.24	−0.84	0.66	NA
Cued recall of nouns	566	0–16	9.10	1.00	15.00	2.43	−0.34	0.10	.52/.64[e,f]
Semantic memory									
Letter fluency	567	0–	12.51	0.00	28.00	4.62	0.26	0.13	.68/.62[g]
General knowledge	567	0–26	17.12	6.00	25.00	3.29	−0.50	0.33	.71[e]
Vocabulary	563	0–30	23.95	9.00	30.00	3.58	−0.99	1.16	.86[e]

Note. Reliability was assessed through Cronbach's alpha, unless otherwise specified.
[a] This variable was reversed before structural equation modeling, with higher scores reflecting better performance. [b] The first number refers to the "self" part of the test; the second number refers to the "others" part. [c] Reliability is not available, but it is typically in the range of .70–.90 for span scores (Conway et al., 2005). [d] This variable was arcsine-transformed to reduce kurtosis and skewness; untransformed statistics are in parentheses. [e] Reliability from Rönnlund and Nilsson (2006), computed with the Spearman–Brown formula on odd–even arranged items. [f] Reliability for sentences/nouns with/without enactment, respectively. [g] Reliability is unavailable; stability coefficients 5/10 years are presented (Rönnlund & Nilsson, 2006).

is estimated only when a valid underlying measurement model exists (Hair, Black, Babin, & Anderson, 2009; Kline, 1998; Miyake et al., 2000). All the models presented in this article have been estimated with the maximum likelihood technique starting from the correlation matrix and using the SEPATH module of the STATISTICA 10 package (StatSoft, 2011).[6] Descriptive statistics and reliabilities for the variables used in the study are reported in Table 2, and they are in line with previous A-DMC studies (Bruine de Bruin, Parker, & Fischhoff, 2007, 2012; Del Missier et al., 2010, 2012).

Stage 1: Measurement model of memory variables. A candidate measurement model with three latent variables (working memory, episodic memory, and semantic memory) was estimated from manifest indicators (i.e., measured variables). This model relies on traditional distinctions between working memory and long-term memory, and between episodic and semantic memory (e.g., Baddeley, 2003; Nyberg & Tulving, 1996; Tulving, 1972, 1987, 2002), and on previous Betula studies that supported these distinctions (Nyberg, 1994; Nyberg et al., 2003). In the present study, however, a strong stance on the structural separation between different memory systems is not taken, and it is just assumed that processes underlying active maintenance and updating of information in the short term and different processes that underlie retention and recall of information in the long term can be (at least partially) functionally differentiated. Moreover, considering the multiple interrelations and interdependencies existing between processes involved in working memory, episodic memory, and semantic memory (e.g., Kane & Engle, 2000; Tulving, 1995, 2002; Unsworth & Engle, 2007), positive correlations between these latent variables were expected. Indeed, it has been postulated that working memory can support retrieval in episodic memory tasks (e.g., Kane & Engle, 2000; Unsworth & Engle, 2007), and that close relationships exist between semantic and episodic memory (e.g., Tulving, 1995; but see also Graham, Simons, Pratt, Patterson, & Hodges, 2000). Furthermore, semantic memory can support working memory and episodic memory when verbal material has to be processed, for instance when verbal tasks are used to measure individual differences in working memory or episodic memory (as in the present study).

The candidate three-factor correlated model was compared with theoretically-grounded potential alternatives (see, e.g., Baddeley, Eysenck, & Anderson, 2009; Miyake & Shah, 1999): (a) a one-factor model in which all the memory indicators reflect a single latent variable (unitary memory model); (b) two-factor models with working memory and long-term memory as the two latent variables (correlated or uncorrelated); (c) a three-factor uncorrelated model in which working memory, semantic memory and episodic memory are considered as fully independent constructs. Following common practice, models were evaluated through multiple indices of fit: standardized root-mean-squared residual (SRMR), Akaike's information cri-

[6] All the models tested in this study have been tested also with the Asymptotically Distribution Free (Gramian) estimation method, which is more robust (not requiring the assumption of multivariate normality). The results obtained were always very similar to the ones provided by the maximum likelihood technique. Moreover, all the models have been tested also after the variable by variable iterative removal of outliers (±3 *SD*s away from the mean; less than 1% of values per variable on average), without any appreciable change in the results and conclusions. In all the models tested, cases with missing data have been deleted listwise. The results were always consistent across models and stages (see notes 9, 12, and 14). Only bootstrapped confidence intervals for indirect effects in the mediation models (fourth stage of data analysis) have been computed after missing data imputation with the regression method, due to the fact that the AMOS 20 package, used for this specific analysis, does not accept missing data. However, as it will be shown, listwise analyses on the indirect effects were consistent with bootstrapped confidence intervals.

Table 3
*Fit Indices for Measurement Models of Memory Variables (*n = *510)*

Model	SRMR	AIC	CFI	APGI	RMSEA	χ^2	*df*	χ^2/df
1. Semantic + Episodic + Working (correlated)	.045	.186	.964	.960	.067	56.93	17	3.35
2. Semantic + Episodic + Working (uncorrelated)	.196	.555	.794	.815	.152	252.51	21	12.02
3. Working + Long-Term (correlated)	.095	.515	.814	.796	.159	228.10	19	12.00
4. Working + Long-Term (uncorrelated)	.163	.682	.737	.771	.171	316.91	21	15.09
5. Unitary	.097	.539	.802	.794	.161	242.50	20	12.16
6. Semantic + Episodic + Working (correlated)—Revised	**.034**	**.147**	**.983**	**.980**	**.048**	**34.77**	**16**	**2.17**

Note. Model 6 is Model 1 with the addition of a working memory → letter fluency relationship (see the main text for an explanation). The endorsed model is indicated in bold. SRMR = standardized root-mean-squared residual; AIC = Akaike's information criterion; CFI = comparative fit index; APGI = adjusted population gamma index; RMSEA = root-mean-square error of approximation.

terion (AIC),[7] Bentler's comparative fit index (CFI), adjusted population gamma index (APGI), the root-mean-square error of approximation (RMSEA), and the χ^2/df ratio.[8] Moreover, the significance of estimated coefficients and the residuals were examined, and the fit of nested models was compared using the χ^2 difference test. Reference thresholds for good fitting models are as follows: SRMR (<.08), AIC (the lower, the better), CFI (>.90), APGI (>.95), RMSEA (<.06), and χ^2/df (< 3).

As can be seen in Table 3, the three-factor correlated model (1) had an acceptable to good fit according to all the indices. The three-factor uncorrelated model (2) was unacceptable according to almost all the indices and significantly worse than the correlated model (χ^2 difference test: $p < .0001$). The two-factor models and the unitary model (3, 4, and 5) showed unsatisfying fit. Thus, only the candidate three-factor correlated model seems to provide an adequate fit to the data. However, after an examination of the residuals, a working memory → letter fluency link was added to this model in view of a potential increment in fit and, even more importantly, considering that the letter-fluency tasks is known to require working memory resources (e.g., Rende, Ramsberger, & Miyake, 2002). This revised model (6), showed an improvement in fit vs. the candidate model (χ^2 difference test: $p < .0001$) and improvements to good fit on all the indices. To conclude, the revised three-factor correlated model is a good measurement model for memory variables, and this model was used as a basis in the following steps of data analysis (see Figure 1 for a representation including standardized coefficients, standard errors, and significance tests).[9]

Stage 2: Relationships between memory and decision making. In this step, the previously-specified hypotheses (see Table 1, first four columns) were tested by specifying corresponding structural models. Following a consolidated approach (see, e.g., Del Missier et al., 2012; Friedman & Miyake, 2004; Miyake et al., 2000), a candidate structural model was specified for each decision-making task by adding the hypothesized relationships between memory latent variables and the target task.[10] Then, the candidate model was always compared with two baseline models: a no-path model that assumed complete independence between memory variables and decision-making competence, and a full-path model assuming that each memory variable contributes significantly to performance in the target decision-making task (thus assessing the relationships between each memory variable and the decision-making task). To fully support the hypothesis, the candidate model should have a significantly better fit than the no-path model, without showing a significantly worse fit than the full-path model. Only when a model presented a satisfying level of fit, the significance of estimated structural coefficients was taken in account in the process of hypothesis testing. Table 4 presents the modeling results for all the tasks.

The candidate model for Resistance to Framing (working memory) showed good measures of fit, it had a better fit than the no-path model (χ^2 difference test, $p < .0001$), and it was not worse than the full-path model (χ^2 difference test, $p = 1.00$). Only the working memory coefficient was significant in the full-path model. The results fully support the hypothesis that Resistance to Framing is positively and selectively related with individual differences in working memory.

The candidate model for Applying Decision Rules (working memory) presented good fit indices, and it was better than the no-path model (χ^2 difference test, $p < .0001$). However, the model was worse than the full-path model (χ^2 difference test: $p < .05$). A model assuming a positive relationship between performance in Applying Decision Rules and both working memory and semantic memory (see Table 4) showed a better fit than the no path model (χ^2 difference test, $p < .0001$) and was not worse than the full-path model (χ^2 difference test, $p = .40$). Additionally, this revised model had a better fit than the candidate working memory model (χ^2 difference test, $p < .05$). Finally, the working memory and semantic memory coefficients, but not the episodic memory coefficient, were signifi-

[7] AIC in STATISTICA 10 is computed with a formula that takes into account the maximum likelihood discrepancy function for a model (Fml), the number of free parameters (v), and the sample size (n): AIC = Fml + ($2v/n$ + 1). This formula makes the AIC more stable across differing sample sizes.

[8] The probability of the χ^2 statistic is not reported, given that with big sample sizes even good fitting models can show a significant χ^2 (e.g., Hair et al., 2009; Kline, 1998). Thus, the significance of this statistics is not useful in discriminating good and bad models in studies like the present one. However, the χ^2/df ratio is reported, which is less sensitive to sample size. Although different researchers suggest different rules of thumb for evaluating the χ^2/df ratio, most agree that values lower than 3 indicate good fit and values greater than 5 unacceptable fit (e.g., Hair et al., 2009; Kline, 1998). Lower values indicate better-fitting models.

[9] In order to test the stability of the memory model endorsed in the first stage of data analysis, we compared its coefficients with the corresponding coefficients of the six structural models endorsed in the second stage of data analysis (see Table 4). Marked differences in coefficients (factor loadings of the individual memory tasks and/or correlations among the memory latent variables) could indicate model misspecification or unstability (Friedman & Miyake, 2004; Miyake et al., 2000). The mean absolute difference in parameter values was very small (.009) and the average correlation between parameter values very high (.99). No marked changes in parameter values or significance levels were detected.

[10] In order to specify directed paths between correlated memory latent variables and manifest decision-making variables, correlations between memory latent variables were modeled as correlations between their errors (Byrne, 2010).

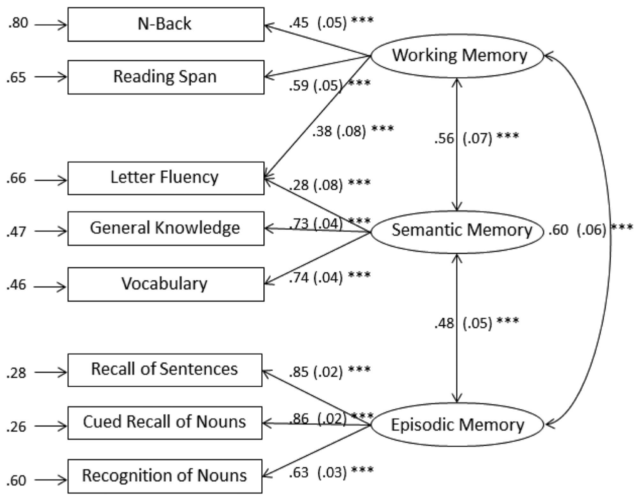

Figure 1. The three-component correlated measurement model of the memory variables. Numbers on arrows are standardized coefficients; those next to the smaller arrows on the left are residual variances, and those on the double-headed arrow are interfactor correlations ($^{***}p <$ .001). Standard errors are in parentheses, after the corresponding coefficients.

cant in the full-path model. The results are consistent with the hypothesis that Applying Decision Rules is positively related with individual differences in working memory, but they highlight also a positive contribution of semantic memory, confirmed by the results of a single-path semantic memory model (see Table 4). This unpredicted influence is possibly related to the role of semantic memory in the complex comprehension processes required by the task (see the Discussion section).

The fit of the candidate model for Under/Overconfidence (working memory) was good, the model had a significantly better fit than the no-path model (χ^2 difference test, $p < .0001$), and it was not worse than the full-path model (χ^2 difference test, $p = .79$). Only the working memory coefficient was significant in the full-path model. These results fully support the hypothesis that performance in Under/Overconfidence is selectively related to working memory.

The candidate model for Recognizing Social Norms (episodic memory) showed good indices of fit, it had a significantly better fit than the no-path model (χ^2 difference test, $p < .01$), and it was not worse than the full-path model (χ^2 difference test, $p =$ .25). Only the episodic memory coefficient was marginally significant in the full-path model. These results agree with the hypothesis that performance in Recognizing Social Norms is positively and selectively related with individual differences in episodic memory.

The fit of the candidate model (semantic memory) for Resistance to Sunk Costs was fully acceptable, and this model had a better fit than the no-path model fit (χ^2 difference test, $p <$ .001). Albeit the candidate model was slightly worse than the full-path model (χ^2 difference test, $p < .05$), the only better-fitting alternative included an additional negative relation between Resistance to Sunk Costs and working memory (see Table 4). However, this alternative model was both theoretically and statistically unconvincing: the lack of a theoretical justification for the negative effect of working memory on Resistance to Sunk Costs (no existing theoretical account supports such a relationship) and additional model fitting results[11] favored the semantic memory model. All the estimated models support the hypothesis that performance in Resistance to Sunk Cost is positively associated with individual differences in semantic memory.

The candidate model (semantic memory) for Consistency in Risk Perception showed good measures of fit, it had a significantly better fit than the no-path model (χ^2 difference test, $p < .001$), and it was not worse than the full-path model (χ^2 difference test, $p =$ .11). Only the semantic memory coefficient was significant in the full-path model. The results fully support the hypothesis that performance in Consistency in Risk Perception is selectively related to semantic memory.

The results of the second stage of data analysis supported all the hypotheses. Although better performance in memory tasks was always associated with better performance in decision-making tasks, the results display a selective network of relations between memory variables and decision making (see Table 1). A single unpredicted finding emerged, in the form of a positive relation between semantic memory and Applying Decision Rules.

Stage 3: The influence of age on memory variables. As a preliminary step for testing the predictions regarding the influence of age on decision making, it was necessary to estimate a model specifying the relations between age and memory variables. Starting from the literature on memory in cognitive aging (e.g., Park, 2000; Park et al., 2002, 1996; Salthouse, 2004) and previous Betula studies (Nilsson, 2003; Nilsson et al., 2004, 1997; Nyberg, 1994; Nyberg et al., 2003; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005), the candidate model assumed that working memory and episodic memory decline with age, while semantic memory was expected to be unaffected by aging. The measurement model estimated in stage 1 was used as a basis, and specific relations between the "age" manifest variable and the memory latent variables were added. This model was compared with a no path model (assuming no relation between age and memory variables) and with a full path model (assuming that age influences all the memory variables). Ideally, the candidate model should be significantly better than the no path model but not significantly worse than the full path model. SEM results are presented in Table 5.

The candidate model showed good measures of fit. In addition, the candidate model had a significantly better fit than the no-path model (χ^2 difference test, $p < .0001$) and it was not worse than the

[11] Considering that bivariate correlations between working memory measures and Resistance to Sunk Costs were actually very close to zero (see the Appendix), the results of this model should be considered with caution. They could be the outcome of statistical accommodation for the lack of positive correlations (albeit slight and nonsignificant) between the working memory tasks and Resistance to Sunk Costs that should be expected on purely statistical grounds, considering the positive correlation between working memory and semantic memory (for a similar case, see Miyake et al., 2000, pp. 81–82, Operation Span models). This interpretation is supported by the observation that a model with a single path from working memory to Resistance to Sunk Costs (see Table 4) exposed a nonsignificant structural coefficient and it was not better than the no-path model ($p = .32$).

Table 4
Fit Indices for Structural Models of the Memory–Decision Making Relationships

Decision-making task	Model	χ^2	*df* (χ^2/*df*)	SRMR	AIC	CFI	APGI	RMSEA	WM → dmc	EM → dmc	SM → dmc
Resistance to Framing	Full path	41.65	21 1.98	.033	.176	.982	.981	.044	$.306^{**}$ (.11)	−.003 (.08)	.006 (.08)
(*N* = 510)	**WM**	**41.65**	**23 1.81**	**.033**	**.168**	**.984**	**.984**	**.040**	**$.309^{***}$ (.05)**		
	No path	72.48	24 3.02	.070	.225	.958	.961	.063			
Applying Decision Rules	Full path	53.75	21 2.56	.038	.201	.973	.970	.055	$.448^{***}$ (.10)	−.065 (.08)	$.197^{*}$ (.08)
(*N* = 506)	WM	60.42	23 2.63	.040	.207	.969	.970	.055	$.544^{***}$ (.04)		
	WM, SM	**54.46**	**22 2.47**	**.038**	**.199**	**.973**	**.971**	**.054**	**$.388^{***}$ (.07)**		**$.196^{**}$ (.07)**
	SM	77.85	23 3.38	.049	.241	.955	.952	.070			$.462^{***}$ (.04)
	No path	160.96	24 6.71	.117	.402	.888	.902	.102			
Under/Overconfidence	Full path	45.67	21 2.17	.035	.184	.979	.977	.049	$.225^{*}$ (.10)	.049 (.07)	.014 (.08)
(*N* = 510)	**WM**	**46.13**	**23 2.00**	**.035**	**.177**	**.980**	**.980**	**.045**	**$.281^{***}$ (.05)**		
	No path	71.23	24 2.97	.068	.222	.959	.962	.062			
Recognizing Social Norms	Full path	32.71	21 1.56	.029	.161	.989	.989	.033	−.080 (.11)	$.138^{\dagger}$ (.08)	.128 (.08)
(*N* = 503)	**EM**	**35.51**	**23 1.54**	**.032**	**.158**	**.989**	**.990**	**.032**		**$.152^{**}$ (.05)**	
	No path	45.68	24 1.90	.050	.175	.980	.983	.042			
Resistance to Sunk Costs	Full path	40.42	21 1.92	.032	.174	.983	.982	.042	$-.222^{*}$ (.11)	−.018 (.07)	$.358^{***}$ (.08)
(*N* = 510)	**SM**	**48.61**	**23 2.11**	**.039**	**.182**	**.978**	**.978**	**.047**			**$.195^{***}$ (.05)**
	WM	62.05	23 2.70	.044	.208	.966	.967	.058	.058 (.06)		
	WM, SM	40.48	22 1.84	.032	.170	.984	.984	.040	$-.238^{**}$ (.09)		$.359^{***}$ (.08)
	No path	63.02	24 2.63	.048	.206	.966	.969	.056			
Consistency in Risk Perception	Full path	44.13	21 2.10	.034	.181	.980	.978	.048	−.074 (.11)	−.086 (.07)	$.296^{***}$ (.08)
(*N* = 510)	**SM**	**48.57**	**23 2.11**	**.038**	**.182**	**.978**	**.978**	**.047**			**$.191^{***}$ (.05)**
	No path	62.33	24 2.60	.048	.205	.966	.970	.056			

Note. Estimated coefficients for memory → decision making relationships (in the last three columns) are followed by respective standard errors (in parentheses). The endorsed model for each Adult Decision-Making Competence battery task is indicated in bold. SRMR = standardized root-mean-squared residual; AIC = Akaike's information criterion; CFI = comparative fit index; APGI = adjusted population gamma index; RMSEA = root-mean-square error of approximation; WM = working memory; EM = episodic memory; SM = semantic memory; dmc = Decision-Making Competence variable, as indicated in the first column. Significance levels of two-tailed tests are as follows:
$^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

full-path model (χ^2 difference test, $p = .65$). The coefficients of the age→working memory and age→ episodic memory relationships were negative and significant, as expected. This model, which is consistent with previous studies and showed a good fit to the data, was used in the last stage of data analysis as a basis for mediation testing.[12]

Stage 4: Mediation models. Does memory mediate the effects of age on decision making? The goal of the fourth and last stage of data analysis was to understand whether age-related memory declines mediate (or partially mediate) some of the observed negative relationships between age and performance in decision-making tasks. Furthermore, given that a previous study on the same tasks observed suppression effects after controlling for the effect of cognitive variables (Bruine de Bruin, Parker, & Fischhoff, 2012), potential suppression effects in relation to memory variables were also examined.

Bivariate correlations showed the expected significant negative relationships between age and performance in three decision-making tasks: Resistance to Framing, Applying Decision Rules, and Under/Overconfidence. The hypothesis for these three more cognitively-demanding tasks is that the decline in working memory will mediate (or partially mediate) the negative influence of age on decision making (see Table 1, last column). No significant correlations between age and performance were observed for Recognizing Social Norms and Consistency in Risk Perception, while a significant positive correlation was apparent between age and Resistance to Sunk Costs. The hypothesis for Recognizing Social Norms is that the episodic memory decline could contribute to the age-related performance decrease. As previously stated, controlling for it could expose a significant suppression effect (i.e., age could be positively related to Recognizing Social Norms after controlling for the age-related negative influence of episodic memory). A relationship between age and Consistency in Risk Perception is not expected after controlling for the positive influence of semantic memory. Finally, considering that a positive relationship between age and ignoring sunk costs has been repeatedly observed and linked to age-related changes in emotion regulation, we expect a positive correlation between age and Resistance to Sunk Costs even after controlling for individual differences in semantic memory.

Each model tested in the fourth stage of data analysis was specified by combining three components: (1) the stage-three memory model, embodying the negative effects of age through working memory and episodic memory (i.e., the age → working memory and age → episodic memory relationships), (2) the structural links between memory variables and the target decision-

[12] We compared the coefficients of the memory models endorsed in the first and third stage of data analysis, to further assess the stability of the solution and to understand to what extent the correlation between working memory and episodic memory latent variables could be explained by the influence of the age variable. The mean absolute difference in parameter values was small (.054) and the average correlation between parameter values was high (.90), confirming the stability of the memory model. The single noticeable change in parameter values concerned the correlation between working memory and episodic memory, which decreased from .595 to .358 (being still significant: $p < .001$). This indicates that only part of the correlation between these two latent variables is due to their negative relations with age.

Table 5
Fit Indices for Age → Memory Models (n = 510)

Model	χ^2	df (χ^2/df)	SRMR	AIC	CFI	APGI	RMSEA	Age → Working memory	Age → Episodic memory	Age → Semantic memory
Full path	52.81	21 2.51	.039	.198	.976	.971	.054	−.641*** (.05)	−.389*** (.04)	.025 (.05)
Age → Episodic memory, working memory	**53.02**	**22 2.41**	**.040**	**.195**	**.976**	**.973**	**.053**	**−.647*** (.05)**	**−.396*** (.04)**	
No path	216.49	24 9.02	.114	.508	.852	.868	.119			

Note. Estimated coefficients for age → memory relationships in the last three columns are followed by respective standard errors (in parentheses). SRMR = standardized root-mean-squared residual; AIC = Akaike's information criterion; CFI = comparative fit index; APGI = adjusted population gamma index; RMSEA = root-mean-square error of approximation. The endorsed model is indicated in bold. Significance levels of two-tailed tests are as follows:
*** $p < .001$.

making task highlighted in the second stage of data analysis, and (3) a link between age and the target decision-making task, to allow testing the previously specified hypotheses on the relationships between age, memory, and the decision-making task (see Table 1, last column).[13] Thus, each model estimated in the fourth stage was built on the three previous modeling stages and it was fully consistent with previously estimated models. SEM results for each model are reported in Table 6.[14]

The candidate model for Resistance to Framing assumes that the age-related decline in working memory mediates (at least partially) the effect of age on performance. Thus, the candidate model comprises an age → Resistance to Framing link and a working memory → Resistance to Framing link. As shown in Table 6, this model has good measures of fit, the relation between age and Resistance to Framing is positive and significant as well as the relation between working memory and Resistance to Framing, while the relation between age and working memory is negative (−0.642, SE = 0.05, $p < .001$) as in the stage-three model. The indirect negative effect of age on Resistance to Framing (through working memory) is −0.26 (95% CI [−0.37, −0.15]),[15] which is significant according to a one-tailed Sobel test (−4.67, $p < .0001$). Confidence intervals computed with the bias corrected percentile bootstrapping method on 1,000 samples provide converging results (95% CI [−0.38, −0.16]).[16] The results show that individual differences in working memory completely mediate the negative effect of age on Resistance to Framing. Moreover, they expose a significant suppression effect: When the negative influence of age on Resistance to Framing through the working memory decline is controlled for, the relation between age and Resistance to Framing is positive, highlighting a positive influence of age.

The candidate model for Applying Decision Rules assumes that the age-related decline in working memory mediates (at least partially) the effect of age on performance. Thus, the candidate model comprises an age → Applying Decision Rules link and a working memory → Applying Decision Rules link. The results show that candidate model presents good measures of fit (see Table 6). The relation between age and Applying Decision Rules is significant and negative, the one between working memory and Applying Decision Rules is positive, but marginally significant only in a one-tailed test (p = .08), while the relation between age and working memory is significant and negative (−0.647, SE = 0.05, $p < .001$). The indirect negative effect of age on Applying Decision Rules (through working memory) is −0.14 (95% CI [–0.33, 0.05]), which is marginally significant according to a one-tailed Sobel test (−1.46, p = .07). However, bootstrapping confidence intervals computed with the bias corrected percentile method on 1000 samples do not allow rejecting the hypothesis that the indirect effect is zero in the population (95% CI [–0.80, 0.69]). The results show a trend compatible with the view that individual differences in working memory may partially mediate the negative effect of age on Applying Decision Rules, but statistical tests reach only marginal significance and confidence intervals do not allow rejecting the hypothesis that the indirect effect could be zero in the population. In any case, the existing trend would suggest partial mediation, indicating that the negative influence of age on Applying Decision Rules cannot be completely traced back to an age-related decline in working memory.

The candidate model for Under/Overconfidence assumes that the age-related decline in working memory mediates (at least partially) the negative effect of age on task performance. Thus, the candidate model comprises an age → Under/Overconfidence link

[13] For instance, in the case of Applying Decision Rules, the following links were added to the model developed in the third stage of data analysis: Semantic Memory → Applying Decision Rules and Working Memory → Applying Decision Rules (from stage two); Age → Applying Decision Rules (to test the working memory mediation hypothesis). This allowed a test of the mediation hypothesis, maintaining at the same time the age → memory relationships detected in third stage of data analysis and incorporating the structural relationships emerged in the second stage.

[14] In order to assess the stability of the memory + age model endorsed in the third stage of data analysis, we compared its coefficients with the corresponding coefficients of the models endorsed in the fourth stage. We observed a very small mean absolute difference in parameter values (.002), a very high average correlation between values (.99), and no marked changes in values or significance levels. To evaluate the robustness of the findings on the relationships between memory and decision making, we also compared the coefficients of the models endorsed in stages two and four for each A-DMC task. The results proved to be robust, showing a small mean absolute difference in values (.052), a high average correlation between parameters (.91), and no marked changes in values or significance levels, with the exceptions of the already-mentioned decrease in the correlation between working memory and episodic memory (see note 12) and a decrease in the coefficient of the relation between working memory and Applying Decision Rules (from .388 to .215).

[15] All CIs for coefficients of the mediation models were computed with the Baron–Kenny equation, but conclusions did not change when using the equation proposed by MacKinnon, Warsi, and Dwyer (1995; see also Shrout & Bolger, 2002).

[16] Boostrapped CIs were always computed by using the AMOS 20 package (Arbuckle, 2011), after missing data imputation with the regression method.

Table 6
Fit Indices for Models Including Age, Memory, and Decision Making

Model	Decision-making variable	N	χ^2	df (χ^2/df)	SRMR	AIC	CFI	APGI	RMSEA	WM → dmc	EM → dmc	Age → dmc
WM mediation	Resistance to Framing	510	57.80	29 1.99	.038	.216	.978	.978	.045	.401*** (.08)		.146* (.07)
WM mediation	Applying Decision Rules	506	62.86	28 2.24	.041	.231	.976	.973	.050	.215 (.15)		−.215* (.11)
WM mediation	Under/Overconfidence	510	60.69	29 2.09	.039	.221	.976	.976	.047	.297*** (.08)		−.005 (.07)
EM suppression	Recognizing Social Norms	503	53.05	29 1.83	.038	.209	.981	.982	.040		.224*** (.05)	.176*** (.05)
No mediation	Resistance to Sunk Costs	510	59.50	29 2.05	.038	.219	.977	.977	.046			.161*** (.04)
No mediation	Consistency in Risk Perception	510	67.47	29 2.33	.041	.235	.971	.971	.052			.010 (.04)

Note. Estimated coefficients for memory → decision making relationships and for the age → decision making relationship (in the last three columns) are followed by respective standard errors (in parentheses). SRMR = standardized root-mean-squared residual; AIC = Akaike's information criterion; CFI = comparative fit index; APGI = adjusted population gamma index; RMSEA = root-mean-square error of approximation; WM = working memory; EM = episodic memory; dmc = Decision-Making Competence variable, as indicated in the second column. Significance levels of two-tailed tests are as follows: $^{*}p < .05$. $^{***}p < .001$.

and a working memory → Under/Overconfidence link. The results indicate that the model fit is good (see Table 6), the relation between age and Under/Overconfidence is nonsignificant and very close to zero, and the relationship between working memory and Under/Overconfidence is positive and significant. The relation between age and working memory is negative (−0.652, SE = 0.05, $p < .001$). The indirect negative effect of age on Under/Overconfidence (through working memory) is −0.19 (95% CI [−0.30, −0.09]), which is significant according to a one-tailed Sobel test (−3.57, $p < .001$). Confidence intervals computed with the bias corrected percentile bootstrapping method on 1,000 samples corroborate the hypothesis that working memory mediates the negative effect of age on Under/Overconfidence (95% CI [−0.34, −0.12]).

The candidate model for Recognizing Social Norms assumes that the age-related decline in episodic memory negatively affects task performance. Additionally, considering that the bivariate correlation between age and Recognizing Social Norms is close to zero, a suppression effect may emerge after controlling for the negative effect of age through episodic memory. To test for these hypotheses, the candidate model comprises an age → Recognizing Social Norms link and an episodic memory → Recognizing Social Norms link. This model exposes good measures of fit (see Table 6), and positive significant relationships are apparent between age and Recognizing Social Norms and between episodic memory and Recognizing Social Norms. The negative relation between age and episodic memory is confirmed (−0.397, SE = 0.04, $p < .001$). The indirect negative effect of age on Recognizing Social Norms is −0.09 (95% CI [−0.13, −0.05]), which is significant according to a one-tailed Sobel test (−4.08, $p < .0001$). These results were corroborated by confidence intervals computed with the bias-corrected percentile bootstrapping method on 1000 samples (95% CI [−0.15, −0.06]). In summary, the results support the hypothesis that that age has a negative influence on the performance in Recognizing Social Norms through its negative impact on episodic memory. However, after controlling for this negative indirect effect, a positive influence of age on Recognizing Social Norms emerges, highlighting a suppression effect.

The candidate model for Resistance to Sunk Costs assumes that age is positively related with performance and that neither working memory nor episodic memory mediates this positive relationship. Table 6 shows that this model has a good fit to the data, and the result confirm the positive relationships between age and Resistance to Sunk Costs, and between semantic memory and Resistance to Sunk Costs (0.206, SE = 0.05, $p < .001$).

Considering the results of the second and third stage of data analysis, the candidate model for Consistency in Risk Perception is a no mediation model, with the inclusion of a Semantic Memory → Consistency in Risk Perception link. The results presented in Table 6 show that this model achieves a good level of fit, confirming the nonsignificant age→ Consistency in Risk Perception link (p = .813) and the significant Semantic Memory → Consistency in Risk Perception link (0.184, SE = 0.05, $p < .001$). Table 7 summarizes the results of the fourth stage of data analysis.

Table 7
Summary of the Results of the Fourth Stage of Data Analysis

Decision-making task	Bivariate correlation with age	Indirect effect	Relation with age after controlling for mediators/predictors
Resistance to Framing	Negative (r = −.11, $p < .01$, n = 568)	Working memory mediation (−.26)	Positive (.146)
Applying Decision Rules	Negative (r = −.36, $p < .001$, n = 564)	Trend toward working memory partial mediation (−.14)	Negative (−.215)
Under/Overconfidence	Negative (r = −.20, $p < .001$, n = 568)	Working memory mediation (−.19)	Nonsignificant (−.005)
Recognizing Social Norms	Nonsignificant (r = .07, p = .12, n = 559)	Episodic memory mediation (−.09)	Positive (.176)
Resistance to Sunk Costs	Positive (r = .15, $p < .001$, n = 568)	No mediation tested	Positive (.161)
Consistency in Risk Perception	Nonsignificant (r = −.01, p = .82, n = 568)	No mediation tested	Nonsignificant (.010)

Discussion

The main goal of the present study was to test specific hypotheses on the relationships between memory and important components of decision-making competence. These hypotheses were generated by coupling the general idea that diverse memory processes may functionally support decision-making performance in different ways with existing accounts of various judgment and decision-making tasks. To test the hypotheses, we carried out an investigation of the relationships between individual differences in semantic, episodic, and working memory, using multiple indicators of each, and individual differences in six tasks of the A-DMC battery. The data were collected in the context of the Betula Prospective Cohort Study (Nilsson et al., 2004, 1997), and data analysis was carried out in four stages. First, a measurement model of memory variables was estimated, finding that a three-factor correlated model (working, semantic, episodic memory) provides the best fit to the data. This model agrees with traditional distinctions between working memory, episodic memory, and semantic memory (e.g., Baddeley, 2003; Tulving, 1972, 1987, 2002).

Building on this model, the relationships between memory latent variables and performance in each A-DMC task were examined. A general conclusion is that better performance in memory tests was always associated with a better performance in decision-making tests, thus underlining the functional role of memory processes for effective decision making. More interestingly, the results showed selective relations between memory and decision making as measured by the A-DMC tasks.

In particular, the results showed that working memory is positively related with Resistance to Framing, Applying Decision Rules, and Under/Overconfidence. This agrees with the view that these cognitively demanding decision tasks require active processing of relevant information (e.g., Bruine de Bruin, Parker, & Fischhoff, 2012; Del Missier et al., 2012). The results on the framing task are consistent with research showing that Resistance to Framing is related to individual differences in cognitive ability in within-subjects designs (e.g., Bruine de Bruin, Parker, & Fischhoff, 2007; Stanovich & West, 2008), it is associated to prefrontal activity (De Martino et al., 2006) and benefits from a more analytic approach to the problems (McElroy & Seta, 2003). Working memory resources seem to be required for the correct accomplishment of this task, probably because it implies a cognitively-demanding analysis and thorough processing of the problem information (in spite of surface changes across the frame versions) and the ability to inhibit impulsive responses based on a superficial and perhaps emotional appraisal of the options (Del Missier et al., 2012; De Martino et al., 2006; Kahneman & Frederick, 2007). After the age-related decline in working memory has been controlled for, a positive effect of age on Resistance to Framing was observed. This can be possibly explained as an effect of the greater role played by emotion regulation in older adults, which can lead to an attenuation of the rough emotional appraisal of the options (see, e.g., Peters et al., 2007), although this potential interpretation clearly needs to be corroborated by further research.

The correct application of decision-making rules was positively related to working memory. Also in this case, the findings agree with previous research showing that processes involved in working memory functioning and executive control are needed for the accomplishment of the Applying Decision Rules task (Del Missier et al., 2010, 2012), which requires comparisons between values, information integration, and suppression of interfering stimuli. An unexpected relation between semantic memory and Applying Decision Rules was also observed, which could be explained by the consideration that this task requires comprehension of particularly complex written instructions (including the description of the rules to be applied) and their translation into procedures (for the role of comprehension skills on decision-making tasks similar to Applying Decision Rules, see also Finucane & Guillon, 2010; Finucane, Mertz, Slovic, & Schmidt, 2005; Finucane et al., 2002). This interpretation of the findings would also agree with studies showing a link between performance in complex comprehension tasks and both working memory and semantic memory (e.g., Calvo, 2005; Dixon, LeFevre, & Twilley, 1988; Engle, Cantor, & Carullo, 1992; Just & Carpenter, 1992).

The results of the present study also highlighted a positive relation between working memory measures and calibration of confidence in knowledge. This finding agrees with a previous investigation carried out on a Swedish sample (Mäntylä, Del Missier, et al., 2012). According to the proposed hypothesis and to existing theoretical views, it can be explained by referring to the cognitively-demanding processes underlying information consideration and the assessment of the degree of support for or against the given answer before the expression of the confidence judgment (Brenner et al., 1996; Hoch, 1985; Koriat et al., 1980). This view implies that a more thorough analysis of evidence/reasons for or against one answer is grounded in working memory processes (for analogous observations on different judgment tasks, see also Dougherty & Hunter, 2003; Sprenger & Dougherty & 2006).

Semantic memory was found to be positively related with Consistency in Risk Perception and Resistance Sunk Costs, and these findings support the theoretical view that these two tasks may be more knowledge-based than other decision-making tasks (Bruine de Bruin, Parker, & Fischhoff, 2012; Larrick et al., 1990; Stanovich & West, 2008). However, in the light of other empirical studies, it would be wise to conclude that performance in Consistency in Risk Perception could require a mixture of knowledge and specific executive processes, like the ability to switch between different evaluation contexts (Del Missier et al., 2010, 2012). Additionally, the ability to resist sunk costs is not only related to semantic memory, but also positively associated with age. Previous studies explained this positive relation by referring to older adults' reduced tendency to focus on painful unrecoverable past costs, due to their increased desire to maintain a positive emotional state (Strough, Karns, & Schlosnagle, 2011; Strough et al., 2008; Strough, Schlosnagle, & DiDonato, 2011).

Finally, episodic memory was found to be positively related with Recognizing Social Norms. In this case, the proposed explanation is that individuals who are more able to encode episodic information on social behaviors may be more successful in estimating the relative frequency of behaviors related to social norms (Brown, 1995, 1997, 2002; Conrad et al., 1998; Haberstroh, 2008), and this would support their capacity to evaluate the acceptability of social norms. Moreover, the positive effect of age on Recognizing Social Norms, observed after the negative age-related effect of episodic memory had been taken into account, could be possibly explained in terms of age-related changes in social skills (Hess et al., 2005; Peters et al., 2007).

To summarize the findings of the present study at a more general level, it can be stated that a major contribution of this research is the empirical demonstration that distinct memory processes contribute differentially to diverse aspects of decision making. Working memory appears to support those decision-making tasks in which a successful performance is known to entail a greater extent of cognitive processing, semantic memory plays a role both in tasks which are assumed to be knowledge-dependent and in a task that probably requires good comprehension skills, and episodic memory appears to be involved in a task that is thought to entail the evaluation of accumulated past experiences. Thus, based on these findings, the relationship between memory and judgment and decision making appears to be multifold, and to depend on the specific requirements of the task at hand. In general terms, these results agree with the view that memory processes fulfill different functions in judgment and decision-making: (1) support active processing and manipulation of information needed for carrying out the task at hand (working memory), (2) provide appropriate knowledge to be applied in the task and support comprehension processes (semantic memory), and (3) provide an appropriate base of relevant experiences to be used in memory-based judgment or estimation (episodic memory).

Even more generally, the findings of the present study suggest that, in order to reach a good understanding of the processes underlying different decision-making tasks, careful consideration should be given to different kinds of memory processes. However, we think that memory functions in decision making are not limited to the ones we identified, and further studies on this topic are thus needed. For instance, semantic memory may have the additional function of assuring access to global evaluations about the options (Hermans, Baeyens, & Eelen, 2003). This possibility may lead us to reconsider some studies that observed independence between memory and judgment in specific processing conditions (e.g., Hastie & Park, 1986) and to conceive episodic memory as a storage support for judgments based on retrieved information (memory-based) and semantic memory as a storage support for global judgments, encoded on-line as associations between options and global evaluations.[17] A similar reconsideration may also involve fuzzy-trace theory's stated independence between some reasoning tasks and memory (Reyna, Lloyd, & Brainerd, 2003), which originates from the distinction between verbatim representations, generally used in memory tasks, and gist-based representations, preferentially used in reasoning tasks. In these cases, reasoning could be seen as mainly related to (gist-based) semantic memory processes but not to episodic memory processes handling verbatim representations.[18]

Another contribution of the present study concerns the analysis of age-related changes in different aspects of decision-making competence. The results showed that age is negatively related with working memory and episodic memory, but not with semantic memory, in accordance with previous research (e.g., Nilsson et al., 2004; Park, 2000; Park et al., 2002, 1996; Salthouse, 2004). After including age in the models, the relationships between age, memory variables, and different aspects of decision-making competence were estimated, in order to understand to what extent the age-related changes in different aspects of decision-making competence could be traced back to age-related changes in memory variables. The negative relation between age and decision making was found to be totally or partially mediated by the age-related decline of working memory in some tasks (Resistance to Framing and Under/Overconfidence, a trend was detected for Applying Decision Rules). This finding is consistent with the idea that more cognitively-demanding DMC tasks rely more on working memory and executive processes (see also Del Missier et al., 2012) and are thus negatively affected by the age-related working memory decline. Another negative effect of age, mediated by episodic memory, was observed in Recognizing Social Norms, further supporting the involvement of episodic memory processes in this task. Moreover, after the negative age-related effect of working memory and episodic memory had been taken into account, suppression effects emerged in Resistance to Framing and Recognizing Social Norms. This shows that if the effects of age-related declines on memory processes are teased out, a positive role of age emerges in some DMC tasks (see also Bruine de Bruin, Parker, & Fischhoff, 2012; Peters et al., 2007). Finally, other decision-making tasks were not affected by age (Consistency in Risk Perception) or a positive role of age on performance was observed (Resistance to Sunk Costs), even after controlling for the influence of semantic memory (see also Bruine de Bruin, Parker, & Fischhoff, 2012; Mäntylä, Del Missier, et al., 2012; Strough et al., 2008). Taken overall, the present findings extend previous investigations on the relation between age and decision making, strengthening our conclusions on the multifold relationship between memory and decision making and providing further evidence of how decision-making competence depends on multiple abilities, which can be differentially affected by age (Bruine de Bruin, Parker, & Fischhoff, 2012; Mather, 2006; Peters et al., 2007; Strough, Karns, & Schlosnagle, 2011).

The results of the present study are generally in agreement with previous investigations employing the same decision-making tasks in different countries and populations (Bruine de Bruin, Parker, & Fischhoff, 2007, 2012; Del Missier et al., 2010, 2012; Parker & Fischhoff, 2005). In particular, the results agree with previous studies in identifying Resistance to Framing and Applying Decision Rules as more "fluid" A-DMC tasks and Resistance to Sunk Cost and Recognizing Social Norms as more "crystallized" tasks, on the basis of their correlations with age and with memory or cognitive variables. However, there are some task-specific differences. First, Under/Overconfidence should be considered as a "fluid" task according to the present study (and to Mäntylä, Del Missier, et al., 2012), while in Bruine de Bruin, Parker, and Fischhoff (2012), this task is considered more as a "crystallized." Second, some differences with Bruine de Bruin et al.'s study concern specific conclusions on mediation/suppression effects involving age. In particular, a suppression effect was observed in the framing task, while it was not observed in Bruine de Bruin et al.'s study, and, unlike Bruine de Bruin et al. and in agreement with Mäntylä, Del Missier, et al. (2012), positive relationships between

[17] In some cases, evaluative summative judgments are formed implicitly after encoding of value-charged stimuli (Betsch, Plessner, Schwieren, & Gütig, 2001) and they can be more accessible, at a later time, than traces of past experiences.

[18] However, other kinds of reasoning tasks (e.g., some forms of inductive reasoning) may rely on an episodic or instance-based substrate (Heit & Hayes, 2011). As in the case of decision making, the nature of memory processes underlying reasoning may well depend on the specific requirements of the task.

fluid measures (in our case, working memory) and performance in the more "crystallized" A-DMC tasks were not found. These differences may depend on the sample or on the type of mediators and measures used. Indeed, Bruine de Bruin et al. used a convenience sample and a fluid intelligence measure as a manifest mediator (Raven's Standard Progressive Matrices), while the present study employed a sample drawn from the general population and used latent memory variables as mediators. Future research may speak to this issue.

The present study has some limitations, which need to be acknowledged and addressed in further research. The first limitation is related to the sample. Although the sample size is big and participants from all the age ranges are taken from the general population, older adults are overrepresented. Thus, the findings would be strengthened by a replication of the study in a sample with a more representative age distribution. However, the general agreement of the results with previous research seems to supports the external validity of the study.

The second limitation pertains to the measures employed in the present study. In particular the study lacks direct measures of specific knowledge relevant for some A-DMC tasks (Resistance to Sunk Cost, Consistency in Risk Perception). Although the semantic memory measures available in the Betula data set have been successfully used as proxies, these measures are only approximations of the specific variables that should to be ideally measured (i.e., knowledge of probability principles, knowledge of the economic rules that state that sunk costs should not be honored; on this point, see also Stanovich & West, 2008; Strough, Karns, & Schlosnagle, 2011). However, despite the roughness of these measures, the selectivity of the relations observed between memory variables and A-DMC tasks is more than encouraging. Future studies could offer a stronger test of the hypotheses by adopting task-specific measures of knowledge. A similar reasoning may be articulated for the episodic substrate that is assumed to play a role in Recognizing Social Norms (accumulated traces of behaviors related to the social norms). Another measurement-related limitation is the use of verbal tasks to assess individual differences in memory. In future investigations, it would be worth appraising the robustness of our findings by using nonverbal memory tests. It should be also acknowledged that not every kind of memory processes and decision-making task has been investigated in the present study. In particular, we have not investigated implicit memory processes (e.g., Berry & Broadbent, 1984, 1987), which may support complex dynamic decision making and some forms of intuitive judgment or decision, and we have not examined less structured decision tasks (like option generation: Del Missier & Terpini, 2009; Gettys, Pliske, Manning, & Casey, 1987) or the so-called "hot" or "affective" decision-making tasks (e.g., Figner, Mackinlay, Wilkening, & Weber, 2009).

A third limitation of the present study may concern part of the age-related conclusions, and it is associated with the cross-sectional nature of the research design. Longitudinal and cross-sectional designs can lead to results that can be partly different in aging research, with longitudinal studies usually showing a less negative picture of age-related changes (e.g., Rönnlund et al., 2005). Recently, the ability of cross-sectional design to provide valid conclusions on age-related changes has been also questioned by relying on formal analysis (Lindenberger, von Oertzen, Ghisletta, & Hertzog, 2011). A productive position on this issue might consist in acknowledging (and possibly reducing or statistically controlling for) the specific limitations of both cross-sectional and longitudinal designs (for instance cohort and practice effects; see, e.g., Rönnlund et al., 2005), and strive toward obtaining converging results with different research designs. Hopefully, we will have the opportunity to compare the results described in the present article with those obtained from longitudinal data that will be collected in forthcoming waves of the Betula project. For the moment, the reader is provided with a note of caution on part of the results, which is related to the use of a cross-sectional design.

A more general limitation of the study is represented by its correlational nature, which suggests caution in establishing the causal nature of the relationships between variables and in specifying potential explanatory mechanisms. Although the hypotheses and explanations of the present study are rooted in existing research, different accounts could be put forward for our findings and should be ruled out using empirical methods. Moreover, future studies may start from the results described in this article and test hypotheses about the memory contributions to specific decision-making tasks (and alternative possibilities) in laboratory experiments with behavioral and/or neuroimaging methods. This would represent an ideal way to complement the relative strengths (and weaknesses) of correlational and experimental approaches (Cronbach, 1957; Engle & Kane, 2004).

In conclusion, the present study advances our understanding of the functional relationships between memory and decision making by relying on a systematic and theoretically-grounded investigation. We hope that this research will stimulate further studies bridging these two important areas of cognition and unveiling further aspects of their functional interaction.

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(*Appendix follows*)

Appendix

Pearson's Pairwise Correlations for All the Measures

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Resistance to Framing	—														
2. Recognizing Social Norms	0.06	—													
3. Under/Overconfidence	0.12^{**}	0.09^{*}	—												
4. Applying Decision Rules	0.23^{***}	0.14^{**}	0.20^{***}	—											
5. Consistency in Risk Perception	0.10^{*}	0.13^{**}	0.09^{*}	0.16^{***}	—										
6. Resistance to Sunk Costs	-0.05	0.02	-0.04	0.04	0.11^{**}	—									
7. Reading span	0.15^{***}	0.03	0.15^{**}	0.23^{***}	0.06	-0.01	—								
8. n-back	0.21^{***}	0.04	0.20^{***}	0.34^{***}	0.05	-0.02	0.27^{***}	—							
9. Recall of sentences	0.19^{***}	0.16^{***}	0.19^{***}	0.32^{***}	$0.07^{\dagger}$	-0.04	0.30^{***}	0.31^{***}	—						
10. Cued recall of nouns	0.15^{***}	0.16^{***}	0.18^{***}	0.29^{***}	0.04	0.02	0.25^{***}	0.26^{***}	0.74^{***}	—					
11. Recognition of nouns	0.09^{*}	0.12^{**}	0.13^{**}	0.13^{**}	0.05	-0.01	0.13^{**}	0.17^{***}	0.56^{***}	0.59^{***}	—				
12. General knowledge	0.13^{**}	0.13^{**}	0.15^{***}	0.34^{***}	0.16^{***}	0.11^{*}	0.26^{***}	0.16^{***}	0.35^{***}	0.37^{***}	0.22^{***}	—			
13. Letter fluency	0.15^{***}	0.12^{**}	0.11^{**}	0.32^{***}	0.04	0.04	0.34^{***}	0.21^{***}	0.34^{***}	0.41^{***}	0.18^{***}	0.39^{***}	—		
14. Vocabulary	0.14^{**}	0.15^{***}	0.16^{***}	0.35^{***}	0.19^{***}	0.13^{**}	0.28^{***}	0.13^{**}	0.35^{***}	0.38^{***}	0.24^{***}	0.57^{***}	0.42^{***}	—	
15. Age	-0.11^{**}	0.07	-0.20^{***}	-0.36^{***}	-0.01	0.15^{***}	-0.27^{***}	-0.42^{***}	-0.40^{***}	-0.33^{***}	-0.22^{***}	-0.04	-0.21^{***}	-0.03	—

$^{\dagger}p < .10.$ $^{*}p < .05.$ $^{**}p < .01.$ $^{***}p < .001.$

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