The aging decision maker: Investigating cognitive processes underlying decision making over the lifespan

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Contents

Abstract

Aging is a complex process that can lead to numerous changes in a person's life. Previous research has described age-related changes in cognitive abilities that may adversely affect decision making processes. This dissertation addressed such effects that have a potential to influence the value-based decision making of older adults.

Three studies were conducted to investigate the contributions of episodic memory, positivity effect and episodic future thinking to decision making of older adults. The first study addressed the contribution of episodic memory to the process of construction of subjective values of alternatives during value-based decisions. The findings demonstrated the involvement of episodic memory in value-based decision making of older adults.

The second study investigated an age-related positivity effect that manifests as an increased bias towards positive stimuli by older adults. Altogether, the results suggested similarities in positivity in information search of older and younger adults, as well as similarities in resulting decision quality.

The third study in this dissertation examined episodic future thinking of older adults and its contribution to decision making. The findings showed that episodic future thinking promoted future-oriented choices in older as well as in younger adults.

Overall, the results from the studies in this dissertation suggest a complex picture of investigated age-related changes in cognitive abilities and corresponding decision processes. Decision making in older adults may be adversely affected by a decline in episodic memory performance, as shown in the first study. However, the second and the third studies did not provide evidence for the lower decision quality due to the positivity effect and for the decline in episodic future thinking. The findings presented in this dissertation provide several directions for future research on value-based decision making in aging as well as for practical applications.

Zusammenfassung

Altern ist ein komplexer Prozess, der zu zahlreichen Veränderungen im Leben eines Menschen führen kann. Frühere Forschungen haben altersbedingte Veränderungen der kognitiven Fähigkeiten beschrieben, die sich nachteilig auf Entscheidungsprozesse auswirken können. Diese Dissertation befasste sich mit solchen Effekten, die die wertorientierte Entscheidungsfindung älterer Erwachsener beeinflussen können.

Drei Studien wurden durchgeführt, um Beiträge des episodischen Gedächtnisses, des Positivitätseffekts und des episodischen Zukunftsdenkens zur Entscheidungsfindung älterer Erwachsener zu untersuchen. Die erste Studie befasste sich mit dem möglichen Beitrag des episodischen Gedächtnisses zum Prozess der Konstruktion subjektiver Werte von alternativen Optionen bei wertebasierten Entscheidungen. Die Ergebnisse zeigten die Beteiligung des episodischen Gedächtnisses an der wertorientierten Entscheidungsfindung älterer Erwachsener.

Die zweite Studie untersuchte den altersbedingten Positivitätseffekt, der sich in einer erhöhten Neigung älterer Erwachsener zu positiven Reizen äußert. Insgesamt deuteten die Ergebnisse auf Ähnlichkeiten in der Positivität bei der Informationssuche älterer und jüngerer Erwachsener sowie auf Ähnlichkeiten in der resultierenden Entscheidungsqualität hin.

Die dritte Studie innerhalb dieser Dissertation untersuchte das episodisches Zukunftsdenken älterer Erwachsener und ihren möglichen Beitrag zur Entscheidungsfindung. Die Ergebnisse zeigten, dass episodisches Zukunftsdenken zukunftsorientierte Entscheidungen von älteren und jüngeren Erwachsenen förderte.

Insgesamt deuten die Ergebnisse der Studien auf ein komplexes Bild der untersuchten altersbedingten Veränderungen der kognitiven Fähigkeiten und der entsprechenden Entscheidungsprozesse hin. Die Entscheidungsfindung älterer Erwachsener kann durch einen Rückgang der episodischen Gedächtnisleistung beeinträchtigt werden, wie in der ersten Studie gezeigt wurde. Die zweite und die dritte Studie zeigten jedoch keine Hinweise auf die geringere Entscheidungsqualität aufgrund des Positivitätseffekts und auf den möglichen Rückgang der episodischen Zukunftsdenken. Die in dieser Dissertation vorgestellte Ergebnisse geben verschiedene Hinweise für zukünftige Forschungen zur wertorientierten Entscheidungsfindung im Alter sowie für praktische Anwendungen.

General introduction

It is common knowledge that growing old can lead to a variety of changes in a person's life. Research on aging has demonstrated that these changes include the manner in which people use their cognitive abilities when confronted with decision situations. In older age, some cognitive abilities may become less effective, whereas others remain relatively stable or even improve. Additionally, aging may influence how people direct their cognitive resources, including attention, during an evaluation of available choice options. These changes in cognitive functioning can ultimately affect decision making processes and decision outcomes. Studying these links between age-related cognitive changes and decision making can benefit the research on aging, as well as inform the more general understanding of decision making processes. One relevant approach that has been used in research is investigating how various factors may influence the evaluation and comparison of available choice options, which may then affect choice outcomes.

Based on the existing literature on these topics, I aimed to address several research questions in the current dissertation: How does aging influence decision making? Do age-related limitations in cognitive abilities lead to worsened decision outcomes? Does the manner in which cognitive functions are modified by age-related changes influence decision quality? Is it possible to support the decision making of older adults by leveraging their cognitive abilities?

This dissertation is structured as follows: in the background section I provide an overview of relevant topics including decision making, age-related changes in cognitive functions and the resulting differences in decision making between older and younger adults. Next, I outline key methodological aspects of the empirical studies. After that, I describe three studies that were conducted for this dissertation in order to test several mechanisms with which aging could influence decision making. Then I conclude with a general discussion addressing the findings and their implications.

1. Background

Previous research has described differences in decision making of younger and older adults (Peters et al., 2011). The relationship between aging and mechanisms underlying decision processes is a growing research topic (Strough, Löckenhoff, et al., 2015), as is consumer behavior in older age (Drolet et al., 2018). One argument in favor of the increasing relevance of research on aging and decision making is the rapidly changing demographic makeup of populations in developed countries. Due to improved longevity, the proportion of older adults is increasing (United Nations, 2015). According to an estimate provided by the United Nations, by 2050 the population of people 60 years old and over may reach up to 2.1 billion, compared to 901 million in 2015. In Europe, the proportion of people aged 65 and older is expected to increase from 29.6% in 2016 to 51.2% in 2070, according to the European Commission report (European Commission, 2018). Increases in longevity can be attributed, to a large extent, to advances in public health and healthcare (United Nations, 2015). Both reports point out the potential challenges arising from the shifting ratio of younger to older people in the population, including challenges in the areas of labor participation, social programs and healthcare. The growing proportion of older adults will also have a considerable wealth and will therefore have a larger role in the economy, making research on the implications of aging for decision making relevant and urgent (Li et al., 2015).

Cognitive ability and decision making can also be necessary for well-being of older adults (Salthouse, 2012). For example, the increased longevity and duration of retirement make choices related to financial planning and accumulation of retirement savings very consequential. However, the maximization of benefits and minimization of mistakes relies on the efficiency of decision making processes in older adults (Agarwal et al., 2009). Health-related decisions may also become highly relevant for an aging decision maker (Morrow & Chin, 2015). These trends and potential challenges confronting older adults highlight the importance of investigating mechanisms underlying decision making and consumer behavior in older age.

In the following section I introduce several concepts that are relevant to the research topics of the current dissertation. First, I describe past research on decision making, as well as a framework of value-based decision making, and review approaches to assessing decision outcomes. I then review research on the effects of aging on cognitive abilities. After that, I describe the research on decision making of older adults that informed experimental studies in this dissertation. This more detailed description of relevant scientific background can be useful as a context for the empirical studies section.

1.1.Decision making

The current dissertation focuses on potential influences of aging on the way people make decisions. Decisions can be defined broadly as instances in which a person selects an option or a course of action from several that are available, and a related term decision making refers to the process of choosing among available options (Kalenscher, 2014). Individuals are often confronted with decisions of various importance that require them to assess and compare various alternatives courses of action in order to select one, for example, what to buy for lunch or whether to help a stranger. In a broad sense, decision making also describes instances of animal behavior (Budaev et al., 2019; Owen et al., 2017); however, the current dissertation focuses on decision making in humans. Research on decision making often addresses underlying cognitive processes that take place when an individual selects one out of two or more actions (Huettel, 2010; Johnson & Ratcliff, 2014; Rangel et al., 2008). Various aspects of decision making occurring in different areas of life are studied by this research. This includes economic choice (Padoa-Schioppa, 2011), social decision making (Ruff & Fehr, 2014), perceptual decisions (Shadlen & Kiani, 2013) and other. Accordingly, research on decision making has been advanced by multiple disciplines, including psychology, economics, neuroscience.

Decision situations that people encounter in life may require consideration of alternative courses of action that have different effects on the current and the future states of an individual. A decision maker would therefore have to assess various characteristics of choice options in order to compare them (Rangel & Clithero, 2014; Rangel & Hare, 2010). Studies on decision making have examined choices with trade-offs between properties of options that may be challenging for decision makers. For example, Hare et al. (2011) investigated conditions under which a consumer would be more likely to select a healthier food product in decisions with potential trade-offs between healthiness and taste. Food choice, as one instance of decision making, has attracted interest because maintaining good nutrition is necessary for health, but regulating food choice may also be difficult for a decision maker (Demos et al., 2011; Ely et al., 2013). Consumers, including older adults, may also be confronted with other, more consequential choice situations that require consideration of multiple properties of options. Such situations include, for example, selecting healthcare plans (Morrow & Chin, 2015; Wood et al., 2011) or choosing financial services (Hershey et al., 2015). Decision making, especially in difficult decisions, can also lead to suboptimal results and decision errors (Milosavljevic et al., 2010). The underlying processes of evaluation and comparison of choice options have been addressed by research on value-based decision making.

1.1.1. Value-based decision making

Value-based decisions can be generally defined as instances in which a decision maker assigns subjective values to options under consideration and selects a preferred action based on these subjective evaluations (Brosch & Sander, 2013; Rangel et al., 2008). Examples of value-based decisions include consumer choices such as buying clothes (Philiastides & Ratcliff, 2013) or selecting a food product (Milosavljevic et al., 2010). The interdisciplinary field of neuroeconomics studies mechanisms of value-based decisions and addresses questions about how subjective evaluations of choice alternatives are represented in the brain, how they are modulated by various factors and compared (Brosch & Sander, 2013, Fehr & Rangel, 2011). Some of the modulators of subjective values that have received attention in research on decision making relate to the effects of attention and self-control (Hare et al., 2011), an effect of a temporal delay of receipt of a reward, as well as effects of uncertainty of outcomes and risk on decisions (Doya, 2008; Kalenscher, 2014)

Rangel and colleagues (Rangel et al., 2008) described steps involved in value-based choice. At first, an organism needs to construct a representation of the decision situation, as well as of internal and external states. Next, the organism evaluates available options and their benefits. Subjective values of options can be informed, for example, by prior knowledge and by information about options available during the decision itself (Enax & Weber, 2015; Polanía et al., 2015). Following the assessment of different benefits and downsides of possible courses of actions, the organism selects among available actions based on their evaluations. During this process, subjective values of options are compared, and the most beneficial option is selected. In the next step, the outcome of the decision is assessed. Feedback about the decision outcome can be used to inform other steps and improve future decisions (Rangel et al., 2008).

Past research has identified specific brain areas responsible for encoding subjective values of options during choice. This includes studies that used electrophysiological recordings in primates (Padoa-Schioppa & Assad, 2006) or examined decisions of patients with lesions located in the ventromedial prefrontal cortex (Fellows & Farah, 2007). Neuroeconomic research using imaging methods has provided further evidence for the involvement of specific brain areas in the decision making processes, such as in value construction and comparison. In a study by Plassmann and colleagues (2007), fMRI signal from orbitofrontal areas was related to subjective values of choice options. This finding supported the role of the medial orbitofrontal cortex in representing values of alternatives under consideration. Hare et al. (2009) further investigated the role of the ventromedial prefrontal cortex in encoding of subjective values of choice options using an fMRI food choice paradigm. The results supported the involvement of the dorsolateral prefrontal cortex in modulating the value signal in the ventromedial prefrontal cortex in choices involving self-control. Polanía and colleagues (2015) used transcranial alternating current stimulation to disrupt fronto-parietal synchronization, leading to a decrease in accuracy of choices between food products. This study confirmed the role of the connectivity between the frontopolar cortex and the parietal cortex in decision making. Weilbächer and Gluth (2017) summarized some of the relevant findings on involvement of brain areas in different steps of value-based decision making process. Apart from brain structures already mentioned, they highlight the role of sensory areas for identification of available choice alternatives, as well as the involvement of the dorsomedial prefrontal cortex, including anterior cingulate cortex and the pre-supplementary motor area, in value comparison. Figure 1 demonstrates the steps of value-based decision making process and brain areas involved in these steps (Weilbächer & Gluth, 2017).

In conclusion, it has been shown that specific brain areas are involved in representing subjective values of choice options in decision making. Neuroeconomic studies have also presented a picture largely consistent with the value-based decision making framework outlined by Rangel et al. (2008). This framework can also be valuable for research on decision making of older adults. Specifically, it can be useful for mapping various changes in cognitive abilities that are known to occur in aging onto separate decision making steps considered in this framework. The current dissertation primarily focuses on aging effects that may have an impact on valuation of options, a step at which a decision maker assigns subjective values to actions under consideration. Processes involved in this step are relevant for research on aging and decision making since they could be vulnerable to decreases in cognitive performance of older adults. Additionally, addressing this step in a decision making intervention can likely offer ways to improve resulting choice outcomes.

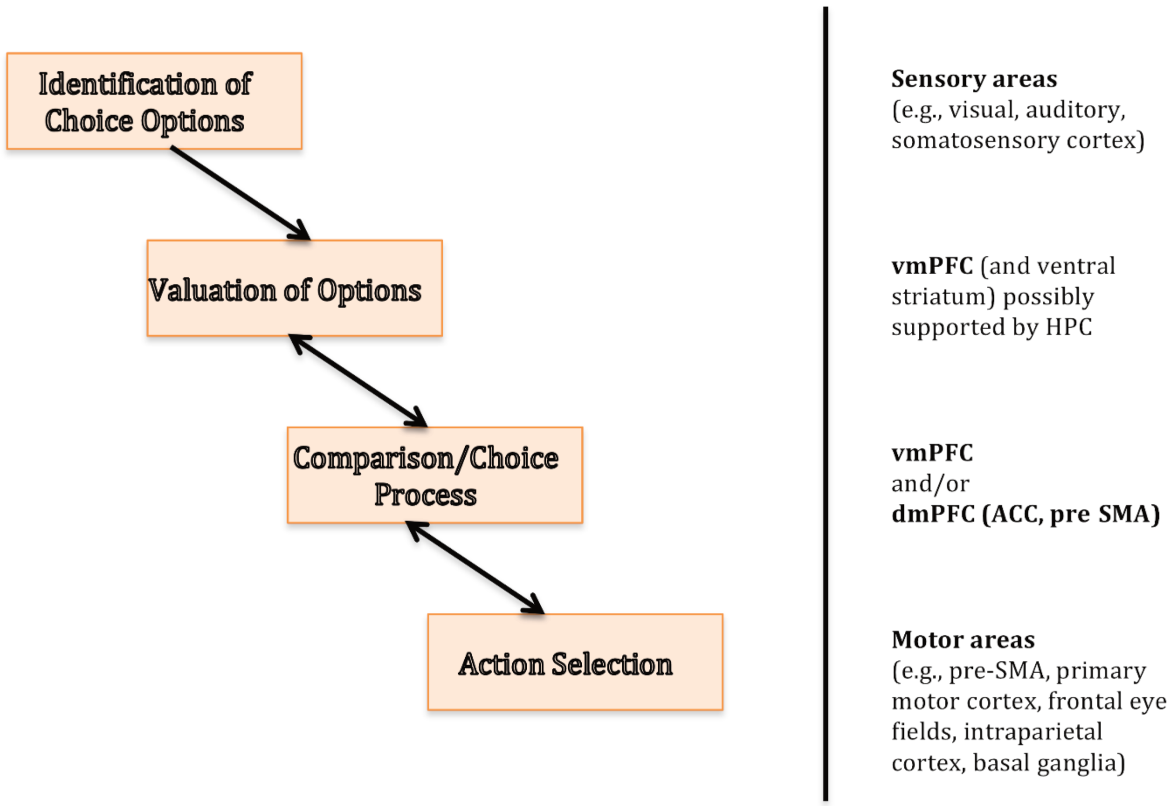

Figure 1. Involvement of brain areas in decision making. Steps of value-based decisions are shown on the left and related brain areas are shown on the right. vmPFC – ventromedial prefrontal cortex; HPC – hippocampus; dmPFC – dorsomedial prefrontal cortex; ACC – anterior cingulate cortex; pre SMA - pre-supplementary motor area. Adapted from Weilbächer and Gluth (2017).

1.1.2. Assessment of outcomes of decisions

Due to potential adverse effects of aging on cognitive functions that underlie decision making, past research has addressed the influence of aging on decision outcomes (Peters et al., 2011; Zaval et al., 2015). Similarly to studies investigating factors underlying advantageous and disadvantageous decisions in younger adults (Del Missier et al., 2012; Philiastides & Ratcliff, 2013), studies in older adults sometimes define desirable choice outcomes to serve as standards for comparing actual choices. This approach is reflected in concepts characterizing decision making, for example decision quality (Queen et al., 2012) or decision competence (Bruine de Bruin et al., 2012). It is important to point out that, as in research on younger adults, studies on aging also investigate types of decisions for which the concept of choice quality may not be as useful or applicable. For example, research on social decisions in aging might consider different measures of outcomes for which the concept of decision quality may not be as clear cut, such as a tendency to exhibit prosocial behavior (Matsumoto et al., 2016). Therefore, it may be beneficial to outline considerations that contribute to the selection of outcome measures used in decision making research. Following paragraphs provide an overview of the rationale used for assessment of decision outcomes in previous studies, as well as approaches that are relevant for the current dissertation.

Fehr and Rangel (2011) reviewed and summarized findings from neuroeconomic research investigating value-based decision making and economic choice. An optimal decision could be defined as the one that takes into account important characteristics of choice options and, as a result, maximizes utility for the decision maker (Fehr & Rangel, 2011; Rangel, 2013). However, individuals do not always make decisions that are assumed optimal by researchers (Agarwal et al., 2009; Sanfey et al., 2006; Samanez-Larkin et al., 2010). Fehr and Rangel (2011) described sources of errors in economic choice that can fall into three categories: stochastic errors, effects that can lead to systematic errors due to failing to account for some of choice-relevant attributes and errors related to directing attention or weighing of subjective values. Stochastic errors in decision making can arise, for example, due to an inherent noisiness of underlying processes (Krajbich et al., 2012). Such errors are more likely to occur under circumstances in which a decision maker cannot immediately and accurately make a choice among alternatives (Oud et al., 2016). For example, a decision would more often result in a stochastic error – a selection of a suboptimal option to which an individual assigned a lower preference rating – if a decision maker is confronted with a choice between very similar alternatives (Milosavljevic et al., 2010; Philiastides & Ratcliff, 2013). Additionally, decision making processes can be adversely influenced in a systematic manner by biases (Strough, Parker, et al., 2015). For example, bias in attention could influence the process of value computation in a choice informed by signals available in the environment (Enax et al., 2016). A decision maker who misses a crucial part of the available information about options could select a suboptimal alternative.

A different type of potentially disadvantageous choices can occur in situations in which one of the outcomes is delayed (Berkman, 2018; Rung & Madden, 2018). In this case, a decision maker would discount the reward that is only delivered after a time delay (Kable & Glimcher, 2007). Therefore, decisions with temporally distant outcomes may be challenging for decision makers (Berkman, 2018).

To establish deviations from optimal choices, previous studies assessed potential benefits of choice outcomes for a decision maker (for example, Agarwal et al., 2009; Camille et al., 2011; Wayde et al., 2017). When an experimental task assesses decisions with monetary reward outcomes, the decision quality can be then defined as the ability of a decision maker to maximize the monetary benefit. For example, in the study by Hanoch et al. (2011) participants aimed to maximize monetary outcomes of a selection among presented hypothetical Medicare Part D coverage plans. However, investigating realistic decision situations may require a more complex definition of decision quality since some benefits might be subjective in nature and involve trade-offs between characteristics, such as taste and healthiness of food products (Hare et al., 2011). Therefore, selecting an adequate measure of choice quality may be more complicated for consumer behavior with non-monetary rewards.

Some studies have used choice consistency to characterize decision outcomes (Fellows & Farah, 2007; Lee et al., 2009). The rationale behind these measures is that a precise and reliable decision making process would mostly produce consistent outcomes, whereas less reliable processing of information can more often lead to reversals of preferences in choices. Other ways of eliciting personal preferences and assessing consistency have also been used. One approach applied in the studies in the current dissertation is to obtain personal evaluations of options or personal evaluations of specific properties of options, and then to evaluate how well people follow these self-reported assessments when making a decision (Milosavljevic et al., 2010; Queen et al., 2012).

Previous literature has described numerous differences in the decision making of older adults compared to younger adults, including aspects of decision making in which older adults are at a relative disadvantage (Peters et al., 2011; Samanez-Larkin & Knutson, 2015; Strough, Löckenhoff, et al., 2015). Correspondingly, there has been extensive research on various factors that may underlie lower decision making ability of older adults (Del Missier et al., 2015; Peters et al., 2011). However, in some contexts older adults demonstrate performance similar to that of younger adults (Li et al., 2015), if not better. For example, older adults can use more efficient strategies for everyday decision making, such as in solving interpersonal problems as demonstrated in a study by Blanchard-Fields and colleagues (2007). In order to identify the cognitive abilities that can be responsible for differences in the decision making of older adults, the following sections review studies on trajectories of cognitive abilities in aging.

1.2. Age-related changes in cognitive functions

A decline in decision making abilities in older age has been strongly linked to processes of cognitive aging (Strough, Löckenhoff, et al. 2015). Age-related decline in cognitive performance could lead to changes in decision making, including deterioration of decision quality (Del Missier et al., 2013; Zaval et al., 2015). However, the full picture of changes in cognitive abilities of older adults is more complicated than just decline. Previous studies have shown that some cognitive abilities tend to decline with aging and are linked to decreased efficiency of decision making, whereas other functions remain relatively more stable, and may even improve (Zaval et al., 2015).

Differences between typical trajectories of various cognitive abilities in aging are reflected in concepts of fluid and crystallized intelligence (Horn & Cattell, 1967). Fluid intelligence refers to cognitive functions that are most vulnerable to aging. Decline in fluid intelligence starts as early as in the twenties and continues into middle life and older age (Salthouse, 2004). Fluid intelligence represents an ability to process and manipulate information in real time, and refers to cognitive functions such as processing speed, working memory and reasoning (Zaval et al., 2015). In contrast to that, crystallized intelligence refers to functions that tend to stay stable or improve throughout lifetime, such as semantic memory associated with general knowledge and language (Del Missier et al., 2015; Li et al., 2004). Zaval and colleagues (2015) summarized prior findings demonstrating that in some situations older adults can leverage their preserved crystallized intelligence, in a form of accumulated knowledge and experience in specific areas, to compensate for the decline in fluid intelligence performance. To conclude, existing evidence points to heterogeneity in the trajectories of various cognitive functions in healthy aging. In some circumstances certain preserved cognitive abilities may compensate for the decline in others.

1.2.1. Age-related cognitive decline

As reviewed above, previous research has described differences in performance of older adults and younger adults with respect to various cognitive functions indicating an age-related decline in cognitive performance. Findings from cross-sectional studies on cognitive aging comparing older and younger adults (Salthouse, 2011) were also supported by longitudinal studies demonstrating gradual decreases in cognitive performance in aging (Colsher & Wallace, 1991; Gerstorf et al., 2011).

Typically, the research on decision making of older adults aims to describe healthy aging, excluding dementias of various etiologies or mild cognitive impairment. Rather, it is assumed that some degree of cognitive decline occurs also in the absence of any specific disease (Fjell & Walhovd, 2010; Nyberg et al., 2012). Healthy aging has been linked to multiple changes in the functioning and in the structure of the brain (Mattson & Arumugam, 2018). As one such neurobiological change in aging, previous studies have described alterations in gene expression in glial cells, which may in turn be linked to changes in synaptic transmission, neurogenesis and inflammatory processes (Soreq et al., 2017; Wruck & Adjaye, 2020). Papenberg et al. (2015) suggested that aging may interact with genotype, and individuals with specific gene variants are therefore more vulnerable to age-related processes. Additionally, healthy older adults can show lower brain metabolism which is linked to decline in cognitive performance (Castellano et al., 2019).

Research has also demonstrated age-related increase in white matter lesions in the brain which was associated with lower cognitive performance (Charlton et al., 2010; Lockhart et al., 2012). A study by Wallhovd et al. (2005) showed numerous links between age and volumes of gray and white matter in various brain regions implying a rather widespread age-related atrophy. In addition, Raz and colleagues (2005) described age-related longitudinal decreases in the volume of various brain regions. Age-related decline in cognitive performance has also been linked more specifically to structural changes in prefrontal, temporal and posterior parietal cortical areas (Tisserand et al., 2004). Rosen et al. (2003) showed a correlation between hippocampal volume and episodic memory performance. Additionally, Becker et al. (2015) showed the link between volumes of left and right lateral prefrontal cortex and associative memory of older adults. Age-related changes in the frontal cortex have also been implicated in decreased decision making quality (Denburg & Hedgcock, 2015). Overall, there is compelling evidence for the adverse effects of aging on cognitive performance, as well as links between gradual changes in the brain and decline in cognitive performance in older age. However, further research clarifying the relationships between changes occurring in the brain and cognitive functions may still be warranted (Salthouse, 2011).

The findings highlighted above suggest a biological basis for cognitive decline in aging. In addition to the heterogeneity in trajectories of different cognitive abilities in older age, previous studies have demonstrated inter-individual heterogeneity with respect to age trajectories of cognitive performance (Nyberg et al., 2012; Rönnlund et al., 2005). Some older adults may experience an earlier and a quicker decline of cognitive performance, whereas others may demonstrate preserved levels of performance. Several concepts have been proposed to account for such heterogeneity in cognitive performance and to link it to age-related changes in the brain. Two of these concepts are brain reserve and cognitive reserve, and they have been applied to cognitive aging as well as to pathology, such as Alzheimer's disease (Stern, 2012). The brain reserve concept assumes that brains with higher numbers of neurons and synapses can sustain more pathological changes before a clinical manifestation. In contrast, the concept of cognitive reserve suggests a higher functional resilience to brain damage which could be explained by a better functioning of brain networks or by an improved engagement of alternate networks (Stern, 2002). For example, a higher level of education or occupational attainment may contribute to a higher level of cognitive reserve which in turn helps maintain cognitive performance in aging (Stern, 2012). A more general definition of reserve as an accumulation of neural resources that may help mitigate cognitive decline has also been proposed (Cabeza et al., 2018).

A related framework, scaffolding theory of aging and cognition (STAC), was proposed by Park and Reuter-Lorenz (2009) and later revised (Reuter-Lorenz & Park, 2014). This framework summarizes and interprets findings on cognitive changes and brain resilience in aging aiming to explain differences in cognitive functioning. Compensatory scaffolding is an important concept in STAC. Briefly, scaffolding represents various mechanisms that support brain functioning despite negative effects of aging. For example, functional imaging has indicated that certain brain areas may be negatively affected by age-related processes, however the cognitive function can be partially supported by other brain areas (Park and Reuter-Lorenz, 2009). The revised version of this framework (STAC-r) maintains the important role of scaffolding, but considers additional factors, including life-course changes (Reuter-Lorenz & Park, 2014). Figure 2 demonstrates the relationship between various factors contributing to changes in brain structure and functioning in older age, and ultimately resulting in changes in cognitive abilities (Reuter-Lorenz & Park, 2014).

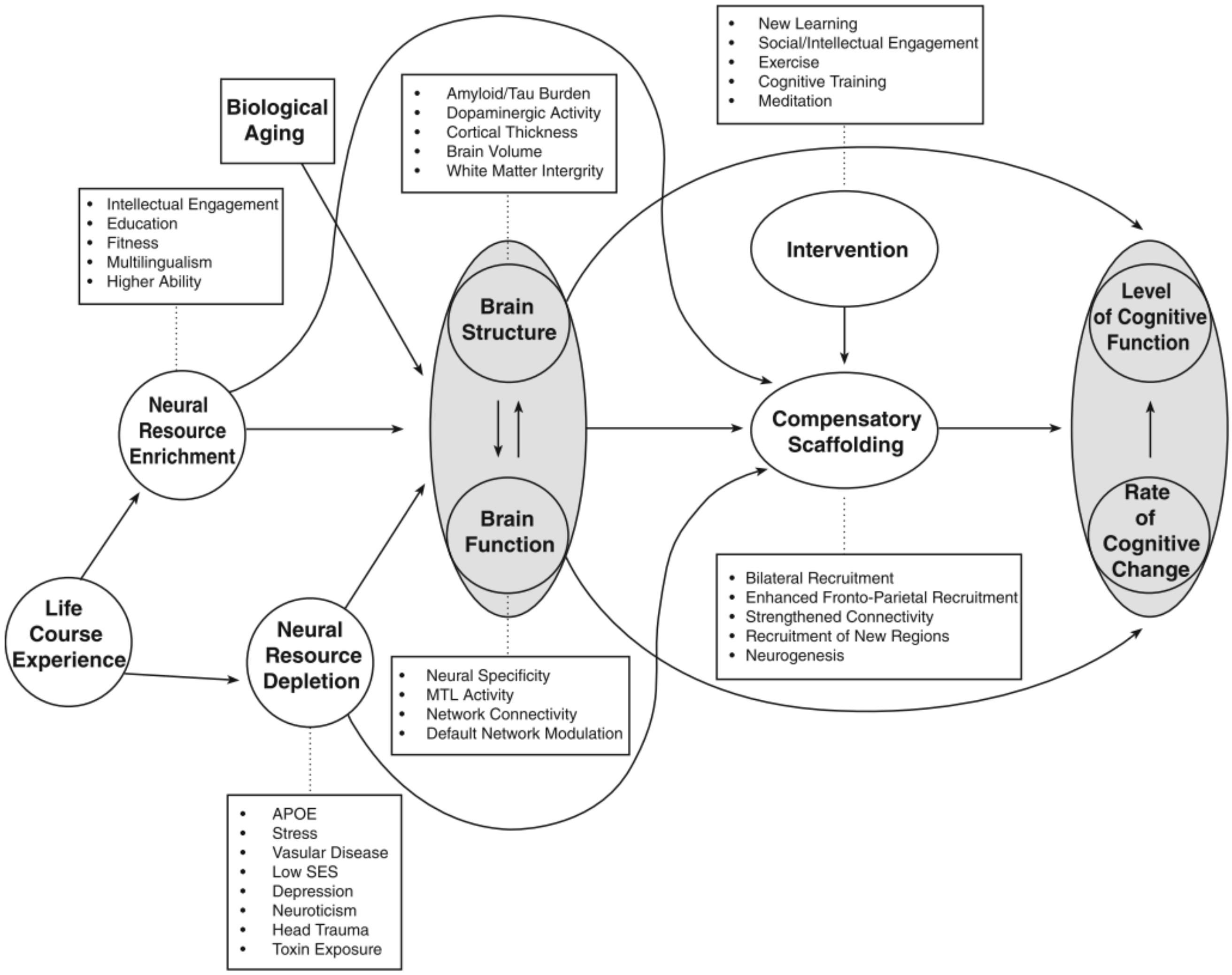

Figure 2. Factors related to aging-related changes in the brain and in cognitive functioning. Schematic representing aging-related risk factors, protective factors and changes in the brain integrated into the scaffolding theory of aging and cognition-revised (STAC-r) which aims to account for the resulting cognitive functioning. Adapted from Reuter-Lorenz and Park (2014).

Nyberg et al. (2012) demonstrated that a proportion of older adults retains a relatively high level of cognitive performance with respect to the memory function. This heterogeneity has been linked to individual differences in pathological processes that underlie cognitive change in older age, as well as in protective factors. Nyberg and colleagues proposed the concept of brain maintenance to explain the observed inter-individual differences. Specifically, brain maintenance postulates that some older adults show minimal age-related changes in the brain and thus maintain relatively high cognitive performance. This heterogeneity in decline of episodic memory outlined by Nyberg and colleagues may be relevant for the first empirical study, which examined the contribution of memory to value-based decisions. A conceptually related function, episodic future thinking, may also become less efficient in older age (Schacter et al., 2017). It refers to the ability to vividly imagine future situations; it serves the purpose of planning and consideration of future rewards. Episodic future thinking is relevant for some forms of decision making, specifically decisions involving delayed rewards (Koffarnus et al., 2013). The efficiency of episodic future thinking in older adults is therefore interesting in the context of research on aging and decision making. Hence, it was investigated in the third study.

To summarize, research on aging has demonstrated that trajectories of longitudinal change of cognitive performance differ for various cognitive functions. Studies have also shown that differential cognitive decline in healthy aging may lead to inter-individual heterogeneity in cognitive performance between older adults. The resulting differences in trajectories of cognitive aging of individuals are therefore relevant for research on decision making in aging.

1.2.2. Age-related changes in cognitive functions not involving decline

Apart from potential limitations in cognitive abilities of older adults, some processes unfolding in aging may also involve changes in how people use their cognitive abilities that cannot be easily categorized as an improvement or as a decline. In the current dissertation this trajectory is represented by the positivity effect. This is defined as an age-related increase in a bias towards positive stimuli, as compared to negative or neutral stimuli, which can be observed in attention and in memory (Carstensen & DeLiema, 2018; Reed & Carstensen, 2012). A predominant theoretical framework that explains the positivity effect is the socioemotional selectivity theory (SST; Carstensen, 2006). SST posits that empirically observed positivity effect results from an age-related change in motivational orientation, which is in turn caused by perceived limitations in time horizons. Future time perspective can be limited by aging and can also be limited by experimental manipulations, such as thinking about limited future (Barber et al., 2016). The SST also predicts that people with a limited future time perspective tend to reduce the number of their social connections to retain only the most meaningful relationships and would also limit their personal goals to exclude long-term aims such as those related to education. According to the SST, the observed increase in positivity bias in older adults is not due to personal goals related to emotion regulation, but rather it occurs as a consequence of the cognitive processing directed towards goal-relevant positive stimuli (Carstensen & DeLiema, 2018).

Some studies have proposed alternative explanations for the positivity effect, such as the deterioration of the amygdala, or the Dynamic Integration Theory, which suggests that processing negative information is relatively more difficult (Carstensen & DeLiema, 2018;

Reed & Carstensen, 2012). Additionally, Depping and Freund (2011) proposed a loss prevention orientation framework that, contrary to the positivity effect, predicts stronger attention and memory to negative stimuli in older age. This effect would occur due to the motivation to avoid potential losses. However, findings from empirical studies on the positivity effect, including in the decision context (Löckenhoff & Carstensen, 2007, 2008) have generally been inconsistent with alternative explanations, and have rather demonstrated support for predictions made by the SST (Carstensen & DeLiema, 2018; Reed et al., 2014). Consequently, the second study in the current dissertation primarily focused on predictions consistent with the SST.

1.3. Previous research on aging and decision making

As reviewed by Strough and colleagues (Strough, Löckenhoff, et al., 2015), changes in decision making in aging have been investigated from various perspectives. Past research has described numerous aspects of differences in decision making of older adults and younger adults (Carpenter & Yoon, 2015; Peters et al., 2011; Samanez-Larkin & Knutson, 2015). The effects of age-related changes in cognitive abilities on decision making, including a relative worsening of decision outcomes, as well as a relative improvement of decision quality under some circumstances have also been investigated (Bruine de Bruin et al., 2012; Del Missier et al., 2015). Some studies have also addressed possible ways to improve decision making outcomes in older adults, for example by using decision aids or behavioral interventions (Van Weert et al., 2016; Zhou et al., 2018). Identification of specific aspects of decision making of older adults that tend to decline is therefore valuable because then they could be compensated for. In the following, I describe several areas of research on aging and decision making that are relevant for the topics addressed by the current dissertation.

1.3.1. Episodic memory and decision making in aging

Previously, research on aging and decision making has established an age-related change in the functioning of the frontostriatal dopaminergic reward system, which is involved in the processing of value-relevant information in certain types of decisions (Eppinger et al., 2013; Samanez-Larkin & Knutson, 2015). Specifically, this system is crucial for learning the probabilities of various rewards and their associations with other stimuli. It has been shown that aging is associated with a decreased functioning of the striatal reward system and frontostriatal pathways (Samanez-Larkin & Knutson, 2015). As a result, older adults demonstrate less efficient learning of reward contingencies (Brown & Ridderinkhof, 2009). Overall, this research has provided broad and compelling evidence for age-related changes in processing of value-related information that plays a key role in certain types of decisions.

Effects of aging on cognitive performance could also be highly relevant for a different type of value-based choice. Research has described decisions that are less reliant on the striatal reward-based learning system and involve declarative memory that is dependent on the hippocampus (Doll et al., 2015; Wimmer et al., 2014). Decisions often depend on past experiences as sources of value-relevant information (Shadlen & Shohamy, 2016). Earlier studies examining a Query Theory framework found support for a preference construction process in decision making that depends on retrieval of information from memory (Johnson et al., 2007; Weber et al., 2007). Consequently, such decisions could be adversely affected by the age-related decline in memory performance.

Barron et al. (2013) investigated decision making in an fMRI task where participants were asked to choose between novel combinations of familiar products. Imagination and evaluation of these composite products was linked to coactivation of memories corresponding to the component products. The results demonstrated the mechanism of value construction that relies on the hippocampus-dependent memory system, as well as on the medial prefrontal cortex. Furthermore, Gluth et al. (2015) demonstrated that in a task in which choice options need to be memorized, recall of the options correlated with connectivity between the hippocampus and ventromedial prefrontal cortex. These findings provided support for a transfer of value-related information from the hippocampus to frontal areas during value-based choice.

A number of studies have also used sequential sampling models (SSMs), such as the drift diffusion modeling (DDM), to investigate value-based decision making (for example, Enax et al., 2016; Milosavljevic et al., 2010; Philiastides et al, 2013). To summarize briefly, SSMs conceptualize decision making as a noisy process of accumulation of relative evidence for one of several available actions, and once the evidence reaches one of decision thresholds, that alternative is selected (Krajbich & Smith, 2015). SSMs have been initially applied to perceptual decision making; however, they are also applicable to preference-based choices due to similarities between these types of decisions (Dutilh & Rieskamp, 2016; Shadlen & Shohamy, 2016).

Summarizing findings from studies on neural mechanisms of decision making and application of SSMs to value-based choice, Shadlen and Shohamy (2016) proposed that decisions based on preferences involve retrieval of value-relevant information from memory.

Furthermore, they suggested that this process likely unfolds in a manner consistent with sequential sampling. Disturbances in regions involved in these processes, including hippocampus and frontal areas, could negatively affect decision making (Camille et al., 2011; Palombo et al., 2015). As reviewed earlier, Fellows and Farah (2007) showed a decrease in choice consistency in participants with lesions localized in the ventromedial prefrontal cortex, whereas Gluth et al. (2015) demonstrated the importance of value transfer between the hippocampus and frontal cortex. Further support for this role of memory in decision making was provided by Enkavi et al. (2017) who found a decreased choice consistency in patients with hippocampal lesions. The role of the hippocampus-based memory in choice is an intriguing topic in the context of aging and decision making research, because memory performance, as reviewed earlier, can decrease with aging. However, the link between memory function and value-based choices in aging has not been examined as extensively as the role of the reward-based learning system. This indicates a need to investigate the plausible connection between the memory function of older adults and value-construction process during choice, which was addressed by the first study in this dissertation.

1.3.2. Positivity effect and information search in decision making

Another topic addressed in the current dissertation is linked to age-related changes in the information search that may occur due to the positivity effect. As reviewed above, older adults may show a stronger bias towards positive stimuli in attention during information search in a decision context (English & Carstensen, 2015; Löckenhoff & Carstensen, 2007, 2008). Studies on the positivity effect have also shown a link between a higher positivity bias and a higher subjective decision satisfaction (Bjälkebring et al., 2016; Kim et al., 2008). Since the positivity effect can influence the way older adults direct their attention when evaluating choice options, it may also influence the way they make decisions. A systematically biased information search could adversely influence the process of option values construction, for example, by causing an individual to omit critical information from consideration. However, the research described above did not explicitly assess the objective decision quality resulting from the positivity effect. Some studies have discussed the likely contribution of the positivity effect to decision making and well-being of older adults overall (Carstensen & DeLiema, 2018; Reed & Carstensen, 2015).

Reed and Carstensen (2012) described the theoretical assumptions underlying the positivity effect and discussed whether it can be considered adaptive. According to the SST, the age-related change in motivation which results in positivity effect is adaptive since it allows people to adjust their goals and priorities in line with perceived time horizons (Carstensen & DeLiema, 2018). It has also been suggested that the positivity effect could be beneficial since it is aimed at emotional regulation; however, this explanation is not consistent with the SST framework (Reed & Carstensen, 2012). Nonetheless, a bias in the information search or processing could adversely affect decision outcomes as considered, for example, by Carstensen and Mikels (2005).

As reviewed earlier, according to the SST, the positivity effect reflects a shift in how cognitive functions, including attention, are deployed during information search, and is not considered a result of cognitive decline. Consistent with that, positivity effect was mitigated in decision situations via experimental instructions (Löckenhoff & Carstensen, 2007). Supporting that, English and Carstensen (2015) further demonstrated a suppression of the positivity effect in hypothetical healthcare choices, and this suppression was related to participants' health status. Combined findings from these studies support the assumption that the positivity effect is likely not linked to cognitive decline, but rather represents a change in the manner cognitive abilities are used.

To summarize, the potential bias in the information search of older adults due to the positivity effect is relevant to the topic of decision making in aging because it could lead to lower decision quality. The influence of the positivity effect on decision making was therefore investigated in the second study in the empirical section of the current dissertation.

1.3.3. Episodic future thinking and intertemporal decisions

The third study within this dissertation investigated whether intertemporal decisions of older adults could benefit from episodic future thinking. The effect of the episodic future thinking on decision making has been studied in the context of intertemporal choices in which available rewards differ with respect to the time delay before the receipt of reward. As an example, in a study on delay discounting, a participant can be asked to choose between receiving 5 Euros immediately, or 10 Euros in a month. It is considered that time discounting acts as a modulator of the value signal during value-based decision making (Rangel et al., 2008).

Past research has indicated that older adults show a higher rate of delay discounting in choices with different types of rewards, including monetary, social and health rewards (Göllner et al., 2018; Seaman et al., 2016). However, it has also been suggested that older adults discount future rewards to a lesser degree than younger adults (Löckenhoff et al., 2011). The rate of delay discounting is considered an important characteristic of a decision maker because it has been linked to an ability to self-regulate in various contexts, including health-related behaviors (Bickel et al., 2015; Story et al., 2014). Decreasing the rate of temporal discounting could therefore be beneficial for a decision maker because it can lead to enhancing self-control and improving adherence to health-related behaviors. Episodic future thinking function can be leveraged to decrease the rate of delay discounting (Koffarnus et al., 2013). In a typical episodic thinking task, a participant first answers questions about likely future events. Presenting participants with cues about these future episodic events during decisions about future rewards decreases the rate of delay discounting – this phenomenon is referred to as a tag effect (Peters & Büchel, 2010). It has been proposed that episodic future thinking influences value construction in delayed discounting tasks and promotes more patient choices in decisions about monetary rewards. It can also promote more health-oriented choices in food choice in dieting individuals, as well as in alcohol and tobacco consumption (Schacter et al., 2017).

Some studies indicated that, analogous to experiencing a decline in the memory function, older adults experience a decline in the ability to imagine the future. Schacter et al. (2007) highlighted similarities between the construction of an imaginary future event and remembering a past episode, which likely arise from dependence on similar mechanisms and the same brain structures. In support of this link, past empirical findings showed a decrease of the episodic future thinking function in older age which correlated with participants' memory deficits (Schacter et al., 2013). In particular, older adults generated fewer episodic details specific to their imagined future events compared to younger adults. A study by Sasse et al. (2017) additionally linked the episodic future thinking ability of older adults to their executive functioning. In that study, older adults overall did not show the tag effect, as opposed to the younger group; however, the size of the tag effect in older adults was associated with attentional control ability. Contrary to those findings, a study by Hu et al. (2017) demonstrated the effect of episodic future thinking on delay discounting in healthy older adults.

To summarize, episodic future thinking is relevant for research on aging and decision making due to its contribution to future-oriented decisions. Specifically, interventions promoting episodic future thinking could be beneficial for older individuals. Such an intervention could modify the extent to which older adults take into account consequences of various behaviors for future outcomes such as health, for example via a stronger attention to healthiness of food products during choice. This could in turn improve decision outcomes in certain situations. However, due to mixed results obtained in previous studies on the efficiency of episodic future thinking in older age, this topic requires further research, and it was addressed in the third study in this dissertation.

1.3.4. Potential age-related improvement in decision making

Studies on aging have also assessed the decision making of older adults by testing their problem-solving abilities in areas that might be relevant to everyday situations, or also relevant to less frequent but consequential choices. Participants typically complete a series of tasks that test various aspects of decision making (Blanchard-Fields et al., 2007; Bruine de Bruin et al., 2012; Finucane & Gullion, 2010). Results from these studies highlighted various age-related changes in aspects of decision making competence, which also included improvements. Blanchard-Fields et al. (2007) found evidence for more effective problem-solving in older adults in examined domains – in instrumental problems and in interpersonal problems. This could be attributed to an improved selection of problem-solving strategies.

In a study by Bruine de Bruin et al. (2012), younger adults performed better in tasks that relied on fluid intelligence, whereas older adults did better in tasks in which they could leverage crystallized intelligence. The results supported a view that decision making performance of older adults interacts with demands of decision situations. These findings also support the combined contributions of declining and maintained cognitive abilities to decision processes. Extending research on decision making in aging into real world outcomes, a study by Agarwal and colleagues (2009) investigated financial decision making. The study considered consumer behavior in ten different types of credit transactions such as credit card balance transfer offers and others. The results demonstrated a gradually increasing benefit of experience accumulated with age for decision making. However, the improvements of decision outcomes due to experience were offset by the detrimental effects of decreases in cognitive functioning in older age. Authors concluded that middle aged adults (53 years old) were most likely to engage in the optimal financial decision making. This result additionally emphasizes the relevance of the research on aging, decision making and cognitive functions to real-world decisions.

A study by Eberhardt et al. (2019) examined several aspects of financial decision making across lifespan in a large sample of participants (n = 926) from 18 to 88 years old using previously developed questionnaires (Figure 3). The findings were consistent with previous research showing improvements in some aspects of decision making in aging. Increasing age was associated with improvements in all four measures of financial decision making, including in resistance to sunk cost, in credit card repayment, in money management and in a financial decision outcomes inventory (DOI) for younger to middle-age participants, which could be linked to an increase in experience-based knowledge. Additionally, older adults showed improvements in resistance to sunk costs and money management. However, the oldest of participants also demonstrated decreases in two of the measures - credit card repayment and in the financial DOI.

Overall, studies on decision making competence and financial choices suggest that an older decision maker may adapt to the demands of decision situations, for example, by using efficient problem-solving approaches or by using accumulated experience. This supports the feasibility of using approaches such as various interventions for improving decision quality of older adults. Additionally, this research highlights avenues with which older adults can compensate for effects that may lead to lower quality of decision outcomes.

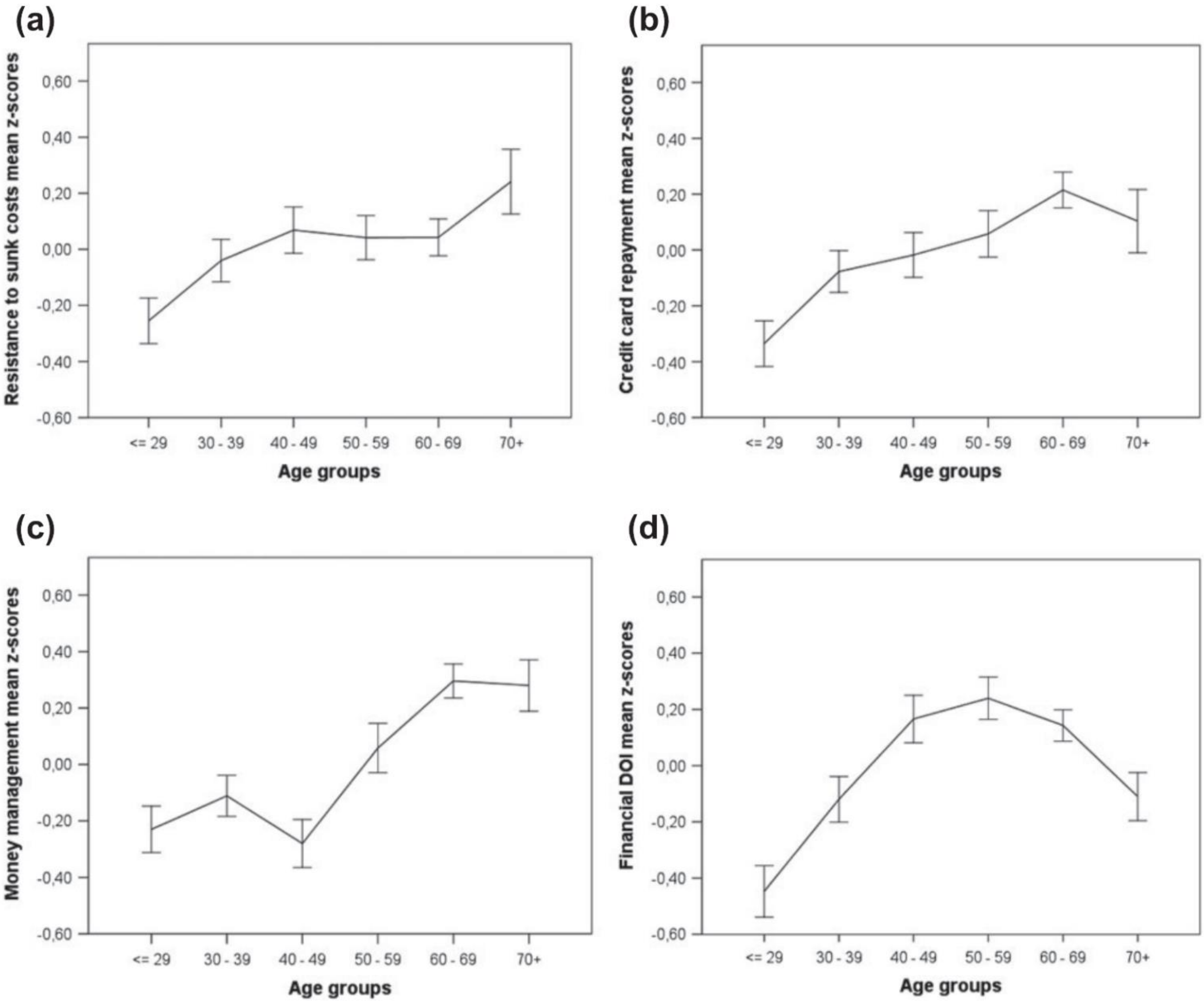

Figure 3. Measures of financial decision making by age group. Values represent mean z-scores for each age group. Error bars represent standard error of ±1. a) Resistance to sunk costs; b) Credit card repayment; c) Money management; d) Performance on the financial decision outcomes inventory (DOI). Adapted from Eberhardt et al. (2019).

1.4. Current empirical studies

As outlined above, the empirical studies in the current dissertation aimed to investigate several aspects of value-based decision making in older adults that are related to cognitive functioning and could therefore influence decision making outcomes. Informed by the previous literature, the studies addressed the hypothesized effects of aging on aspects of value construction during choice, as well as the possible links between these age-related differences and decision quality.

The first study assessed the potential contribution of the episodic memory function to value-based decision making in a group of older adults. A decline in episodic memory performance in older age could lead to decreased accuracy of value construction. This would in turn increase the rate of stochastic errors in choice. In the study, older adults completed a memory task with a delayed recall of a wordlist as a measure of episodic memory. They also completed a food choice task representative of an instance of value-based decision making.

The second study evaluated positivity effect in information search and whether it contributed to decision making outcomes in an online task with decisions about donating to various charities. A stronger focus of older adults on positive characteristics of charities could direct their attention away from decision-relevant information about negative characteristics. This would result in a biased review of information and suboptimal choices by older adults. This study was conducted in a form of a registered report, and the data were collected after peer review of the stage 1 submission which included the introduction and the method sections.

The third study within this work investigated the episodic future thinking function in older adults and its effect on decision making in older age. Specifically, it assessed the effect of an online task promoting future thinking on performance in a delay discounting task. A lowered rate of delay discounting due to instructions promoting episodic future thinking would be considered a beneficial outcome. Such a paradigm administered to older adults could also offer a way to improve adherence to beneficial behaviors with long-term rewards, such as health-related behaviors. Apart from discounting rate in the monetary delay discounting task, the study assessed an effect of episodic future thinking on consideration of healthiness of food products in food choice. Effects investigated in the three studies and their potential contribution to value-based decision making in older adults are summarized in Figure 4.

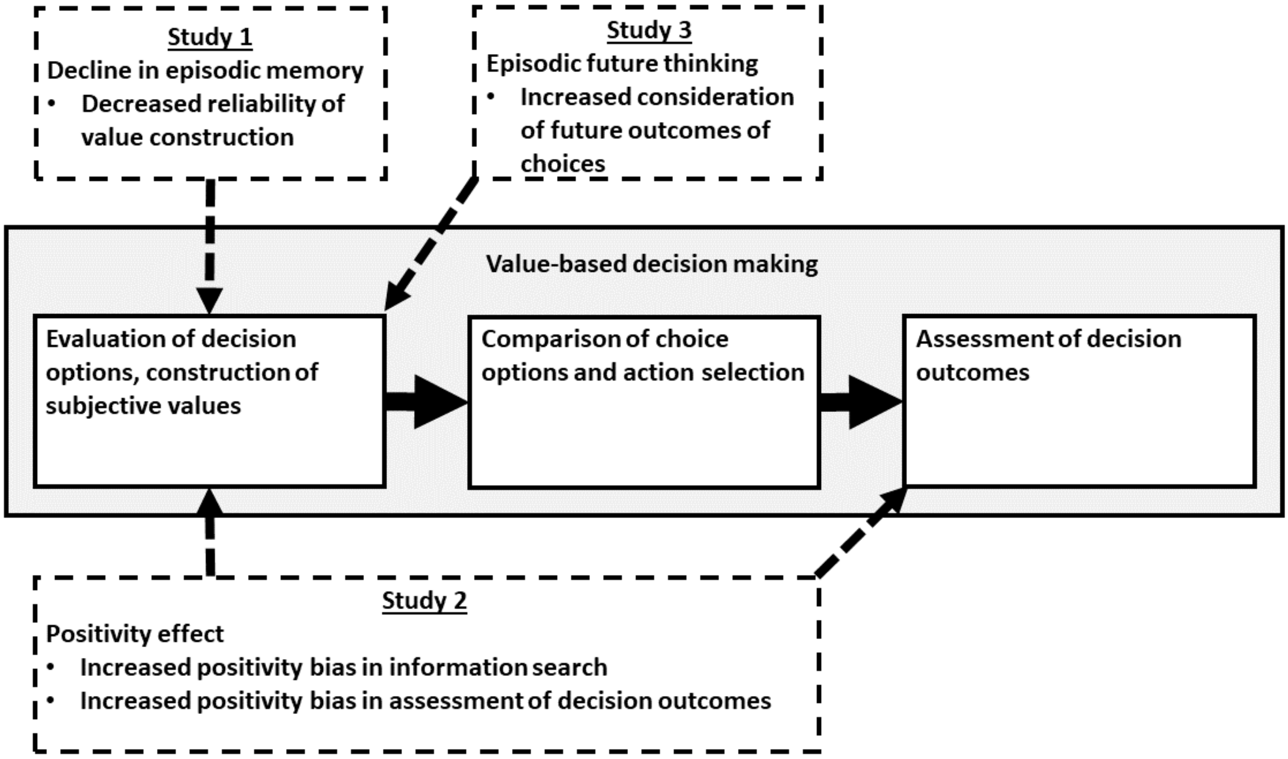

Figure 4. Hypothesized contributions of effects addressed in the three studies to decision making in older age. The schematic depicts several steps of decision process investigated in research on value-based decision making. Dashed arrows represent potential influences of effects addressed by the empirical studies within this dissertation. Steps of value-based decision making are based on the framework proposed by Rangel et al. (2008).

2. Methods

Following section describes methodological approaches used in the empirical studies conducted within this dissertation. First, I describe decision making tasks and some of the key measures used in the studies. Next, I describe measures of cognitive performance that were used.

2.1. Decision making tasks

Three studies conducted within the current dissertation utilized tasks to assess decision making of participants. All tasks were computer-based and were administered either in the lab (for the first study) or as online tasks (for the second and the third studies). Tasks recorded characteristics of presented trials, such as available choice options and their properties, as well as characteristics of decisions made by participants, such as choices and reaction times. Each of the studies also included some form of a rating task, which elicited individual evaluations of options or of characteristics of options, for example personal importance of various characteristics of charitable organizations in the second task.

2.1.1. Decision making task in the first study

The task in the first study was designed to assess several aspects of decision making which would then be used to test the relationship between memory and value-based decision making processes in older age. Accuracy of value-based choices was assessed via several different measures, including intransitivity of choices, change of choices on retest and consistency of choices with individual liking ratings of options. Additionally, the relationship between episodic memory and the speed of choices was assessed.

The decision task is depicted in Figure 5. The decision task used food products as choice options. First, participants rated how much they liked 50 food products depicted on presented photos. Based on those individual ratings, a pool of 20 products was selected to be used in the main decision making task. In this forced choice task, food items were presented in all possible unique pairings, which results in 190 decision trials, and participants were required to select a more preferable alternative. The results were used to calculate the number of intransitive choice triplets, which indicate consistency and, correspondingly, accuracy of decision making (Fellows & Farah, 2007; Lee, Amir, & Ariely, 2009). An assumption behind this measure is that a less consistent decision maker would likely show intransitivity in choices more often, than a consistent decision maker. Later in the study, the food choice task was repeated, and participants made choices between same pairs of products again. Reversals of choices between the two presentations of the task were also used as a measure of inconsistency (Brown & Peterson, 2009). Choices in which participants selected an option with a lower individual rating of preference were utilized as an additional measure of decision accuracy similarly to previous research on value-based decision making (Milosavljevic et al., 2010).

Between the first and the second presentations of this task, participants also completed a shorter task similar to the food choice trials, but with choices among simple numbers to verify that any potential mistakes in the food choice task were not due to an inability to make simple comparisons.

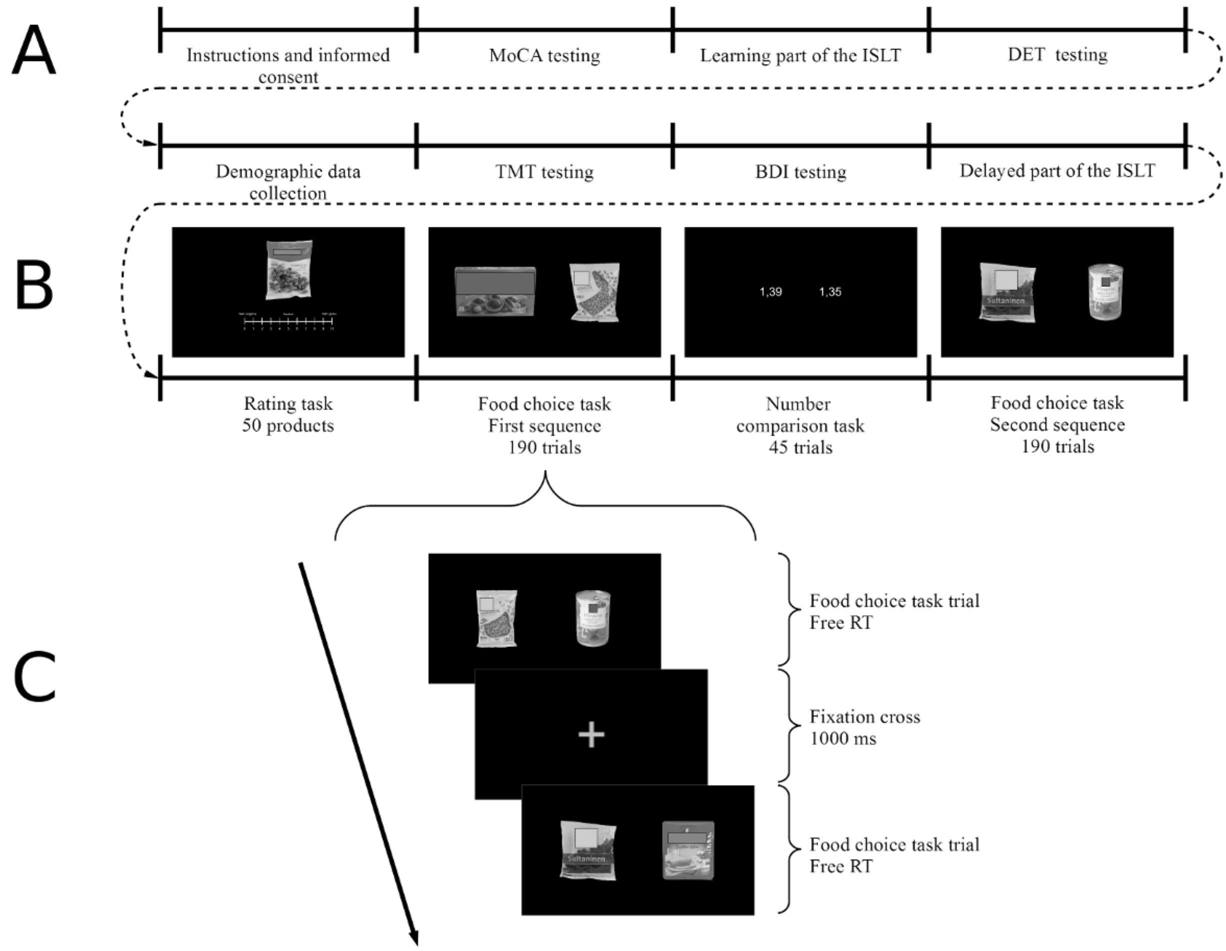

Figure 5. Procedure of the first study. Panel A depicts the procedure of administering the tests. Panel B demonstrates the behavioral task. In the first part participants rated 50 food stimuli on a scale from 0 to 10. Next, they made choices between all possible pairings of 20 food stimuli selected based on their ratings (N = 190). In a number comparison task participants were then asked to select the higher number of two. Lastly, they were presented again with the choice pairs from the second part of the experiment, but in a re-randomized order. Brand names are covered on this figure, but they were present in the task. Panel C demonstrates a trial from the paired choice task. Reaction times for paired choices were not limited. On this figure the fixation cross is presented larger, than it was in the task, for demonstration purposes. In order to test participants' ability to make comparisons without the need for retrieving preferences, we administered a simple paired values choice task between the test and the retest of the food choice task. It included overall 10 prices of the featured food products (with two decimal places, range 0.79–2.59) presented in all possible pairings, which amounted to 45 trials.

2.1.2. Decision making tasks in the second study

The second study used a decision grid task designed to test the positivity effect in decision making of younger and older adults (Löckenhoff & Carstensen, 2007, 2008). The design was similar to previously used Mouselab-type tasks (Willemsen et al., 2011) which allow to assess characteristics of information search. In such a task, participants are presented with a table where rows represent options and columns represent corresponding characteristics. The task is depicted in Figure 6. Decision options used in this task represented real charitable organizations and their characteristics shown in the task were based on publicly available data. To see characteristics, participants opened corresponding cells by clicking on them. The variation of the Mouselab task used in the second study included labels on the information cells that indicated whether the content was a negative or a positive value. This allowed to assess relative preference for positive and negative information among younger and older adults. Data on information search was used to calculate several measures, including positivity index representing the bias of a participant towards positive information, as opposed to negative. Bias index represented a relative tendency to review positive as well as negative information and was based on numbers of all reviewed cells, whereas a similar ignorance-based bias index was based only on unique openings of the cells for each trial. After each decision grid trial, participants used a nine-point scale to provide subjective ratings of decision satisfaction.

Before the beginning of the decision grid task, participants also completed a similar but simplified task with two options in each trial all values from the information cells presented openly. Participants' choices allowed to compare the degree to which participant groups took into account characteristics of choice options

In the beginning of the study participants also provided individual ratings of importance of different characteristics of the charitable organizations using a nine-point scale. These ratings were used to calculate expected value ratio (EVR) which was then used as a measure of decision quality, similarly to the study by Queen et al. (2012).

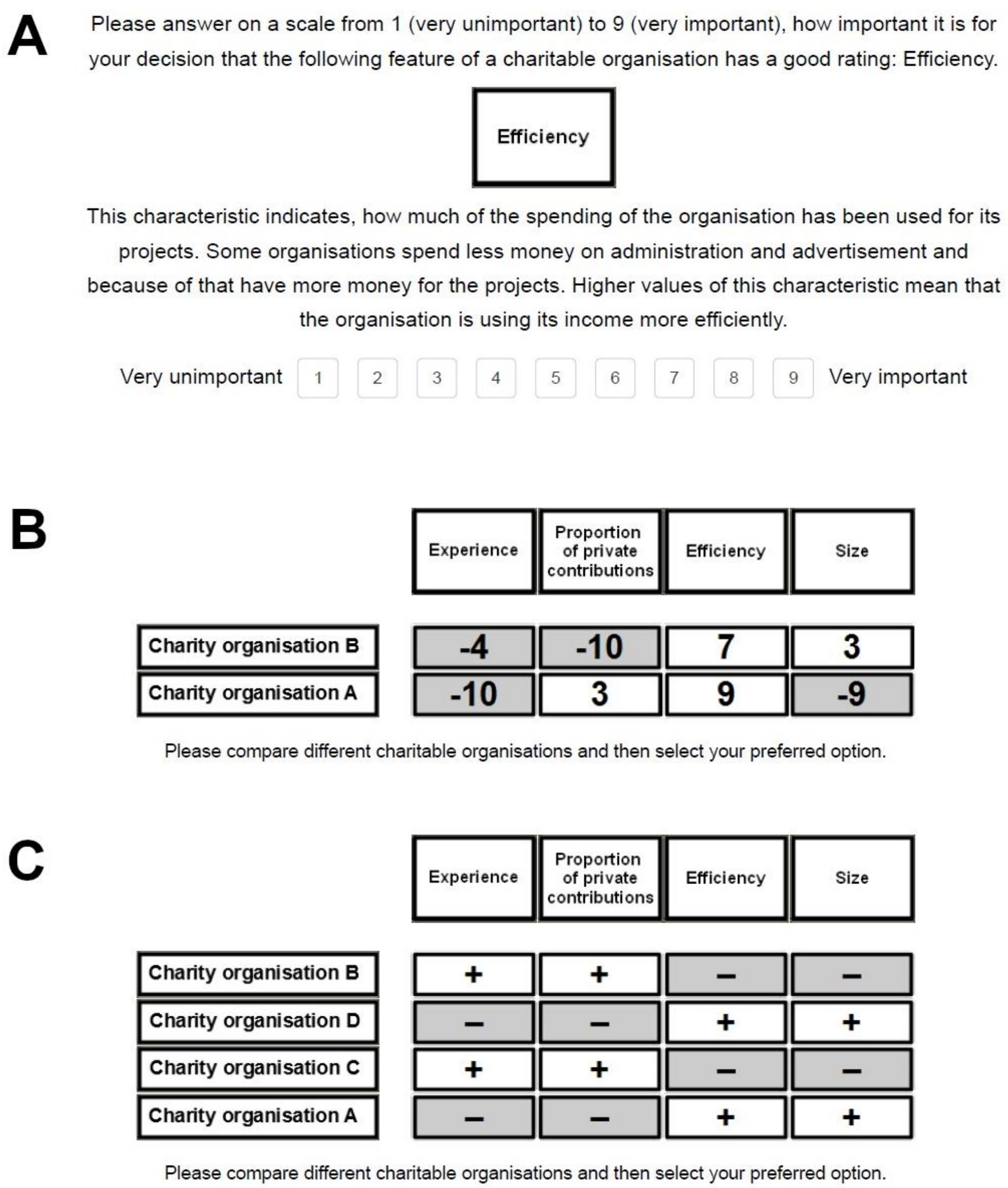

Figure 6. Procedure of the second study. Panel A depicts the rating task in which participants rate 4 characteristics on a scale from 1 to 9. Panel B demonstrates the simplified decision task. Choice options have a characteristic with positive values, a characteristic with negative values and two characteristics with mixed positive and negative values. Participants are asked to compare the options and select a preferred one. Panel C demonstrates the decision grid task. Participants see the cues indicating whether the contents are negative or positive and have to click on the cells in order to review the values.

2.1.3. Decision making tasks in the third study

The third study was designed to assess the effect of episodic future thinking on future-oriented decision making in aging. Groups of older and younger participants completed several decision tasks. First, participants completed a task aimed to assess baseline delay discounting. This measure would represent the tendency of a participant to devaluate future consequences of decisions. As reviewed previously, decision makers in general tend to evaluate future outcomes and rewards lower than those that are available immediately (Koffarnus et al., 2013).

Behavioral studies have shown that the rate of delay discounting can be modelled with a hyperbolic discounting function (Rangel et al., 2008). Such a function can be expressed with a formula $V = A/(1 + kD)$. In this equation, V represents a discounted subjective value, whereas A represents the objective value of the reward; D represents the time delay, and k represents the discounting rate of the individual (Stein et al., 2018). These findings have also been supported by findings showing that hypothesized delay discounting is reflected in value-related neural signal (Kable & Glimcher, 2007).

A common method for assessing individual rates of temporal discounting is to administer a task offering choices between rewards of different magnitudes and available after various temporal delays, such as monetary rewards of different values (Koffarnus & Bickel, 2014). Correspondingly, in the third study, participants made a series of hypothetical decisions between a fixed larger monetary reward available only after a specific time delay and a lower reward available immediately. The delay discounting task was designed as adjusting-amount task, and participants made 6 choices for 6 different time delays similarly to the study by Stein et al. (2017). Figure 7 presents decision tasks used in the Study 3. After each choice, the lower reward was adjusted in order to approximate the values at which the delayed larger reward and the immediate smaller reward are similarly likely to be picked by the participant. Data on these choices for each of time delays were used to infer the so-called indifference points which reflect the degree to which a reward is discounted at a specific temporal delay. These data were in turn analyzed as area under curve of the discounting function to compare the tendency of participants to discount future rewards (Hu et al., 2017; Myerson et al., 2001).

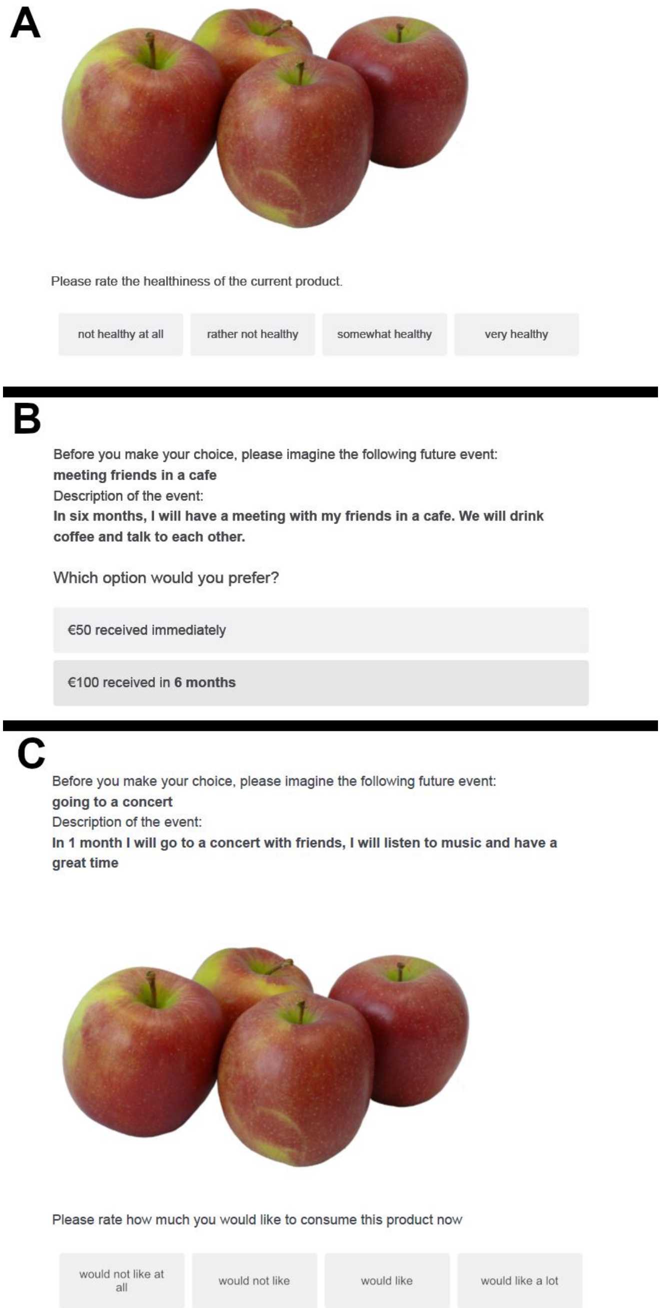

Figure 7. Behavioral task in the third study. Figure demonstrates parts of the behavioral task. (A) Rating of healthiness of a food product. (B) Delay discounting trial presented with an EFT event cue. (C) Food choice trial presented with an EFT event cue. Please note that the original text in German was replaced with an English translation, and event cue examples were generated for demonstration purpose.

After completing the first delay discounting task, participants were presented with a task designed to elicit personal event cues for promoting either episodic future thinking or episodic recent thinking (Stein et al., 2018). The task adapted for the current study was self-paced and participants were asked to think about such events corresponding to specific future time periods.

The self-generated cues were then presented during the second repetition of the delay discounting task in order to assess the effect of future thinking on discounting. In addition to that, the cues were presented in trials of a food choice task designed similarly to the one used by Hare et al. (2011). Choices of participants were analyzed in conjunction with their individual ratings of healthiness and taste of products. The comparative effect of episodic future thinking cues, as compared to the control group presented with episodic recent thinking cues, allowed to evaluate the effectiveness of EFT for promoting healthy eating.

2.2. Assessment of cognitive performance

Cognitive performance of participants in the conducted studies was assessed via tests and also via measures based on self-report which reflected domain-specific or general cognitive functioning. In the first study, several measures of cognitive performance were obtained via a computerized Cogstate Research™ platform. Memory function was assessed via a verbal list learning task – the International Shopping List Test (ISLT; Lim, Pietrzak, et al., 2012). The task included three learning trials and a recall trial delayed by 20 minutes. The number of words recalled after the delay was used as a measure of episodic memory performance. For use in analyses of reaction time, a measure of psychomotor function was obtained using the Detection task (DET; Maruff et al., 2013). In addition to computerized tests, the first study also included a measurement of executive function via the paper-based Trail Making Test (TMT) which consists of parts A and B (Bowie & Harvey, 2006). Cognitive performance of older adults in the first study was also assessed via the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). It includes several parts evaluating various aspects of cognitive functioning, and the resulting MoCA score was used to control for a potential general cognitive decline.

The second and the third studies also included measures of cognitive performance based on self-report assessments. The second study included a short seven-item version of the Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE; Ehrensperger et al., 2010; Ehrensperger & Monsch, 2016). It was administered as a self-report questionnaire (Eramudugolla et al., 2013) and was used to exclude participants with a score exceeding a threshold suggestive of cognitive decline. Additionally, some of the analyses in the second study controlled for numeracy assessed with the seven-item Subjective Numeracy Scale (SNS; Fagerlin et al., 2007; Garcia-Retamero & Galesic, 2013). The third study included the 14-item Adult Executive Functioning Inventory (ADEXI) – a self-report measure of executive function (Holst & Thorell, 2017). This measure was used to test the hypothesized link between executive function and the effectiveness of the EFT procedure.

3. Empirical studies

3.1. Study 1: The influence of episodic memory decline on value-based choice

The following study has been published in Open Access with the following attribution: Fedor Levin, Susann Fiedler & Bernd Weber (2018): The influence of episodic memory decline on value-based choice, Aging, Neuropsychology, and Cognition, DOI:10.1080/13825585.2018.1509939

3.1.1. Abstract

Recent studies suggest the involvement of episodic memory in value-based decisions as a source of information about subjective values of choice options. We therefore tested the link between age-related memory decline and inconsistencies in value-based decisions in 30 cognitively healthy older adults. Within the preregistered experiment, the inconsistencies were measured in two ways: i) the consistency between stated preferences and revealed choices; ii) the amount of intransitivities in choice triplets, revealed in a forced paired choice task including all possible pairings of 20 food products. Although no significant association of memory functions to number of intransitive triplets was observed, participants with lower memory scores were more likely to choose the item for which they stated a lower preference. The results suggest a higher noise in the underlying preference signal in participants with lower memory. We discuss the results in the context of the unique needs of elderly consumers.

3.1.2. Introduction

The global population is aging rapidly. According to the UN, by 2050 the proportion of people older than 60 is expected to double compared to 2015 (United Nations, 2015) Altered decision-making abilities of older adults (OAs) in domains such as finance (Agarwal et al., 2009; Hershey et al., 2015; Li et al., 2015), healthcare (Morrow & Chin, 2015), or consumer choices (Carpenter & Yoon, 2015) may have a negative impact on their wellbeing. Thus, investigating the relation of decline in cognition to decision-making abilities is considered highly relevant (Carpenter & Yoon, 2011; Strough, Löckenhoff, et al., 2015). A number of recent empirical studies (Barron et al., 2013; Bornstein & Daw, 2013; Gluth et al., 2015; Wimmer et al., 2014; Wimmer & Shohamy, 2012) and reviews (Palombo et al., 2015; Shadlen & Shohamy, 2016) suggested an important role of episodic memory in value-based learning and value-based choices. These findings are relevant to research on decision-making in aging, as episodic memory starts decreasing at the age of approximately 60–65 with large individual differences (Nyberg et al., 2012). However, the precise impact of this age-related decline on value-based choices is unclear. In the current study we address the relationship between episodic memory function and value-based decision-making of OAs using a food choice task.

In value-based decisions, an individual chooses between the available options according to their subjective values, which can be influenced by previous experiences (Rangel et al., 2008). Our research is in line with the framework of value-based decision-making proposed by Rangel et al. (2008), which assumes several computational steps within a decision: (1) representation of the choice as well as internal and external states, (2) valuation of the alternatives, (3) comparison of their values, (4) evaluation of the outcome of the choice and, finally, (5) learning process aimed at improving future behavior. Valuation of alternatives and the learning process potentially depend on memory, since they involve memorizing and, consequently, retrieval of information related to the properties of choice alternatives.

Our approach to testing the link between memory and value-based choice was additionally informed by the Query Theory (QT) framework (Weber et al., 2007). The QT assumes that preferences of the decision-maker are not immediately known to the decision-maker or are not sufficiently precise. Hence, decision-makers construct preferences during the choice process by retrieving memories related to alternatives under consideration. As a result, preference-based decisions rely on memory and follow the same dynamics and biases as memory processes, such as, for example, output interference (Weber et al. 2007). Previous empirical studies tested whether the QT framework could account for behavioral effects observed in a set of value construction decisions such as the endowment effect (the difference in willingness to pay between owners and buyers, Johnson et al., 2007) or asymmetry in delay discounting (Weber et al., 2007). Results within the domain of delay discounting suggest, for example, that individuals show more patient behavior under conditions when they were thinking about more distant outcomes first. Building on this previous work we adopted the general assumptions of the QT framework about the processes of preference construction and their dependence on memory.

Recent research provided findings supporting this role of memory in value-based choice. Wimmer and Shohamy (2012) demonstrated how the hippocampus, a key structure involved in episodic memory, contributes to the spread of reward value across related memories. They observed a behavioral bias toward non-rewarded stimuli that had been presented together with rewarded stimuli earlier. This bias was associated with hippocampal activation and functional connectivity between the hippocampus and the striatum. These findings provided support for the role of the hippocampal memory system in value-based choice. Further evidence was offered by research showing altered feedback-driven learning and disadvantageous decisions in patients with medial temporal lobe (MTL) damage suffering from amnesia (Foerde et al., 2013; Gupta et al., 2009). A recent study assessed an effect of the episodic future imagination on delay discounting in participants with subjective cognitive decline (SCD) who reported a decrease in episodic memory performance (Hu et al. 2017). The results showed increased delay discounting and a decreased effect of episodic future imagination in the SCD group as compared to a cognitively healthy control group. Shadlen and Shohamy (2016) reviewed the evidence for the role of episodic memory and the hippocampus in decision-making. They suggested that assignment of values to options under consideration in value-based decisions involves retrieval of value-relevant memories and experiences in a way that is similar to the process of evidence accumulation described by sequential sampling models (SSMs). SSMs have previously been applied to perceptual and preference-based decisions (Krajbich et al., 2012; Philiastides & Ratcliff, 2013; Polanía et al., 2015; Ratcliff et al., 2011), and describe them as an evidence accumulation process for the choice options. A decision is made when the amount of evidence reaches a specific threshold. The account by Shadlen and Shohamy (2016) thus offers an interesting perspective on the role of memory processes in choice and allows to make predictions about regularities of value-based choice. To summarize, recent studies have provided considerable evidence for neural mechanisms linking memory processes to value-based choice. A decrease in memory performance could lead to decreased choice quality.

Building upon the existing research which links episodic memory to value-based choice, we hypothesized that heterogeneity in episodic memory performance would be related to differences in retrieval processes of value-related information during choice. Lower episodic memory would thus lead to less reliable value construction. In turn, this would decrease efficiency of decision-making, leading to less accurate and slower value-based choices. There are different approaches to measuring accuracy of value-based choices, which vary in how they define optimal choice. We combined several approaches in order to comprehensively describe the link between memory and quality of choice. In the next section we outline these approaches to assessing accuracy, as well as specific hypotheses and our analysis plan. One approach to measuring precision of value-based choices is the assessment of choice accuracy based on stated personal preferences. Some previous studies collected independent liking ratings of items (Milosavljevic et al., 2010) or bids on a Becker–Degroot–Marshak (BDM) auction (Krajbich et al., 2012). This allowed to classify choices as correct or incorrect based on whether an item with a higher stated preference is picked in a forced choice task. High differences between stated preferences of alternatives represented choices with low difficulty, whereas low differences between stated preferences represented choices with high difficulty. This approach allows testing factors that affect accuracy on trial level, while also taking into account choice difficulty and other relevant variables that differ between trials. Additionally, it is possible to evaluate the overall accuracy of a decision-maker by calculating the rate of errors in choices. We formulated three hypotheses with regard to this measure. We hypothesized that episodic memory performance would be related to accuracy. Specifically, we predicted that participants with lower memory would be more likely to choose inconsistently with their independently stated liking ratings, and would commit more errors—decisions where a food item with a lower stated preference is selected—than participants with higher episodic memory (Hypothesis 1a). Furthermore, we tested whether inconsistent choices (errors) were more likely when differences between ratings were low rather than high (Hypothesis 1b). For example, choices between products that are very similar in their values and are thus hard to discriminate would more often result in errors. We planned this test as confirmatory analysis because it allowed to link the errors that we observed to the amount of value-relevant information in support of presented options. We additionally tested whether an interaction effect between memory and rating differences predicted the probability of making an error (Hypothesis 1c). We expected that better episodic memory would not provide a strong advantage when choice options are close to identical in their subjective value, because there would be relatively little value relevant information available for retrieval to help discriminate between the options. Additionally, people with lower episodic memory performance would have a smaller improvement of accuracy in easier trials, which for them would result in a weaker relationship between difficulty and accuracy, than for people with higher memory performance. Our prediction is partially in line with findings from a study by Polanía et al. (2015), who used transcranial alternating current stimulation (tACS) to influence synchronization between the frontopolar and the fronto-parietal areas of the cortex. The stimulation produced a larger decline in accuracy of value-based choices in trials with highest value differences. The authors interpreted these value differences as corresponding to intermediate levels of evidence. We also adopted another approach to assessing accuracy using transitivity of value-based choices (Fellows & Farah, 2007; Lee et al., 2009). For example, after choosing option A over option B and B over C, subjects were expected to choose A over C. Selecting C in favor of A would thus constitute an intransitive choice. Since a triplet of choices is a minimal structure that can be intransitive, it is possible to calculate intransitive triplets among choices between all possible combinations of items and use them to construct a measure of choice accuracy. The advantage of the measure of intransitivities is that it does not require any assumption about the link between liking ratings and the respective choices. Testing the relationship between memory performance and the measure of intransitivity would allow us to explore whether the effect of memory on accuracy persists with the measure based only on choices and independent of liking ratings. We hypothesized that participants with lower episodic memory would make more internally inconsistent choices and display a higher rate of intransitivities (Hypothesis 2). One disadvantage of the intransitivity measure is that it is not straightforward for use on the level of trials. Therefore, in order to complement the analysis of intransitivities, we also assessed a test–retest measure of reliability (Brown & Peterson, 2009) as a part of exploratory analysis. Presenting participants with the same sets of choices twice allowed us to test whether memory performance predicted a reversal of the initial choice. A participant with lower choice accuracy would be more likely to choose differently when confronted with a same pair of products a second time. We also tested whether the overall frequency of choice reversals by participants was predicted by memory performance. We expected that lower memory performance would be associated with lower test–retest reliability, both on the level of trials and the level of individuals.

With regard to the speed of information processing, we expected that differences in retrieval of value-related information would also have an effect on reaction time. We hypothesized that increased average reaction times would be linked to reduced episodic memory confirming slower processing in OAs with reduced memory (Hypothesis 3a). Thus, a participant with lower episodic memory performance and a lower efficiency of memory retrieval processes would take longer to make choices. Similarly to Hypotheses 1b and 1c, we tested whether reaction times depended on rating differences with slower decisions between similarly valued options (Hypothesis 3b) consistently with the previous studies on value-based choice (Krajbich et al., 2010; Milosavljevic et al., 2010). As an example, a decision in a trial with high difficulty would take longer than in an easy trial. We also tested whether an interaction between memory and rating differences indicated a weaker relationship between rating differences and reaction times for people with reduced memory (Hypothesis 3c). The rationale for this prediction was similar to the rationale for the Hypothesis 1c—the advantage of higher memory performance for the speed of choices would be most apparent in the trials with a relatively lower difficulty, as compared to trials with the highest difficulty.

Apart from our measures of interest, several other individual difference factors could influence processes of decision-making. As has been shown by previous literature, executive function is related to aspects of decision-making (Del Missier et al., 2015) and memory (Bouazzaoui et al., 2013). We therefore included the measure of the executive function as control for all analyses. Additionally, the literature has described an age-related decline of psychomotor functions (Lim, Ellis, et al. 2012). We added the psychomotor function measured with a simple reaction time task as a control. Previous studies using eye-tracking suggested that stimuli difference measures (position of the chosen food item, trial number) could potentially influence attention to choice options (Orquin & Mueller Loose, 2013). Therefore, in multilevel trial analyses we controlled for these stimuli difference measures.

3.1.3. Method

The study was approved by the ethics committee of the University of Bonn. All participants signed the informed consent before taking part in the study. The sample size was determined a priori based on practical considerations such as anticipated recruitment rate as well as time constraints. Sample size was pre-registered together with all hypotheses and analysis plan before the start of data collection at the Open Science Framework (https://osf.io/dpfn7/register/565fb3678c5e4a66b5582f67). The complete instructions (https://osf.io/y695g/), data (https://osf.io/h6jat/) and analysis script (https://osf.io/rqtu9/) are also available at the Open Science Framework.

Participants

Thirty-seven OAs participated in the study. We recruited participants from the general population via local community organizations, with the help of flyers, email-based advertisements and by word of mouth. Based on pre-specified selection criteria, six participants were excluded from analyses due to having a BDI (Beck Depression Inventory—II; Kühner et al., 2007) score greater than 14 and thus meeting criteria for depression. This exclusion criterion was necessary since depression is associated with cognitive impairments (Rock et al., 2014). Additionally, one participant reported intake of a central nervous system-active medication and was excluded. The final sample consisted of 30 participants (63% female). Ages ranged from 65 to 88 years (*M* = 74.6, *SD* = 6.1). All participants had normal or corrected to- normal vision.

Material

ISLT

To measure episodic memory performance, we used the delayed International Shopping List Test (ISLT) score. We administered the German version of the ISLT using the computerized test battery Cogstate Research™. ISLT is a verbal learning task with three learning trials and a delayed recall trial (Lim, Pietrzak, et al., 2012; Lim et al., 2009). The delayed ISLT was measured as a number of words remembered in the delayed recall 20 min after the last learning trial.

MoCA

We additionally administered the Montreal Cognitive Assessment cognitive screening test (MoCA) to rule out dementia or mild cognitive impairment (MCI). Only 43% of our sample have reached a cut-off threshold recommended in the original validation study by Nasreddine et al. (2005). This could be explained by a relatively low specificity of MoCA when used with a standard threshold. The original study (Nasreddine et al., 2005) reported specificity of 87%. However, in later studies using the MoCA (Rossetti et al., 2011; Tiffin-Richards et al., 2014), specificity was lower—only 38% of participants reached the standard threshold in the study by Rossetti et al. (2011; note that participants were not screened for cognitive impairment) and about 57% of healthy participants reached the standard threshold in the study by Tiffin-Richards et al. (2014) Consequently, in order to control for possible differences related to the overall cognitive performance, we added the MoCA score as a control variable to our analyses while still including participants who scored below the threshold.

Additional cognitive assessment

To control for possible alternative mechanisms underlying the variability in reaction times, we additionally measured the psychomotor function using the Detection task (DET) from the Cogstate Research™ software (Maruff et al., 2013). In order to control for executive function, participants completed the Trail Making Test (TMT; Bowie & Harvey, 2006). TMT consists of two parts—TMT A and TMT B. This data allowed to calculate two measures of executive function—the TMT ratio score defined as a ratio between TMT B and TMT A, and the TMT difference score defined as a difference between TMT B and TMT A.

Behavioral task

In order to record food choices we developed a computer-based task consisting of four parts (see Figure 5). First, participants rated 50 food stimuli according to how much they liked them on a discrete scale from 0 to 10. Based on these ratings, 20 of the 50 items were selected to ensure that a set of products used in the paired choice task included items with various liking ratings, and without the experiment taking too long. The algorithm ordered the list of 50 products by liking ratings and then picked every second product ignoring the 10 lowest-rated products.

In the food choice task, participants then chose their preferred products from a randomized sequence of all possible pairs of the selected 20 products, which amounts to 190 pairs. In order to assess test–retest reliability we presented the same choice pairs at a later point of the experiment again. Choice pairs had a new presentation order and reversed display sides in the retest. Participants chose products by pressing buttons on a keyboard corresponding to the left or the right product. There were no enforced time limits on trials, and participants were instructed to press a button as soon as they made a decision. Participants were informed that at the end of the session they would receive a product of their choice from one randomly picked trial. Since any trial could be selected, it provided an incentive for participants to treat each choice as equally important.

Overall procedure

Participants were instructed to select the highest number in each trial. The set of numbers was identical for each participant. The behavioral paradigm was presented using in-house software of the Department of NeuroCognition/Imaging, Life & Brain based on Python. The study took overall between 70 and 120 min and participants received a fixed payment of 25 Euro for their participation. To incentivize their choices, we additionally allowed them to receive one product of their choice from one randomly selected choice trial of the experiment. During the study, participants were shown an assortment of food before the beginning of the session to demonstrate that the products were available in the lab. They read instructions describing the procedure and after that MoCA was administered.[1] Participants completed the initial list learning part of the ISLT with three repetitions of the list. The retrieval part of the ISLT was conducted after a 20 min delay. During the delay, participants completed a set of other tasks. Within the Cogstate Research™ they completed the DET. Then participants answered questions about their age, level of education, whether they had neurological or psychiatric disorder, and whether they were taking central nervous system-active medications. Next, they completed the TMT, the BDI, and the delayed part of the ISLT. Following these tests, participants performed the behavioral task consisting of the liking rating task, the food choice task, number comparison task and the retest part of the food choice task (Figure 5). At the end of the session participants received their payment and a product of their choice from one randomly selected food choice trial.

Data preparation

Both parts of the paired choice task—test and retest—were used in the analyses. We used data from the paired choice task to examine triplets of choices and calculate percentages of intransitive triplets for each subject. According to the pre-registered criteria, reaction time outliers and other nonviable trials were excluded.

Reaction times

As pre-registered, we excluded trials with reaction times shorter than 300 ms and reaction time outliers (± 3 *SD*) to remove trials in which participants most likely did not pay attention. This criterion applied to 1.8% of all trials.

Error measure

We identified trials in which participants picked a product with a lower rating. For the error measure analysis, in addition to excluding trials based on reaction time criteria, we excluded trials in which products had the same ratings, since errors could not be identified for those trials. Overall, 16.7% of trials met this criterion. To account for different numbers of trials excluded for each participant, we calculated the error measure as a percentage of error trials

[1] For the first seven participants, MoCA was administered after the retrieval part of the ISLT and controlling for the order of administration in the analysis did not indicate an effect of the order change.

among all included trials. Higher values on this measure represented higher error rates and less accurate decision-making.

Missing data

One participant's responses in the rating task had likely been caused by accidental presses on a key not intended for use in the task, and were then registered as a series of entries unrelated to the liking rating scale with implausibly short reaction times. This affected 8 out of 20 preselected products and subsequently 65.3% of this participant's trials. Hence, the participant was excluded from all error measure analyses and mixed effects analyses involving rating differences. This participant was included in the analyses of intransitive triplets, average reaction times and percentages of choices changed in retest since these measures did not depend on product ratings. For another participant, the DET measure in the testing program output was missing most likely due to incorrect execution of the task, and was excluded from all analysis including DET.

Intransitivity

We calculated percentages of intransitive triplets among all triplets for each participant. For example, a triplet containing trials with choices between products A, B and C was labeled intransitive if product A was selected over product B, product B was selected over product C, but product C was selected over product A. Each sequence of 190 trials produced 1140 possible triplets and percentages of intransitive triplets were averaged across the two sequences of choices for each participant.

Data transformation

Due to the skewed distribution of reaction time data, we log-transformed it for all analyses. In all regression models we centered independent variables around the mean before including their respective interaction in the analysis. Additionally, for the logistic regression model predicting errors in trials, we mean centered the two control variables TMT difference and presentation order, as well as rescaled them dividing by 100 in order to ensure the convergence of the model. For the linear regression model predicting reaction times, we mean centered and rescaled the presentation order variable.

3.1.4. Results

Regression analyses included models specified on the level of individuals as well as mixed effects models specified on the level of trials, which included random intercepts for participants in order to account for individual differences. Reported linear repeated measurement mixed effects regression models were fit by the restricted maximum likelihood (REML) and associated *t*-tests used Satterthwaite approximations for degrees of freedom. Descriptive statistics for demographic variables and collected measures are presented in Table 1. Coefficients of correlations between cognitive and behavioral task measures are presented in Table 2 Additionally, frequencies of MoCA scores are presented in Figure 8 and frequencies of delayed ISLT scores are presented in Figure 9.

Table 1. Distributions of all collected measures.

Measure	*n*	*M*	*SD*	Range
Age	30	74.63	6.11	65 - 88
Delayed ISLT score	30	7.7	2.17	2 - 11
Detection task (log10 ms)	29	2.54	0.08	2.4 - 2.7
TMT-A (s)	30	54.7	23.72	22 - 140
TMT-B (s)	30	132.8	87.43	51 - 440
TMT ratio	30	2.51	1.5	1.33 - 8.8
TMT difference	30	78.1	79	19 - 390
BDI-II score	30	6.4	3.79	0 - 13
MoCA score	30	24.67	3.11	14 - 29
Percentage of intransitive triplets	30	2.35	2.13	0.35 - 10.31
Percentage of errors	29	17.72	8.16	1.86 - 36.66
Mean reaction time (ms)	30	1825.02	645.63	1113.08 - 4028.82
Percentage of choices changed in retest	30	14.11	6.2	4.74 - 33.68

Note. ISLT = International Shopping List Test; TMT = Trail Making Test; BDI-II = Beck Depression Inventory = II; MoCA = Montreal Cognitive Assessment.

Table 2. Correlations of all measures.

Measure	Age	Delayed ISLT	Detection task	TMT-A	TMT-B	TMT ratio	TMT difference	BDI-II	MoCA	% intransitive triplets	% of errors	Mean reaction time
Delayed ISLT	-.52**	-										
Detection task	.22	-.11	-									
TMT-A	.53**	-.31	.29	-								
TMT-B	.52**	-.46*	.31	.47**	-							
TMT ratio	.2	-.3	.14	-.13	.81***	-						
TMT difference	.42*	-.42*	.25	.22	.96***	.93***	-					
BDI-II	.51**	-.3	.14	.18	.25	.14	.22	-				
MoCA	-.35	.33	-.08	-.22	-.66***	-.58***	-.66***	-.15	-			
% intransitive triplets	.38*	-.02	.36	.13	.26	.17	.25	.24	.03	-		
% errors	.13	-.25	.1	-.02	-.14	-.14	-.15	.16	.35	.26	-	
Mean reaction time	.26	-.48**	.57**	.36*	.1	-.12	.01	.22	.15	.27	.53**	-
% choices changed in retest	.39*	-.07	.32	.18	.31	.2	.29	.29	-.03	.95***	.24	.23

Note. ISLT = International Shopping List Test; TMT = Trail Making Test; BDI-II = Beck Depression Inventory = II; MoCA = Montreal Cognitive Assessment. Missing values for the percentage of errors and the Detection task measures were excluded. * $p < .05$, ** $p < .01$, *** $p < .001$.

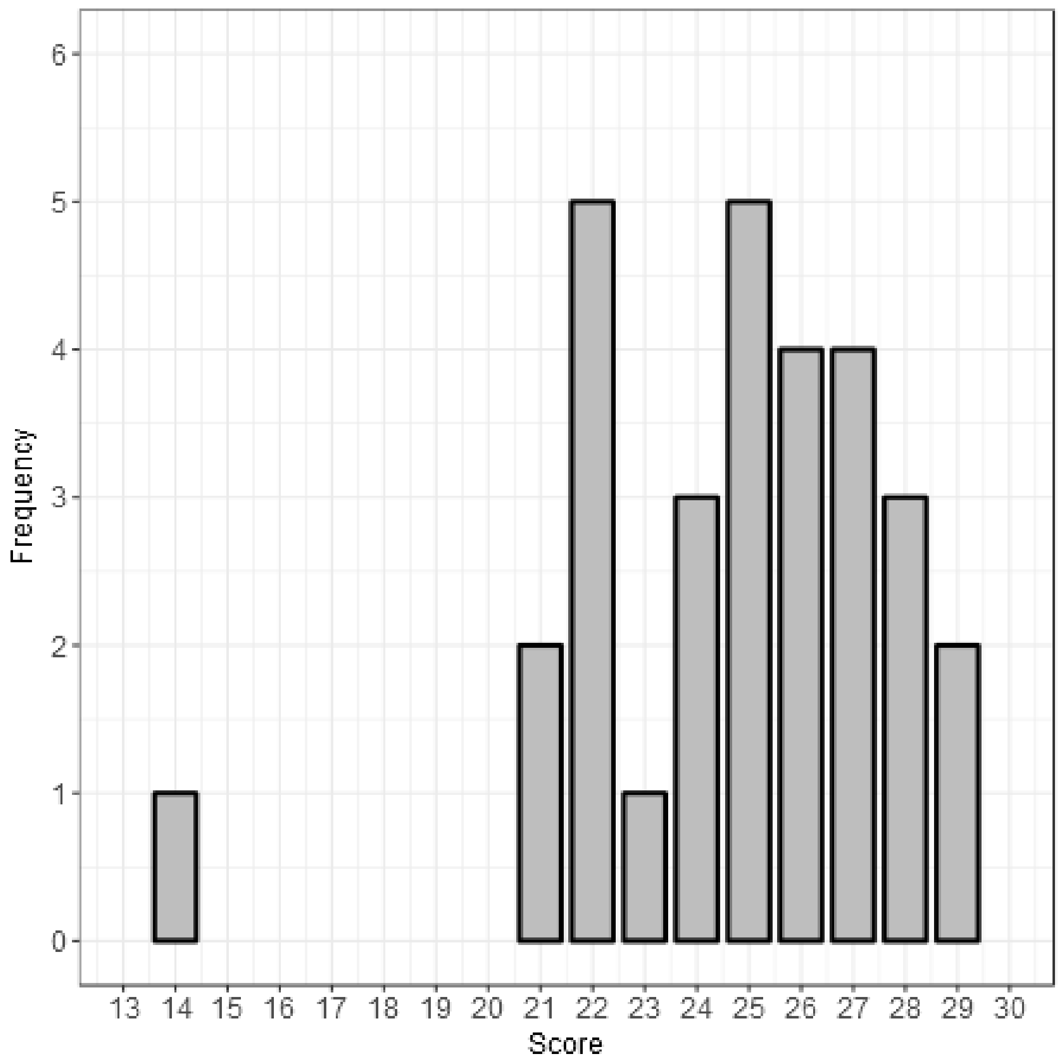

Figure 8. Frequencies of MoCA scores.

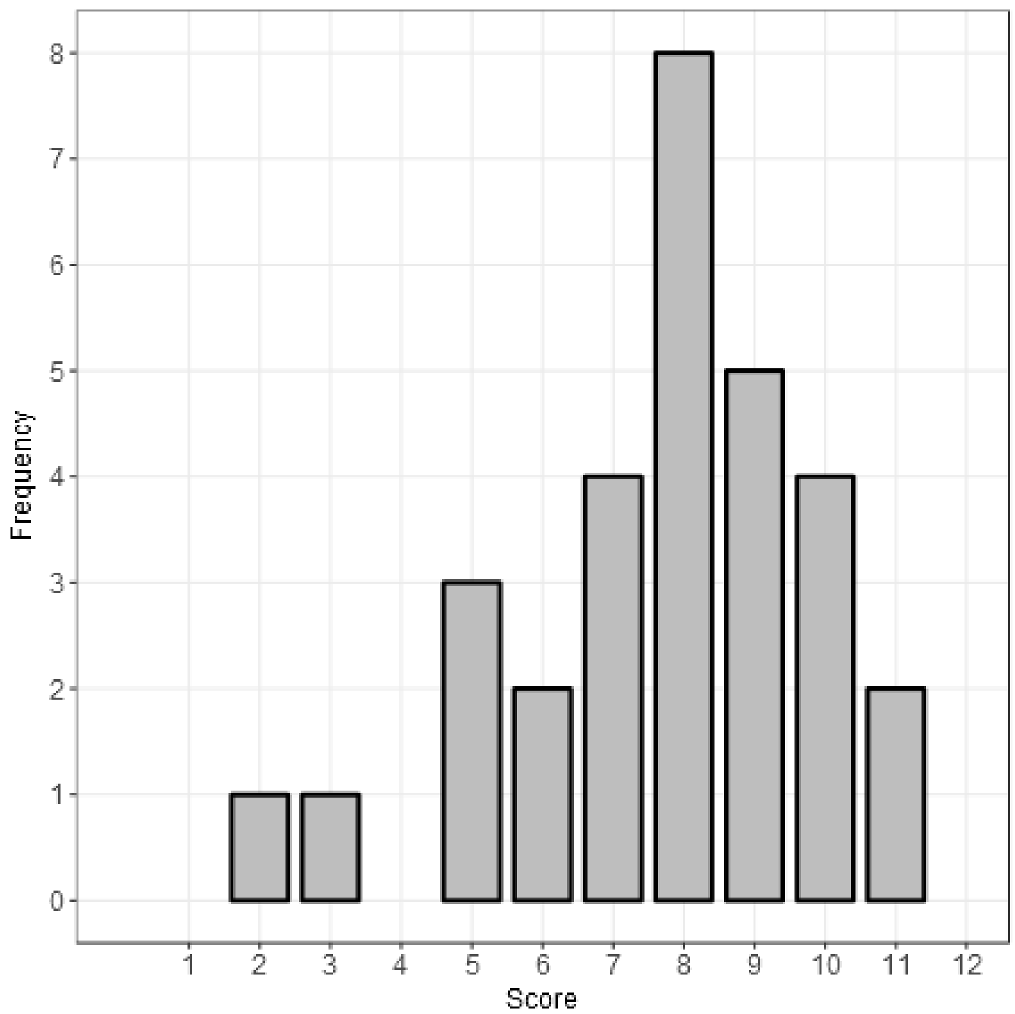

Figure 9. Frequencies of delayed ISLT scores.

Choice analysis

We examined the relationship between episodic memory and the percentage of deviations of choices from previously stated preference ratings (percentage of errors) using a linear regression model on an individual level with the percentage of errors as the dependent variable, delayed ISLT as the independent variable and controlling for MoCA scores.[2] The delayed ISLT was significantly negatively associated with percentages of errors confirming that better memory performance was associated with a lower rate of errors (Table 3).

[2] For this model, we excluded the participant for whom the proportion of errors was likely affected by a high number of trials excluded due to missing ratings. For completeness we performed additional analysis including this participant and regression model yielded similar estimates (Table 4).

Table 3. Linear regression analyses predicting percentages of errors, percentages of intransitive triplets and average reaction times from delayed ISLT.

	Percentage of errors		Percentage of intransitivities	Average reaction time	
Estimate	Simple model	With controls		Simple model	With controls
Delayed ISLT	-1.51* (-2.26)	-1.51* (-2.12)	-0.03 (-0.15)	-178.54** (-3.62)	-177.4*** (-4.48)
MoCA score	1.24* (2.7)	1.25* (2.11)	0.03 (0.2)	72.63* (2.12)	49.93 (1.48)
TMT difference		0.01 (0.03)			-1.92 (-1.36)
Detection task speed					4721.32*** (4.64)
Constant	-1.24 (-0.11)	-1.55 (-0.09)	1.88 (0.57)	1408.27 (1.74)	-9902.4*** (-3.75)
Observations	29	29	30	30	29

Note. Unstandardized estimates are presented with *t*-statistics in parentheses. * $p < .05$, ** $p < .01$, *** $p < .001$.

ISLT = International Shopping List Test; TMT = Trail Making Test; MoCA = Montreal Cognitive Assessment. Percentage of errors was calculated as a percentage of trials in which a product with lower rating had been chosen among all trials. Percentage of intransitivities was calculated as a percentage of intransitive choice triplets among all choice triplets.

Table 4. Linear regression analysis predicting percentages of errors from delayed ISLT and including participant with partially missing rating data.

Estimate	Percentage of errors
Delayed ISLT	-1.27 (-1.83)
MoCA score	1.25* (2.59)
Constant	-2.96 (-0.26)
Observations	30

Note. Unstandardized estimates are presented with *t*-statistics in parentheses. ISLT = International Shopping List Test; MoCA = Montreal Cognitive Assessment. * p < .05.

Surprisingly, MoCA scores included for control were related to proportions of errors and longer average reaction times; however, the effect was absent in multilevel models. We tested the relationship between trial difficulty, episodic memory and errors in a repeated measurement logistic regression that predicted error in a trial by differences in product ratings, delayed ISLT and their respective interaction (Table 5). Confirming Hypothesis 1b, the analysis showed a significant effect of rating differences on probability to make an error, meaning that as trials become more difficult, participants are more likely to make errors (Figure 10). To test whether lower memory would correspond to a weaker relationship between the delayed ISLT and rating differences signifying stronger effects of ISLT on easier trials (Hypothesis 1c), we included the interaction effect of delayed ISLT and rating difference. The results showed a significant interaction effect implying a stronger relationship between the delayed ISLT and rating differences for individuals with lower memory. The finding indicated a larger effect of memory on the probability to make errors in more difficult trials and contradicted our prediction made with regard to Hypothesis 1c.

Table 5. Logistic and linear random intercept regression analyses predicting errors and reaction times from differences in ratings of products, delayed ISLT and their respective interaction.

	Error[a]		Log-transformed reaction time[b]	
Estimate	Simple model	With controls	Simple model	With controls
Delayed ISLT	0.04 (0.76)	0.04 (0.71)	-0.07** (-3.07)	-0.07*** (-4.18)
Rating difference	-0.51*** (-25.79)	-0.51*** (-25.51)	-0.03*** (-18.40)	-0.03*** (-19.11)
Rating difference × delayed ISLT	0.06*** (6.05)	0.06*** (6.11)	0.01* (2.39)	0.01* (2.51)
MoCA score	0.02 (0.66)	0.01 (0.2)	0.02 (1.52)	0.01 (0.66)
Detection task speed		2.05 (1.53)		2.21*** (5.17)
TMT difference		-0.11 (-0.58)		0.01 (-1.89)
Right product selected		0.03 (0.41)		-0.02*** (-3.33)
Presentation order		0.06* (2.09)		-0.1*** (-30.26)
Constant	-1.98*** (-18.51)	-2*** (-18.07)	6.8*** (17.71)	1.61 (1.46)
Observations	9009	8680	10819	10445

Note. Unstandardized estimates are presented with z statistics in parentheses for the models predicting errors and with *t*-statistics in parentheses for the models predicting reaction time. * $p < .05$, ** $p < .01$, *** $p < .001$.

ISLT = International Shopping List Test; TMT = Trail Making Test; MoCA = Montreal Cognitive Assessment.

[a]Rating differences equal to zero were excluded. Rating differences and delayed ISLT were mean centered, reaction times were log-transformed due to skewness of the distribution. MoCA scores and Detection task speed were mean centered, TMT difference and presentation order were mean centered and rescaled by dividing by 100 to ensure convergence of the model. Errors were defined as trials in which participants had picked a product with a lower rating.

[b]Presentation order was mean centered and rescaled by dividing by 100 to ensure convergence of the model.

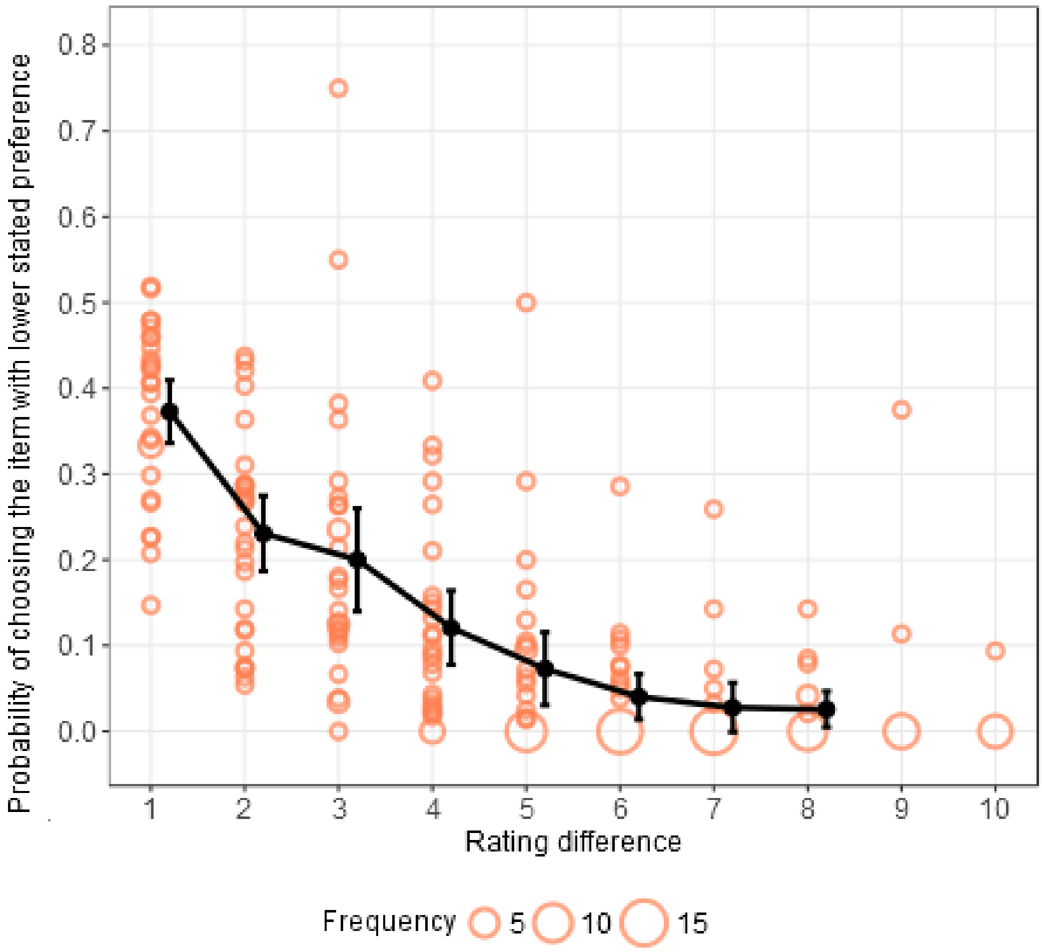

Figure 10. Empirical probabilities of errors occurring on various levels of rating differences. Circles represent empirical probabilities for individual participants, solid data points with error bars represent means. Error bars represent 95% confidence intervals. For rating differences of 9 and 10 means of percentages of errors were omitted due to low numbers of observations.

Comparison between these results and the performance in the number comparison task indicated that errors in the food choice task were not due to deficiencies in simple comparisons, but due to differences specific to value-based decision-making (Figure 11). Nine of the participants made one error each and one participant made three errors out of 45 trials. The rest of the participants did not make mistakes.

Next, we assessed the relationship between episodic memory and intransitivity using a linear regression model on an individual level with intransitivity as the dependent variable, delayed ISLT as the independent variable and MoCA score as a control variable. Contrary to Hypothesis 2, our results did not show a significant relationship between episodic memory and percentage of intransitive triplets (Table 3).

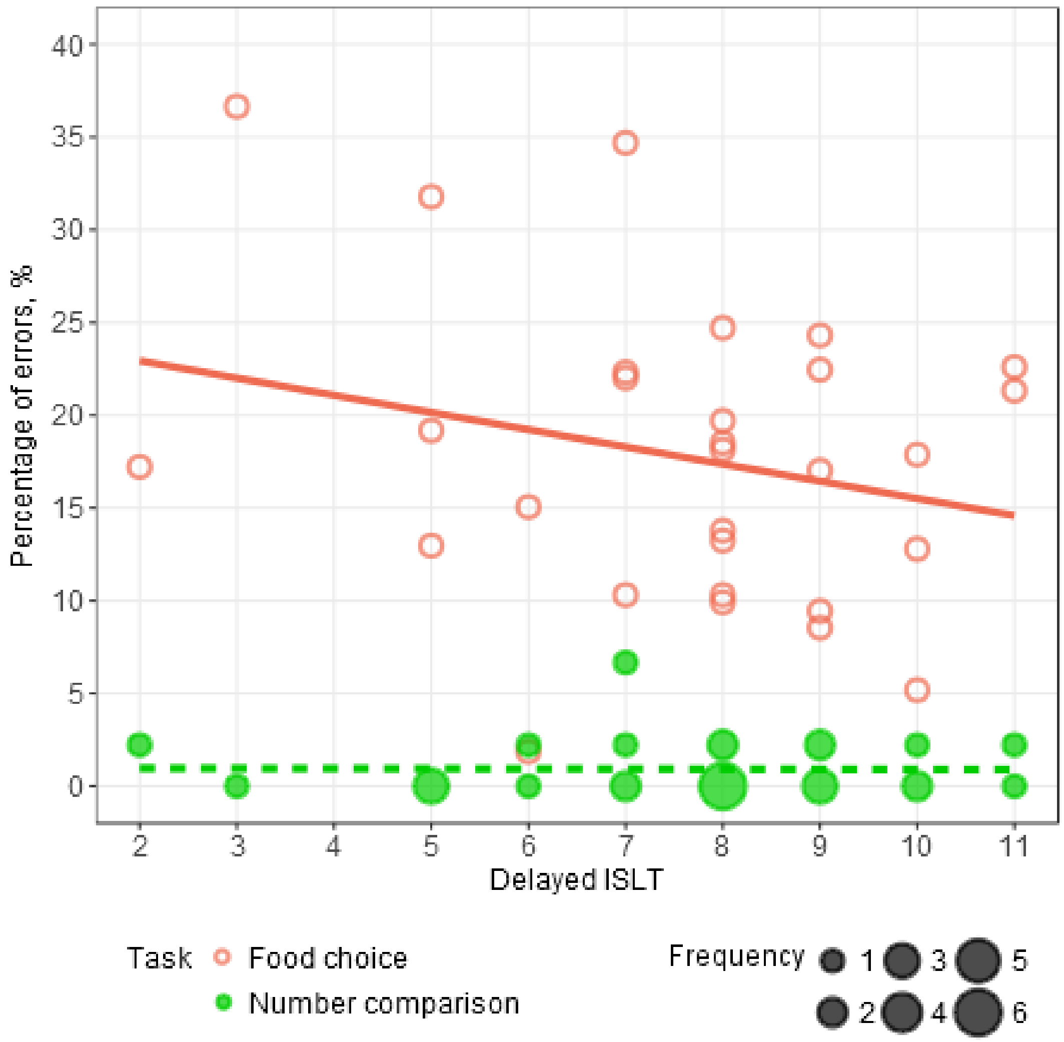

Figure 11. Linear regression models with the percentage of errors in the food choice task and percentage of errors in the number comparison as dependent variables and delayed ISLT as an independent variable. Fitted linear regression line for the percentage of errors in the food choice task: $r = -.25$, $p = .199$. Fitted linear regression line for the percentage of errors in the number comparison task: $r = -.03$, $p = .863$.

Reaction time analysis

We next tested the relationship between episodic memory and reaction times using a linear regression model on an individual level, with the average reaction times as the dependent variable, delayed ISLT as the independent variable and MoCA scores as a control variable (Table 3). The analysis showed a significant inverse relationship between delayed ISLT scores and average reaction times in accordance with our Hypothesis 3a. We also tested the relationship between trial difficulty, episodic memory and reaction time on each trial, using a repeated measurement linear regression model predicting transformed trial reaction time by differences in ratings of products, delayed ISLT and their respective interaction (Table 5). The analysis revealed a significant effect of difficulties on reaction times—higher difficulties were associated with longer reaction time—confirming Hypothesis 3b. Additionally, the results showed a significant interaction effect of delayed ISLT and reaction times. The positive interaction effect indicated that lower delayed ISLT scores corresponded to a stronger relationship between difficulty and reaction times, which does not support Hypothesis 3c.

Controls

In order to control for additional inter-individual differences which might be crucial for value-based decision-making and our experimental task in particular, we additionally collected individual difference measures of psychomotor (DET) and executive function (TMT ratio and TMT difference), as well as stimuli difference measures (position of the chosen food item, trial number). The reaction time in the Detection task (Psychomotor function) was significantly related to both average reaction times and reaction times for each trial, but did not affect the predictive power of delayed ISLT or the rating difference (see Tables 3 and 5).

To explore the links between age, cognitive measures as well as decision-making, additional correlation analyses were run (see Table 2). Notably, older age was associated with lower episodic memory performance ($r(28) = -.52$, $p = .003$), lower executive function as measured by TMT difference ($r(28) = .42$, $p = .022$), a higher percentage of intransitivities ($r(28) = .38$, $p = .041$) and a higher rate of choice changes in retest ($r(28) = .38$, $p = .036$).

Analyses predicting changes of choice in retest

In order to explore whether episodic memory performance also influenced the probability of a choice reversal between the test and retest measure of the behavioral task, two regression models were specified (Table 6). One model used the individual measure of test–retest reliability, which was calculated as a percentage of choices that differed between the first and the second runs of the paired choice task.[3] This analysis did not show an effect of episodic memory. Utilizing the repeated measurement structure of the data, we specified a mixed effects logistic regression model predicting on a trial level whether the choice was changed in the retest part of the task. In line with the analysis predicting errors on a trial level, the results of the repeated measurement random intercept logistic regression showed no relationship between

[3] DV indicated if participants changed their choice between test and retest even though the same pair of two items was presented.

delayed ISLT and choice reversals, but identified as predictors task difficulty (B = −.27, z = −10.47, p < .001) and its interaction with delayed ISLT (B = .04, z = 2.68, p = .007; see Table 6). Meaning, that participants were more likely to reverse choices made in trials with higher difficulty. The effect of the interaction implies a stronger negative relationship between memory and probability to change the choice in the retest in harder trials, as opposed to easier trial.

Table 6. Linear regression analyses predicting percentages of choices changed in retest from delayed ISLT and logistic random intercept regression analysis predicting change of choice in retest from delayed ISLT, rating difference and their respective interaction.

Estimate	Percentage of choices changed in retest	Choice reversals between test and retest[a]
Delayed ISLT	-0.19 (-0.32)	0.03 (0.63)
MoCA score	-0.01 (-0.02)	-0.02 (-0.5)
Rating difference		-0.27*** (-10.5)
Rating difference × delayed ISLT		0.03** (2.68)
Constant	15.73 (1.64)	-1.75 (-1.92)
Observations	30	4479

Note. Unstandardized estimates are presented with *t*-statistics in parentheses for the model predicting percentage of choices changed in retest and with z statistics in parentheses for the model predicting choice reversals between test and retest. ISLT = International Shopping List Test; MoCA = Montreal Cognitive Assessment.

[a]Rating differences equal to zero were excluded. Rating differences, delayed ISLT and MoCA scores were mean centered. ** p < .01, *** p < .001.

3.1.5. Discussion

Recent advances describing the role of episodic memory in value-based choices as a source of preference-related information have the potential for improving the understanding of decision-making of OAs. Since episodic memory declines with age, it has been hypothesized to lead to less accurate value-based decision-making of OAs. The current study assessed the relationship between episodic memory performance and value-based decisions of community-dwelling OAs. A simple binary food choice task was used to test whether episodic memory performance predicted accuracy and speed of decisions made by OAs. Results provided partial support of this assumption, in that OAs with lower memory performance exhibited more inconsistencies between their stated preferences and their actual choices. Even though our results showed a link between episodic memory and the percentages of errors, we found no support for the hypothesized inverse relationship between episodic memory and choice consistency as measured by the percentage of intransitive triplets of choices.

We confirmed an association between lower memory performance and increased average reaction times, indicating slower memory retrieval. This finding makes it unlikely that higher rates of errors are explained by a speed-accuracy trade-off. However, there is still a possibility that a speed-accuracy trade-off somewhat improved accuracy with even lower reaction times. Similarly, in a study by Lighthall, Huettel, and Cabeza (2014) OAs took more time to make memory-dependent choices than younger adults, which allowed them to reach similar accuracy.

We also confirmed an inverse relationship between trial difficulties and the performance measures of speed and accuracy. Choices between products closer in stated subjective preference were slower and more likely to result in a choice of the previously less preferred product. These results replicate consistent findings from previous literature on economic decision-making (Milosavljevic et al., 2010; Oud et al., 2016; Polanía et al., 2015). This effect of difficulty indicates that observed errors and reaction times relate to differences in subjective valuations of alternatives, and thus likely reflect properties of value construction processes.

We predicted that a relationship between episodic memory and accuracy as well as speed would differ with trial difficulty. This relationship would reflect an interaction between evidence availability, as determined by trial difficulty, and potential restrictions imposed by memory function. We hypothesized that, in addition to lower overall accuracy and speed, people with lower memory performance would display relatively smaller improvements in easier trials compared to people with higher memory. However, present results suggested a different effect and stronger memory-related differences in accuracy and speed in harder trials, rather than in easy trials. We also observed effects of trial difficulty and an interaction between memory performance and trial difficulties in the model predicting reversal of choice in the retest part of the paired choice task.

One potential limitation of the current study was that valuations of products and, consequently, difficulties of trials, differed to some extent from person to person, even though they were based on the pre-selection based on ratings. This has likely decreased the precision of measures on the individual level; however, the repeated measurement models accounted for ratings of products and interactions with memory. An additional limitation might be the slightly unbalanced composition (63% female) of the participant sample. Previous research has shown that female participants perform better on episodic memory tasks, and this advantage is retained in older age (Herlitz et al., 1997; Kramer et al., 2003). The effect depends on the type of the task, with a maximal advantage observed for tasks involving verbal material such as word lists (for a review, see Herlitz & Rehnman, 2008). This protective effect of gender on episodic memory performance is potentially relevant to the interpretation of the current study since the measure of verbal memory, the delayed ISLT, could have slightly overestimated the episodic memory of female participants and this could have affected results from multiple regression models. However, this reported effect of gender on memory is small (Herlitz & Rehnman, 2008) and we refrained from testing gender effects. One potential direction of future research could address a question about whether male OAs are more vulnerable to the effect of memory on decision making due to lower average memory performance. Another limitation was that we measured episodic memory performance at a given time point rather than longitudinally. An inverse relationship between episodic memory and age was consistent with the previous literature though (Bouazzaoui et al., 2013; Nyberg et al., 2012), and indirectly supported an assumption that memory heterogeneity in our sample was related to age. Further research—including, for example, neuroimaging methods—would be needed to confirm contributions of specific neural structures and their activity to properties of choice behavior. Another potential future research direction would be to allow participants to learn properties of novel choice options in a controlled fashion (for example, similarly to the procedure used in the study by Lighthall et al., 2014). Such an approach with a greater control over option values and trial difficulty would allow to test how memory performance and forgetting influence retrieval of value-relevant information. Assessment of the learning and forgetting of new information, for example, introduced in a form of a dietary advice, could contribute to identification of factors underlying dietary adherence and thus link the findings about the role of memory in choice to practical health-related outcomes.

Conclusion

The present work provides novel findings on the association between episodic memory and performance on a value-based task. They are broadly consistent with previous experimental studies and reviews that proposed involvement of memory and related neural structures in value-based decisions (Barron et al., 2013; Bornstein & Daw, 2013; Gluth et al., 2015; Shadlen & Shohamy, 2016; Wimmer et al., 2014; Wimmer & Shohamy, 2012). Previous literature has described decision-making deficiencies in learning (Foerde et al., 2013) and advantageous complex decision-making (Gupta et al., 2009) in individuals with amnesia due to hippocampal or MTL damage. Overall, our results suggest that the quality of decision-making is linked to variations in memory performance in the absence of overt amnestic symptoms. We employed a food choice task, but similar regularities can be potentially expected in other value-based decisions relying on common mechanisms (Rangel et al., 2008). The results have implications for research on decision-making in aging and, more specifically, for mechanisms of value-based decisions as well as decision quality in various areas. Within the domain of food choice, one relevant topic is adherence to dietary guidelines, which has been linked to health outcomes in OAs (Jankovic et al., 2014) including cognitive health (Gopinath et al., 2016). Further research is warranted in order to assess the impact of episodic memory on consumer satisfaction and potential personal losses due to less efficient decision-making.

3.2. Study 2: Positivity effect and decision making in ageing

The manuscript for the following study has been submitted to the journal Cognition and Emotion as a Stage 2 Registered Report under the title "Positivity Effect and Decision Making in Ageing" with following authors: Fedor Levin, Susann Fiedler and Bernd Weber.

3.2.1. Abstract

Across various contexts older adults demonstrate a positivity effect – an age-related increase in a relative bias towards positive emotional stimuli, as compared to negative stimuli. Previous research has demonstrated how this effect can influence decision making processes, specifically information search and choice satisfaction. However, the potential impact of the positivity effect and resulting age differences in information acquisition on decision quality has not been conclusively determined. We conducted an online decision making study with choices between charitable organisations in 152 younger and 152 older adults to investigate this relationship. The results replicate the link between the positivity bias and decision satisfaction. However, we did not observe age-related differences in the positivity bias (positivity effect) or a link between a bias in the information search towards positive or negative stimuli and the decision quality. Further research is required to address potential factors underlying age-related changes in the positivity.

3.2.2. Introduction

Past research has described an interplay between affect, cognition, and decision making (Shadlen & Shohamy, 2016). An important perspective on the role that emotions play in cognition and decision making is how these relationships transform with ageing (Mikels et al., 2015). Research has shown age-related changes in how emotions influence attention, memory, and aspects of decision making (Reed et al., 2014). Despite advances in studies on age differences in cognitive and emotional processes, more research on potential real-life implications is needed (Scheibe, 2018). Paradoxically, studies on ageing demonstrate that, despite a potential decrease in quality of life (Kahana et al., 2012) and declines in health (Tovel & Carmel, 2014) and cognitive abilities (Zaval et al., 2015), older adults often maintain relatively high emotional well-being (Charles & Carstensen, 2010). These observations are consistent with a socioemotional selectivity theory (SST) – a life-span motivation theory describing changes in priorities that occur with age (Carstensen, 2006). SST posits that, unlike younger adults, older adults perceive time horizons, or the time remaining in life, as limited. This leads to a prioritization of goals related to emotional well-being.

Positivity effect

One of the implications of the SST that has received wide attention in literature is that older adults show a relatively stronger affinity to positive emotional stimuli than to negative ones. Studies have shown that older adults preferentially attend or memorise information with a positive valence over a negative one, as compared to younger adults (Reed et al., 2014). This age by valence interaction is referred to as a positivity effect (PE). The current study aimed to investigate whether the PE and the resulting bias in information search can adversely influence the decision making quality of older adults.

Loss prevention orientation

A different perspective on age-related changes in motivation is the "selection, optimisation, compensation" (SOC) framework (Baltes et al., 1999; Ebner et al., 2006). The SOC posits that older adults are confronted with limitations in available resources, and thus adaptively focus on goals related to maintenance of their current resources and prevention of losses (Ebner et al., 2006). Elaborating on the loss prevention orientation, Depping and Freund (2011, 2013) suggested that in a decision situation older adults would preferentially attend and memorise information related to potential losses. In the current study, we derived hypotheses primarily from the PE and the SST research; however, we also aimed to assess whether a loss prevention orientation potentially contributed to the information search and choice behaviour in our decision task.

Positivity effect and decision making

Several studies have shown that the age-related PE also extended to aspects of decision making, such as information search (English & Carstensen, 2015; Löckenhoff & Carstensen, 2007, 2008) and decision satisfaction (Bjälkebring et al., 2016; English & Carstensen, 2015; Kim et al., 2008). Some authors have raised the notion that decision quality can be negatively affected by the PE – decision situations can require individuals to consider attributes of choice alternatives that are associated with negative emotional stimuli (Carstensen & DeLiema, 2018; Reed & Carstensen, 2015). Despite the wide interest in the PE in literature and the evidence of the PE in the information search, the research examining the potential influence of the age-related positivity bias during information search on the quality of resulting decisions is limited. The potential existence of such a link is of considerable interest in the context of the decision making of older adults and the SST. Our main research question is whether the PE and the resulting bias are related to the quality of value-based decisions. We aimed to answer this question by conducting a study with a group of younger adults and a group of older adults using a task in which participants made donation decisions between sets of charitable organisations. Bjälkebring et al. (2016) have shown that decisions about charitable donations might be susceptible to the PE, which makes donation decisions suitable for the current study.

The framework of value-based decision making (Rangel et al., 2008) considers several computations involved in the choice: representation of the decision problem; valuation of available actions; comparison of their values; evaluation of the outcome; learning process; and updating of other processes. Previous research has shown the PE in information search (Löckenhoff & Carstensen, 2007) and in decision satisfaction (Kim et al., 2008). Therefore, the PE could potentially influence the valuation of available actions and an evaluation of the outcome. Decision makers with a positivity bias or a negativity bias would fail to conduct a balanced information search and would not make necessary trade-offs between positive and negative characteristics of alternatives. Based on the previous studies using comparable tasks (Löckenhoff & Carstensen, 2007, 2008), we expected younger adults to review similar amounts of positive and negative information, whereas we expected older adults to show positivity.

Methodological approach in the current study

One approach to measuring information search is Mouselab, a computer-based process-tracing tool that presents decision relevant information in a matrix of cells. It also records contents, amount, and sequence of information looked up prior to making a decision (Willemsen et al., 2011). In the study by Queen et al. (2012), younger adults and older adults completed a Mouselab task with hypothetical choices between cars. Participants clicked the cells in the matrix to see the scores presented as pluses or minuses. The results indicated similarities in the decision making of younger adults and older adults, including a similar extent of information search. Studies on the PE and information search used a decision grid task similar to Mouselab, in order to demonstrate the age-related difference in positivity (English & Carstensen, 2015; Löckenhoff & Carstensen, 2007, 2008). One distinct property of tasks used in those studies was that cells containing information were labelled to indicate whether they contained positive or negative values.

We used a similar task to present decision scenarios with choices between charitable organisations. Our version of the decision grid task had several differences from the tasks used in the previous literature (e.g., Löckenhoff & Carstensen, 2007). Our task did not include characteristics that have the same ratings for each option, since these characteristics would not be relevant to measures of bias or expected value. These characteristics were previously referred to as neutral (English & Carstensen, 2015; Löckenhoff & Carstensen, 2007, 2008) and were intended to increase the subjective difficulty of choice. At the end of the task we randomly selected five trials for each participant and presented five charities chosen in those trials. Each participant made a final selection of a preferred organisation, and we implemented that decision by transferring a donation to the charitable organisation. Participants were informed beforehand about the consequences of their choices. Thus, by using incentivized donation decision, we additionally deviated from the previously used hypothetical healthcare choices or consumer choices (English & Carstensen, 2015; Löckenhoff & Carstensen, 2007, 2008). Resources available to prospective donors sometimes provide systematic evaluations of characteristics of charities. For example, a non-profit consulting firm Phineo AG assessed aspects of transparency of select German charities (Buttkus & Schäffler, 2014; von der Ahe & Lüdecke, 2016). Our task thus represented a plausible situation in which a person considers donating to one of several charities, and the choice involves trading off some characteristics of alternatives for others.

In the current study, the decision quality measure was conceptualised similarly to previous research on the decision quality in older adults (Queen et al., 2012; Queen & Hess, 2010). Specifically, for each option, we calculated the expected value based on the values of all characteristics weighted by the importance ratings of each characteristic provided by participants. We used this approach to assess how well participants selected charities that best met their own priorities.

Some of the limitations of Mouselab research also apply to the current study: the Mouselab procedure favours a serial review of information, requires holding information about options in memory, and prevents quick comparisons among multiple items (Glöckner & Betsch, 2008). We considered that the relatively low number of information cells in our task would minimise the potential effect of memory limitations in older age. For example, the previously mentioned study by Queen et al. (2012) demonstrated a comparable information search and decision quality of older adults and younger adults in a Mouselab task in two conditions – with a simple matrix with five options and five characteristics (5x5 grid), and with a complex matrix with eight options and six characteristics (8x6 grid). With the caveat that in our task values had more possible increments, our matrix had fewer pieces of information – four options and four characteristics (4x4 grid).

The current study considered two possible mechanisms through which the PE can influence the information search of older adults in the decision grid task. One mechanism is the avoidance of negative stimuli values due to the valences of cues. A stronger positivity bias could lead older adults to ignore more frequently the negative but value-relevant information. Thus, older adults would not be able to take this information into consideration when making decisions. Another mechanism is an overweighting of positive values of options due to a stronger attention to them. Research has demonstrated a role of attention in stimulus value computation during choice (Fehr & Rangel, 2011; Hare et al., 2011). We considered that both of these potential consequences of an increased positivity bias could decrease decision quality. We assessed the potential influence of the PE on decision quality, through both of these mechanisms. We also tested whether ignoring characteristics with a specific valence more often was on its own predictive of decision quality.

Potential contribution of the loss prevention orientation

We also considered the possibility that loss prevention orientation could contribute to age differences in information search. Depping and Freund (2011, 2013) suggested an increased sensitivity of older adults to negative information during decisions. However, it is not completely clear how an increased sensitivity to negative information would interact with the design of the decision grid task. If older adults demonstrated a high sensitivity to potential losses, it could influence their assumptions about the content of negative cells. Specifically, a high sensitivity to negative information could lead older adults to perceive information cells labelled with negative cues as highly negative. If participants expected all negative cues to be associated with strong losses, it could decrease the perceived informativeness of negative cells, thus decreasing the incentive to review them. This effect could potentially contribute to a less frequent review of negative cells by older adults. To assess the evidence for this potential alternative explanation, we administered a simplified version of the decision grid task. This task presented values of information cells openly. Each trial included two options with four characteristics each. Assuming the contribution of the loss prevention orientation, we expected that in the simplified decision task an increased sensitivity to negative values would most strongly influence the perception of comparisons between positive and negative values because these comparisons would provide the strongest contrasts between the options. We used an approach similar to the analysis performed by Hare et al. (2011). In that study, participants used a four-point scale to indicate how much they wanted food products that were presented in three attention conditions. Participants also rated the healthiness and taste of the products. A regression analysis using choices as a dependent variable and ratings with conditions as independent variables demonstrated an increased responsiveness of participants to the healthiness of food products in the health attention condition. We intended to use a similar approach to compare how older adults and younger adults respond to characteristics that compare positive and negative valences. The analysis would indicate whether the loss prevention orientation influenced performance on the decision grid task.

Hypotheses

Based on the SST and the existing empirical evidence we formulated several hypotheses. First, we predicted that we would observe the PE, specifically that older adults would show a stronger positivity bias in review of option attributes than younger adults (H1), which is similar to findings in healthcare and consumer choices. We refer to the measure of the positivity bias as positivity index. It indicated the relative preference of a participant for positive information cells, as compared to negative information cells. The positivity index was calculated as a difference between the numbers of the reviewed positive cells and the reviewed negative cells divided by the sum of all cells reviewed.

Next, we hypothesised that a stronger bias towards either positive or negative information in the review of the characteristics of choice options would result in lower decision quality (H2a). Specifically, we considered that this relationship could reflect two potential mechanisms – a complete avoidance of stimuli of one valence and a relatively stronger attention to one valence. We refer to this measure as bias index and it was calculated as the absolute difference between the number of reviewed positive information cells and negative information cells divided by the sum of all reviewed information cells. Higher values on this measure thus reflected both higher positivity and higher negativity biases. We used the bias index measure instead of the positivity index for this analysis because it represented better the hypothesised mechanism linking the information search and decision making quality. In our task, negative and positive information had identical diagnostic values. Accordingly, a high decision quality would require a consistent review of negative and positive information. The bias index represented the degree of deviation from consistent review. In previous decision grid task studies, younger adults showed close to an even-handed review of positive and negative information (Löckenhoff & Carstensen, 2007, 2008), whereas older adults showed a preference for positive information. Based on these findings, we expected the bias index measure to be very similar to the positivity index.

We also conducted analyses with an alternative measure of bias towards either positive or negative valence, which were based solely on numbers of unique cells opened – ignorance-based bias index. Unlike the bias index, this measure reflected only the extent to which either negative information or positive information was ignored relatively more often. Thus, a higher measure of ignorance-based bias index would indicate that a participant tends completely to avoid some of the information about choice options due to its valence. We hypothesised that a higher ignorance-based bias index would be linked to a lower decision quality (H2b). The analysis would indicate whether this component of the PE can on its own account for the differences in the decision quality.

We also hypothesised that a higher measure of the positivity index would be associated with higher decision satisfaction, as measured by choice satisfaction ratings (H3). We expected that the bias towards positive valence would specifically predict more positive evaluations of choice outcomes, which is consistent with previous findings (e.g. English & Carstensen, 2015).

Next, we predicted that the decision quality would be lower in the older adults group than in the younger adults group (H4). Because we expected age differences in the positivity as well as a relationship between bias index and decision quality, we also expected group differences in choice quality.

To rule out an alternative explanation for the PE – the loss prevention account – we additionally used choice data from the simplified decision task to test age differences in how participants compare information with different valences. If older adults focused on loss prevention, we would expect them to base their decisions most strongly on characteristics where one option has a negative value and another option has a positive value because these characteristics potentially offer the strongest contrasts between the options. We expected older adults to take these characteristics with mixed valences into account during decisions – more so than younger adults (H5).

3.2.3. Method

The meta-analysis by Reed et al. (2014) reported an effect size of the PE measured as Cohen's *d* equal to .482 in the absence of constraints on processing. Authors considered a possibility of publication bias and tested for it, concluding that the likelihood of publication bias was minimal. Based on this effect size estimate, we performed a power analysis for a one-sided *t*-test with $\alpha = .05$ and power = .9 with G*Power 3.1.9.2 (Faul et al., 2007) which indicated that we required at least 75 participants in each age group. To account for a potentially increased noisiness of data collected in an online task, we increased the group size to 150 participants in each age group. We anticipated the possibility that several more participants might complete the study, than the planned number. This could have potentially happened if some participants were still completing the task at the time point when it is verified that the target sample size of people meeting the inclusion criteria is reached for either of the age groups. In case this happened, we planned to include these extra participants in the analysis. We planned to use the repeated measurement analysis which additionally increased the statistical power. A power analysis for equivalence testing using the two one-sided tests procedure indicated that sample size of at least 74 participants per age group would be enough to reject the effect size of d = .482 with power = .8 (Lakens, 2017). The complete instructions and stimuli material are available at the Open Science Framework (https://osf.io/xne5s/).

Participants

The younger adults group included participants in the age range between 18 and 30 years, whereas the older adults group included participants in the age range between 65 and 80 years. We aimed to recruit a similar number of men and women in both age groups. Before participants started to work on the experimental task, they were asked whether they had any current or previous neurological or psychiatric disorders such as dementia, depression, or other major illnesses. They also completed the IQCODE. We expected the study to take roughly between 30 and 45 minutes in total. Participants were recruited with the help of the online panel and survey technology provider Toluna, which finds respondents either by using maintained panels, or through other websites by using the “Real-Time Sampling®” method. Toluna maintains panels in various countries and has offices worldwide. We recruited German participants and, correspondingly, all instructions and materials were presented in the German language. A set of various checks that ensure data quality verifies that participants responding to surveys are real, valid, and not duplicated. Checks against careless responses were included in the decision task itself, such as exclusion based on insufficient information review, trial durations that are too short or too long, an attention check in the rating task, catch trials in the simplified decision task and the decision grid task.

Material

Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE).

To rule out cognitive decline, we used a short seven-item version of the IQCODE (Ehrensperger et al., 2010; Ehrensperger & Monsch, 2016) and administered it as a self-report questionnaire. Participants used a scale from 1 (strong improvement) to 5 (strong decline) to describe changes in several aspects of their cognitive functioning across two years. The score is calculated as an average response across all items. The cut-off was based on a previously proposed threshold for detecting dementia of 3.43 using the informant-based seven-item IQCODE (Ehrensperger et al., 2010). The self-reported sixteen-item IQCODE has been shown to be suitable for detecting dementia with similar thresholds of 3.6 (Jansen et al., 2008) and 3.38 (Eramudugolla et al., 2013).

Subjective Numeracy Scale (SNS).

To control for potential differences in numeracy, we administered the SNS (Fagerlin et al., 2007). The German version includes seven items (excluding an item from an English version which is related to calculating 15% tips, since it is not relevant in the German context) which measure subjective numeracy skills and attitudes towards information presented in numeric form on a scale from 1 to 5 (Garcia-Retamero & Galesic, 2013). The SNS measure is calculated as an average response.

Behavioural task.

The online behavioural task was developed with the help of the jsPsych library (de Leeuw, 2015) and was administered via web browser. It consisted of five parts. First, users read a description of the procedure, provided their informed consent, and completed the questionnaires. Next, all four characteristics of charitable organisations from the rating and choice parts of the task were presented together with brief descriptions, so that participants had a chance to familiarize themselves with the whole set of option characteristics. Participants then rated personal importance of four characteristics using a 9-point scale in randomized order (see Figure 6A). To prevent inadvertent repeated clicking on buttons that could lead to skipping trials, inter-stimulus intervals were set to 500 ms. After the rating task, participants completed the simplified decision task with eight regular trials and two catch trials. Then they completed the decision grid task with ten regular trials and two catch trials. In both decision tasks, participants were offered a chance to review values describing the characteristics of a set of charities. Each charity was described by two negative and two positive characteristics (except for charities presented in the catch trials). After a review of the information, participants chose a preferred alternative by clicking a button with its name. Before beginning of both decision tasks participants were required to complete practice trials.

Participants were informed that five of their decisions would be randomly picked and presented together at the end of the task, including decisions made in the simplified decision task, the decision grid task, and catch trials, but not including the practice trials. The charitable organisations corresponding to those choices were revealed and presented along with short lists describing their areas of work. Thus, participants made their final selection knowing the names and priorities of the specific charities they would be donating to. Each of the participants' decisions could be picked for this final selection list, and therefore each decision was equally important.

Values for the characteristics of the charities were constructed based on publicly available information. The "Experience" characteristic is based on the age of the organisation; the "Efficiency" characteristic is based on the proportion of spending that is not used for administrative, PR and fundraising purposes; and the "Size" characteristic is based on the number of employees working for the organisation. Previously, these characteristics were predictive of donations to charitable organisations (for a review, see Trussel & Parsons, 2007). The "Proportion of private contributions" characteristic reflects the share of contributions such as donations, membership fees, and others, in the total income. Evidence from some experimental studies points to a negative relationship between governmental support and contributions made to charities by participants (for a review, see De Wit & Bekkers, 2017); thus, a higher proportion of private income is likely to be perceived as a positive characteristic. The scores for various characteristics were constructed as relative percentile scores in the larger pool of 203 charitable organisations and then transformed into scores between -1 and -10, or between 1 and 10 for negative and positive values respectively. Then, 68 of the charities were selected from the larger pool to be used in the simplified decision task and decision grid task trials.

Positive and negative scores of charitable organisations were described in the instructions as values above and below typical values for characteristics respectively. Participants were also informed about the minimal and maximal possible values of the scores (-1 and -10 for negative cells, 1 and 10 for positive cells). We interpreted positive and negative values of characteristics of choice options as corresponding to positive or negative emotional valences, since they require participants to consider potential gains or losses (Löckenhoff & Carstensen, 2007). Each trial included either two (in the simplified decision task) or four (in the decision grid task) choice alternatives presented in rows. We used anonymized charity names (e.g. "Charitable organisation A" or "Charitable organisation B") in order to eliminate the influence of potential brand preferences. The letters "A", "B", "C", and "D" were assigned to options randomly. We instructed participants that they could determine themselves what information to review in order to avoid any demand effects. The positions of the options in both decision tasks were randomized in each trial, while the positions of the characteristics were randomized between subjects to avoid confusing the participants between trials.

Simplified decision task.

Each simplified decision task trial presented two options with four characteristics. One characteristic in each trial had two positive values, and another characteristic had two negative values. These characteristics were referred to as characteristics with fixed valences. The third characteristic had a positive value for the first option and a negative value for the second option, whereas the fourth characteristic had a negative value for the first option and a positive value for the second option (see Figure 6B). Thus, in each trial, a participant needed to consider trade-offs with regard to characteristics with positive or negative valences and two characteristics with mixed valences. Participants completed two practice trials before starting the simplified decision task. Pairs of options had the following properties (excluding the catch trial and the practice trials): (1) simple tallies of values of characteristics for each option are never equal in a trial, and the differences between the pairs of tallies throughout the trials range between 2 and 9; (2) considering only the characteristics with mixed valences and ignoring the characteristics with fixed valences would change the simple tallies of scores for options, so that a different option would be preferable. Thus, participants who focused primarily on characteristics with mixed valences would typically prefer different options, compared to participants who considered all characteristics. Throughout the trials, each characteristic was, at least once, negative, positive, or with mixed valences. One catch trial for the simplified decision task included one obviously preferable option with three positive values and one negative one; additionally, all values for this option were higher, than for the alternative. The second catch trial for the simplified decision task included one obviously inferior option with four negative values, which were also all lower, than for the alternative.

Decision grid task.

Before starting the decision grid task, participants completed four practice trials to become accustomed to the procedure. In the first two practice trials, there were two options with two characteristics, and participants were required to click on each of the four information cells before proceeding. In the third and the fourth practice trials, there were four characteristics with four characteristics each, as in the regular trials, and participants were instructed that they could decide themselves which cells to click. The characteristics of the choice options were demonstrated in a way that is similar to the decision grid task from Löckenhoff and Carstensen (2007). Information related to specific attributes was concealed in cells, which were labelled as negative or positive by pluses on a white background, or minuses on a light grey background, respectively (see Figure 6C). Participants opened the cells one by one by clicking to review the information contained in them. Clicking on a new cell automatically closes the previous one. Simple tallies of the numerical values of the characteristics presented in the decision grid task for each choice option are unique and range between -8 and 11 throughout all regular trials (excluding the catch trial and the practice trials). After each trial, participants rated their satisfaction with their decision on a scale from 1 to 9. One catch trial for the decision grid task included one option with four positive values and thus, if participants paid attention to the task, represented an obviously preferable alternative even without opening the cells. Another catch trial for the decision grid task included one inferior choice alternative with four negative values, which should not be selected if a participant pays attention to the task.

Pilot study.

To assess the feasibility of the planned study and the clarity of instructions, we conducted a small online pilot study (8 OAs; ages between 66 and 79). Seven out of eight participants reviewed information cells in the decision grid task and they correctly answered the catch trials. One participant did not review the information cells in the decision grid task and respectively failed a catch trial with a dominating option with four positive characteristics. This observation shows the importance of attention checks throughout the experiment. One additional participant answered an attention check trial of the rating task incorrectly. However, the patterns of lookups of this participant were in accordance with previously stated importance ratings, which likely indicated an understanding of the rating task. This pilot indicated that participants were generally able to understand the instructions and engage with the online task.

Planned analysis.

Data exclusion.

Participants were excluded in case they reported neurological or psychiatric disorders such as dementia, depression, other major illnesses, or if they reported cognitive decline exceeding the threshold on the IQCODE. To decrease potential noisiness of the measure of positivity in review that can occur if only one cell, positive or negative, is reviewed in a trial, we excluded – in all trial-level analysis – any trials in which a participant opened less than two cells. We excluded all trials with decision times quicker than 300 ms, because quick RTs could indicate careless responders (Curran, 2016). Trials with durations longer than five minutes were also excluded, since they could indicate being distracted from the task. Additionally, participants with fewer than two trials in the main behavioural task that meet inclusion criteria, were also excluded from the analyses of the decision grid task data, since the lack of eligible data would also indicate inattentiveness. Finally, participants were excluded if they failed to provide a correct answer on the attention check trial during the rating task, or if they failed catch trials by selecting an obviously inferior option.

Data transformation.

All variables that were included in regression analysis as interactions were mean centred.

Measures.

A list of measures and indices that we used for analyses of the decision grid task data is available in Table 7 and a list of measures and indices that we used for analyses of the simplified decision task data is available in the Table 8. Apart from measures derived from behavioural data and required for the planned analyses, we also planned to collect data on the age, gender, and years of education in order to characterize our sample and assess the generalizability of the findings.

Index of positivity in review. Following Löckenhoff and Carstensen (2007) we calculated the positivity index as a difference between counts of reviewed positive and negative cells divided by the sum of all positive and negative cells reviewed. It varies between -1 and 1, and positive values indicate that the positive cells are reviewed more often, whereas negative values indicate a more frequent review of negative cells. Repeated reviews of the cells were counted for the purpose of calculating the index of positivity in review the same way as first initial reviews of the cells. We also calculated the bias index by taking the absolute values of the positivity index. The bias index varies between 0 and 1, and higher values indicate a more frequent review of cells of either valence - positive or negative. The bias index also reflects an aspect of the information search. Higher values of this index represent a stronger bias towards information with positive or negative valence. We additionally used an ignorance-based bias index that were restricted to only unique reviews of the cells similarly to the study by Löckenhoff & Carstensen (2008). This measure reflects whether relatively more of the positive or negative information is completely ignored (in comparison to just receiving relatively less attention). It was calculated as an absolute value of a difference between the numbers of unique reviewed positive cells and unique reviewed negative cells, divided by the number of all unique cells reviewed.

Table 7. Measures and indices used in the analyses of the decision grid task.

Variable	Description
iteration	Number of the participant.
age_group	Dummy variable indicating the age group (0 = younger adults, 1 = older adults).
trial_number	Presentation order of the trial.
sns	The score on the Subjective Numeracy Scale measure.
evr	Expected value ratio - ratio between the expected value of an option that was chosen in the trial and the maximum expected value in the trial.
review_index	Index of positivity in review calculated as a difference between the numbers of positive and negative cells reviewed, divided by the number of all cells reviewed.
review_index_abs	Index of bias in review calculated as an absolute value of the positivity index.
review_index_unique_abs	Index of bias in review calculated based on unique cells reviewed.
decision_satisfaction	Rating of decision satisfaction provided after the trial.
review_all_repeated	Number of repeat reviews of information cells.

Table 8. Measures and indices used in the analyses of the simplified decision task.

Variable	Description
iteration	Number of the participant.
age_group_c	Dummy variable indicating the age group (0 = younger adults, 1 = older adults), centred.
pos_score_c	Difference between expected values of the first and the second options for the positive characteristic, centred.
neg_score_c	Difference between expected values of the first and the second options for the negative characteristic, centred.
posneg_score_c	Difference between expected values of the first and the second options for the positive-negative characteristic, centred.
negpos_score_c	Difference between expected values of the first and the second options for the negative-positive characteristic, centred.
sns	The score on the Subjective Numeracy Scale measure.
choice	Variable indicating whether an upper choice option has been selected

Decision quality.

Decision quality were based on the expected values for each choice option calculated from the individual ratings of the importance of the charity characteristics and the values presented in the corresponding information cells. Specifically, for each option the expected value was calculated as a sum of cell values weighted by the importance ratings of the characteristic (cell value × importance rating of the characteristic). These weighted values were divided by the expected value of the best option in the trial in order to calculate the expected value ratio (EVR) scores, similarly to the analysis described by Queen et al. (2012), but taking into account all available information cells in the trial, including those that have not been opened by a participant. Picking the best option thus resulted in a score of one. Selecting the option with the highest value is considered desirable, since it maximizes the potential impact of a donation. Thus, by design, optimal choices were most likely when all of the information was considered, and when negative and positive properties of options were weighted similarly. We also used the obtained ratings of choice satisfaction after each trial on a scale from 1 to 9 to test a relationship between the PE and the choice satisfaction.

Data analysis plan.

We tested hypotheses H1-H4 using results from the main decision grid task with linear repeated measurement mixed effects regression models fitted by the restricted maximum likelihood (REML). Models included random intercepts corresponding to participants. The analyses were conducted with RStudio (R Core Team, 2018; RStudio Team, 2015). Regression models were specified and tested with the help of packages lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017). The reported results of the *t*-tests for estimates used Satterthwaite approximations for degrees of freedom. The number of the trial was included as a control variable to hypotheses H2a-H4 to account for potential learning effects (Orquin & Mueller Loose, 2013). The SNS score was also included as a control variable to hypotheses H2a, H2b, and H5, to control for potential numeracy differences.

To test hypothesis H1, we conducted a regression analysis using the age-group dummy as an independent variable and the positivity index in each trial as a dependent variable. Hypothesis H2a was tested by a regression model with the bias index as the independent variable and decision quality as the dependent variable. In order to test whether a specific component of the information search bias - ignoring relatively more negative or positive information – can account on its own for lower decision quality, we tested H2b with the ignorance-based bias index as an independent variable and the decision quality as a dependent variable. This analysis would contribute to understanding the underlying mechanism through which the PE could be linked to decision quality. For the purpose of testing hypothesis H3, we used a regression model with the positivity index as an independent variable and reported decision satisfaction as a dependent variable. To test hypothesis H4 which predicts lower decision quality in the older adults group, we specified a regression model with the dummy variable for the age group as an independent variable and the decision quality as a dependent variable. Finally, to test hypothesis H5 we specified a repeated measurement logistic regression model with a dependent variable which indicated whether a participant selected the first of two options in the simplified decision task. As in the other analysis models, random intercepts corresponded to participants. As predictors, we used four variables that consist of differences between the two options for each of the characteristic (i.e., one characteristic with positive values, one characteristic with negative values, and two characteristics with mixed values) multiplied by the individual importance ratings of each characteristic. Negative values indicate that the values of the characteristic favour the second of two alternatives, whereas positive values indicate an advantage of the first alternative. Thus, we were able to compare how responsive participants were to characteristics with different valences. The estimated coefficients for these variables indicated the extent to which a specific type of characteristic was taken into account by participants. In order to test age differences, we specified interactions between these variables and the dummy variable indicating the age group. Thus, these interactions indicated whether the responsiveness to stimuli values with specific valences was different for the two age groups. We expected older adults to be more responsive to characteristics with mixed valences, and hence regression estimates for interactions between the age group variable and the values of the two characteristics with mixed valences would be significantly different from zero. However, if only one of these interactions was significant, we would also consider it an indication that older adults are more responsive to characteristics with mixed valences. For the tests of these two interactions, we used Bonferroni corrected significance thresholds of $p = .025$.

3.2.4. Results

In the following section we first describe the results of the confirmatory analysis. We then describe the data in more detail and report exploratory analyses to provide additional context to the confirmatory tests. We collected data from 152 younger adults and 152 older adults meeting inclusion criteria. For 11 of the participants included in the analysis, data on final selection of the charity out of 5 presented options was not saved, likely due to a technical issue. For two of participants in the younger adults group, decision satisfaction ratings after the last decision making trial were also not saved. We included available data from these participants in the analysis, apart from the two missing decision satisfaction ratings. Characteristics of younger and older adults are presented in the Table 9 (please find additionally correlations between participants' characteristics, dependent and control measures in Table 10). Task materials, raw data and the analysis script are available on the Open Science Framework (https://osf.io/xne5s/), as well as the stage 1 registered report (https://osf.io/r6jfh/).

Table 9. Characteristics of younger and older adults.

	Younger adults	Older adults
Demographics		
n	152	152
Age, years (*SD*)	23.9 (4.0)	69.3 (3.6)
Gender, female (%)	69.7%	50%
Education, years (*SD*)	13.4 (5.4)	12.9 (5.5)
Test measures		
IQCODE (*SD*)	2.7 (0.4)	3.0 (0.3)
SNS (*SD*)	4.3 (0.9)	4.2 (0.9)
Behavioral measures		
Number of cells reviewed (*SD*)	12.491 (8.296)	13.412 (6.717)
Positivity index (*SD*)	0.246 (0.330)	0.205 (0.293)
Bias index (*SD*)	0.288 (0.294)	0.239 (0.266)
Ignorance-based bias index (*SD*)	0.291 (0.292)	0.242 (0.253)
EVR (*SD*)	0.639 (0.192)	0.601 (0.172)
Decision satisfaction (*SD*)	6.576 (1.108)	6.905 (1.052)

Note. Mean values are presented with standard deviation in parentheses.

IQCODE - Informant Questionnaire on Cognitive Decline in the Elderly, SNS – Subjective Numeracy Scale, EVR – Expected Value Ratio.

Table 10. Correlations of characteristics of participants and measures used in analyses.

	SNS	IQCODE	Mean positivity index	Mean bias index	Mean ignorance-based bias index	Mean EVR
Age, years	-0.054	0.407***	-0.059	-0.083	-0.087	-0.125*
SNS	-	-0.066	-0.069	-0.129*	-0.117*	0.034
IQCODE			0.136*	0.060	0.056	-0.006
Mean positivity index				0.804***	0.737***	0.077
Mean bias index					0.945***	0.072
Mean ignorance-based bias index						0.043

Note. * $p < .05$, ** $p < .01$, *** $p < .001$.

SNS – subjective numeracy scale, IQCODE - Informant Questionnaire on Cognitive Decline in the Elderly, EVR – expected value ratio.

Confirmatory analyses.

We analysed the collected data in accordance with the registered analysis plan. Results from regression models are presented in Tables 11 and 12. We first tested whether our sample demonstrated the positivity effect (H1), defined as a higher positivity bias in the group of older adults, in comparison to the group of younger adults. We did not observe a significant difference in the positivity index between the age groups.

Table 11. Mixed effects regression models predicting index of positivity in review, EVR and decision satisfaction.

	Positivity index			EVR			EVR			Decision satisfaction			EVR		
	H1			H2			H2b			H3			H4		
	Estimate	*SE*	*p*-value	Estimate	*SE*	*p*-value	Estimate	*SE*	*p*-value	Estimate	*SE*	*p*-value	Estimate	*SE*	*p*-value
Intercept	0.246	0.025	< .001	0.607	0.053	< .001	0.605	0.053	< .001	6.824	0.072	< .001	0.661	0.019	< .001
Age group	-0.041	0.036	.253										-0.041	0.021	.051
Positivity index										.259	0.065	< .001			
Bias index				0.013	0.024	.590									
Ignorance-based bias index							0.021	0.023	.366						
SNS				0.007	0.012	.544	0.007	0.012	.529						
Trial number				-0.004	0.002	.101	-0.004	0.002	.094	-.026	0.006	< .001	-0.004	0.002	.115
Observations	2970			2970			2970			2968			2970		

Note. Unstandardized estimates are presented with standard errors and p-values. Random intercepts for participants are included to account for multiple measurements.

SNS – subjective numeracy scale, EVR – expected value ratio.

Table 12. Mixed effects logistic regression model predicting choices in the simplified decision task from differences between the scores of features with positive, negative and mixed values interacted with the age group.

	Choice		
	Estimate	*SE*	*p*-value
Intercept	-0.301	0.225	.181
Age group	0.068	0.094	.466
Positive score difference	0.026	0.001	< .001
Negative score difference	0.018	0.003	< .001
Positive-negative score difference	0.039	0.003	< .001
Negative-positive score difference	0.039	0.003	< .001
Age group × positive score difference	-0.002	0.003	.428
Age group × negative score difference	-0.003	0.005	.596
Age group × positive-negative score difference	0.001	0.006	.905
Age group × negative-positive score difference	0.004	0.006	.473
SNS	0.064	0.052	.214
Observations		2430	

Note. Unstandardized estimates are presented with standard errors and *p*-values. For interactions between the age group and score differences, the younger adults group acts as a reference. Random intercepts for participants are included to account for multiple measurements.

Score differences and the age group variable were centred before being included in the model.

SNS – subjective numeracy scale.

We then tested whether the bias index was linked to a decreased quality of decisions measured by the EVR (H2)[4]. The bias index was calculated as an absolute value of the positivity index and represented a degree of deviation from an equal review of positive and negative information. Considering the results from previous studies using a similar task (Löckenhoff & Carstensen, 2007, 2008), we expected that younger adults would demonstrate a low absolute bias, whereas older adults would show a higher bias due to the positivity effect. Since positive and negative information cells were equally important in the task, we predicted that a more biased review of the available information due to the positivity bias would be linked to lower decision quality. The bias index would thus be a measure linking the age-related difference in positivity to differences in decision quality. However, in our data both age groups showed a similar extent of the information acquisition bias. We also did not observe a significant effect of the bias index on the EVR (H2). Additionally, we tested whether the ignorance-based bias

[4] Please note, that the calculation of the EVR included an adjustment of the expected values of options in each trial by detracting the minimal expected value in the respective trial to avoid cases in which the expected value would be divided by a negative value or by a zero.

index was linked to a decreased quality of decisions measured by the EVR (H2b). Unlike the bias index, this measure was based only on unique reviews of information cells and did not include repeated openings. This index allowed us to test whether a bias not just in the information search itself, but in being exposed to information of specific valence, would drive a decrease in decision quality. Similarly to the H2, we did not observe an effect of the bias in review of unique cells on the EVR.

We then tested the link between the positivity index and decision satisfaction (H3). Positivity was significantly related to ratings of decision satisfaction, confirming the hypothesized effect. Next, we compared decision quality measured with the EVR between the two age groups (H4). The regression coefficient suggested a lower decision quality of older adults; however, the effect was not significant. We used a mixed effects logistic regression model to analyse choices in the simplified decision task (H5). Interactions of interest between the age group variable and values of characteristics with mixed valences represented age group difference with respect to how strongly participants took the characteristics contrasting negative and positive values into account when making a choice. We expected that a loss prevention orientation would increase the relative importance of such characteristics for older adults. However, the interactions of interest were not significantly related to choices, suggesting a lack of support for the loss prevention orientation in decisions of older adults in the presented task.

Exploratory analyses.

We explored information search and decision quality measures to provide additional context to confirmatory testing results. First, we addressed potential differences in the search pattern variability operationalized as standard deviation of the positivity index throughout the task. We did not observe a difference between age groups in the positivity index variability (Table 13), therefore it is unlikely that our measures were confounded by age differences in stability of information search patterns. We also evaluated whether older adults conducted a less extensive information search; however, we did not observe a significant difference between the age groups (Table 14). Younger adults have on average opened 12 information cells before making a decision, and older adults – 13 cells. Most of the participants (94%) have opened at least some information cells repeatedly, with no significant difference between the age groups in the numbers of repeat reviews (Table 15).

Table 13. Exploratory analysis - regression models predicting search pattern variability from age group.

	Search pattern variability		
	Estimate	*SE*	*p*-value
Intercept	0.240	0.012	< .001
Age group	-0.014	0.018	0.412
Observations		304	

Note. Unstandardized estimates are presented with standard errors and *p*-values. Positivity index variability and the age group variable were centred before being included in the model.

SNS – subjective numeracy scale, EVR – expected value ratio.

Table 14. Exploratory analysis - mixed effects regression model predicting extent of information review.

	Number of cells reviewed		
	Estimate	*SE*	*p*-value
Intercept	12.516	0.613	< .001
Age group	0.898	0.866	.301
Observations		2970	

Note. Unstandardized estimates are presented with standard errors and *p*-values. Random intercepts for participants are included to account for multiple measurements.

Table 15. Exploratory analysis - mixed effects regression models predicting the number of repeat reviews of information cells from trial number and age group.

	Number of repeat reviews of information cells		
	Estimate	*SE*	*p*-value
Intercept	3.676	0.288	< .001
Age group	-0.304	0.576	0.598
Trial number	-0.132	0.028	< .001
Age group × trial number	0.066	0.055	0.236
Observations		2970	

Note. Unstandardized estimates are presented with standard errors and *p*-values. Random intercepts for participants are included to account for multiple measurements.

Trial number and the age group variable were centred before being included in the model.

We assessed whether older adults and younger adults showed a positivity or a negativity bias in review. For each age group we used one-sample two-sided *t*-tests with the positivity index. Younger adults had an average positivity index of .246 ($p < .001$), which indicates that on average the difference between numbers of reviewed positive and negative information cells constituted 24.6% of all reviewed cells in a trial. Interestingly, older adults had a slightly lower average positivity index of .205 ($p < .001$). These results suggested that both groups showed a positivity bias. Therefore, it is unlikely that our task has constrained information processing by participants, because that would result in a lack of bias. We tested whether it was possible to reject a specific effect size for an age group comparison of the positivity index. We used the two one-sided tests (TOST) procedure (Lakens, 2017) implemented in R for equivalence testing using the positivity index averaged across trials for each participant. The planned sample size of 150 participants per group would allow to reject an effect size of approximately $d = .34$ with power of .8 for a *t*-test comparing measures on the level of participants, which is lower than previously reported $d = .482$. Therefore, we used the TOST procedure with equivalence bounds of $d = .34$. In the current results, younger adults had a numerically higher average positivity index, than older adults. Correspondingly, the result of the TOST procedure indicated that we could reject the upper equivalence bound (younger adults have a higher positivity index) with $p = .037$, and we could reject the lower equivalence bound (older adults have a higher positivity index) with $p < .001$. We can consequently rule out an effect size of at least $d = .34$ for the positivity effect in our data.

We next tested age differences in change of performance throughout the trials which could result from fatigue. This effect could potentially mask age differences in relevant measures. We specified mixed-effects models predicting number of reviewed information cells, the positivity bias and the EVR (Table 16). We observed a decrease in the number of cells opened by participants throughout the task trials, as well as an increase of the positivity index. Importantly, observed effects did not interact with the variable indicating the age group, therefore we could not establish age differences in performance change throughout the trials. We also did not observe a change in the EVR from earlier to later trials. The specified model indicated a lower EVR for older adults; however, that effect was not supported by the specified confirmatory testing.

To rule out a potential effect of a relatively quicker completion of the task on decision quality, we ran exploratory regression models similar to analyses testing H2, H2b and H4 in a subset of participants who took longer than at least half of the mean duration of about 11 minutes 22 seconds (*n* = 241, including 99 younger adults and 142 older adults) to complete the study (Table 17). The pattern of results was in general similar to the findings from confirmatory tests; therefore, it is unlikely that decision quality analysis was adversely affected by participants who completed the task quickly.

Table 16. Exploratory analysis - mixed effects regression models predicting measures of information search and EVR from trial number and age group.

	Number of cells reviewed			Positivity index			EVR		
	Estimate	*SE*	*p*-value	Estimate	*SE*	*p*-value	Estimate	*SE*	*p*-value
Intercept	12.967	0.433	< .001	0.225	0.018	< .001	0.597	0.051	< .001
Age group	0.921	0.867	0.289	-0.041	0.036	0.245	-0.040	0.021	0.055
Trial number	-0.291	0.035	< .001	0.010	0.002	< .001	-0.004	0.002	0.114
Age group × trial number	0.028	0.070	0.695	0.003	0.004	0.359	0.005	0.005	0.276
SNS							0.006	0.012	0.636
Observations	2970			2970			2970		

Note. Unstandardized estimates are presented with standard errors and *p*-values. Random intercepts for participants are included to account for multiple measurements.

Trial number and the age group variable were centred before being included in the model.

SNS – subjective numeracy scale, EVR – expected value ratio.

Table 17. Exploratory analysis - mixed effects regression models predicting EVR in a subset of participants who spent more than half of average duration for completing the task.

	EVR			EVR			EVR		
	Estimate	*SE*	*p*-value	Estimate	*SE*	*p*-value	Estimate	*SE*	*p*-value
Intercept	0.589	0.061	< .001	0.585	0.060	< .001	0.667	0.023	< .001
Age group							-0.043	0.023	0.07
Bias index	-0.011	0.028	0.699						
Ignorance-based bias index				0.001	0.027	0.965			
SNS	0.013	0.013	0.336	0.013	0.013	0.323			
Trial number	-0.004	0.003	0.105	-0.004	0.003	0.096	-0.004	0.003	0.095
Observations	2386			2386			2386		

Note. Unstandardized estimates are presented with standard errors and *p*-values. Random intercepts for participants are included to account for multiple measurements.

SNS – subjective numeracy scale, EVR – expected value ratio.

3.2.5. Discussion

In the current study, we investigated the relationship between the age-related positivity effect and decision making in a sample of older adults and younger adults. Previous literature has demonstrated a stronger positivity bias in information search of older adults, in comparison to younger adults, in various contexts, including in decision tasks (Carstensen & DeLiema, 2018). We did not observe such positivity effect in the information search in our donation task. Equivalence testing for a comparison of the positivity index between younger and older adults supported rejecting an effect size of at least $d = .34$, which is lower than the previously reported $d = .482$ (Reed et al., 2014). Exploratory analyses suggested that both age groups showed positivity bias. Therefore, it is unlikely that our task has inadvertently constrained information processing by older adults and suppressed the positivity effect. Such constrained information processing would have led to a lack of the positivity bias (Reed et al., 2014), which was not the case in our findings. Previous research has demonstrated that older adults tended to review more positive information than negative, and younger adults reviewed similar amounts of positive and negative information (Löckenhoff & Carstensen, 2007, 2008). On the contrary, in our study younger adults showed on average even a numerically higher positivity bias, than older adults. It is possible that the lack of the positivity effect in our results and therefore the discrepancy with the previous literature were due to the positivity in younger adults. It is also possible, that the mode of administration (as an online task) or the type of decisions (incentivized charity donations) specific to our current study have contributed to the lack of age differences in the positivity bias. This null finding suggests that the future research on the positivity effect needs to identify the specific conditions required for observing it or examine the reliability of the positivity effect.

Consistently with the literature, a stronger positivity bias during decision was associated with a higher decision satisfaction. This result indicates that focusing more on positive information is linked to a higher subjective assessment of a resulting choice. However, we did not observe the hypothesized links between the bias index or the ignorance-based bias index and decision quality. Observed heterogeneity between participants in EVR ruled out potential floor or ceiling effects for the decision quality. One potential explanation for the lack of the relationship between the bias and the EVR is that the present heterogeneity of the positivity index and, consequently, the bias index, was insufficient to cause detectable differences in decision outcomes among participants. Correspondingly, we did not establish a significant difference in decision quality between age groups in confirmatory analysis, although older adults had a numerically lower average decision quality. Another possibility is that a potential improvement of decision quality of participants was limited by a factor other than an unbiased information search, for example, limitations in processing of information by both older and younger adults. Overall, these findings indicate the need for research to more closely examine age differences in attention to positive and negative stimuli during information search, as well as their influence on decision making. Additionally, a potential contribution of other factors such as cognitive functioning to decision quality could pose interest in the context of the positivity effect.

We also considered a possibility that younger and older adults showed a different susceptibility to fatigue, which could have affected their performance in the task to a different extent. In the exploratory analyses, we compared the age groups with respect to changes in the extent of information search, in the positivity bias and in the EVR throughout the task. Both age groups showed some decrease in the quantity of information looked up prior to a decision, and an increase in positivity bias throughout the task; however, we observed no differences in these changes between the age groups. Exploratory test has also confirmed that older and younger adults showed a similar extent of information search and in repeat reviews of information. We also observed no difference in variability of the positivity bias which indicates a similar stability of information search patterns of younger and older adults in the task.

In the confirmatory analysis of performance on the simplified version of the decision task, we did not find support for the loss prevention orientation during decision making. We anticipated a possibility that a loss prevention orientation could manifest as a relative avoidance of negative information by older adults and thus contribute to the positivity bias. A different effect of the loss prevention orientation discussed by Depping & Freund (2013) would lead to an increased processing of negative information and could have potentially contributed to the lack of age differences with respect to the positivity bias. However, we did not observe age difference in consideration of characteristics contrasting positive and negative information in the simplified decision task. Therefore, it is unlikely that a loss prevention orientation has contributed to information search in older adults.

Current study has investigated a potential contribution of the positivity effect to value-based decision making. Contrary to the previous literature, we did not observe the positivity effect defined as an age-related increase in the positivity bias. We also did not establish an effect of bias in the information search on the decision quality. Correspondingly, confirmatory analyses did not provide support for a systematically compromised decision quality of older adults due to the positivity effect. Present findings suggest comparability of examined characteristics of information search and decision making of younger and older adults. Further research would be required to investigate additional factors underlying age differences in positivity and resulting decision outcomes. Our task is similar to a range of various decision situations that younger and older adults may be confronted with in real life, such as charitable donations or online shopping. Applied to consumer behaviour, our findings would suggest that during choice older and younger adults could show a preference for information related to advantages and positive characteristics of options. Additionally, both age groups would be similarly likely to make beneficial decisions.

Supplemental material for study 2.

Sample characteristics.

In accordance with the registered plan for data collection, we aimed at recruiting similar numbers of men and women in both age groups. However, in the process of data collection, the gender balance among younger adults who completed the task shifted towards a higher proportion of women. This was likely due to a lower response rate for men in this age group. We partially compensated for that by emphasizing recruitment of male participants. Present gender composition of the younger adults group is not expected to influence performance on the decision making task.

Exploratory analysis

Analysis of H5 prompted a warning message in R suggesting rescaling variables due to a very large eigenvalue and a large eigenvalue ratio. Therefore, as an exploratory test, we ran a similar model, but with rescaling (by dividing by 100) of variables that indicate differences in ratings of characteristics, which produced the same *z*-values and *p*-values for effect coefficients as the original model. Therefore, the results from this analysis were most likely unaffected by the scale of variables, and we report only the original model.

3.3. Study 3: Episodic future thinking and decision making in aging

The manuscript for the following study is titled "Episodic future thinking and decision making in aging" with following authors: Fedor Levin, Bernd Weber.

3.3.1. Abstract

Previous research has demonstrated that episodic future thinking (EFT) can increase consideration of future outcomes of decisions. However, findings in older adults have not been conclusive. We used an online decision making task to investigate EFT in a group of older adults (n = 89), in a comparison group of older adults engaged in episodic recent thinking (ERT; n = 55), and in an EFT group of younger adults (n = 39). EFT decreased the rate with which older adults discounted future monetary rewards but did not significantly influence consideration of healthiness during food choice. Findings suggest that older adults can benefit from EFT. The effect of future thinking on food choice in older adults requires further research.

3.3.2. Introduction

Many important choices, such as decisions related to health or finance domains, have long-lasting consequences. Both of these domains are considered especially important in older age (Hershey et al., 2015; Morrow & Chin, 2015). Similar to traditionally studied economic choices, some health-related decisions require consideration of outcomes that occur only after a time delay (Berkman, 2018). Similarly, modifiable lifestyle factors that affect health in later life, such as a healthy diet and physical exercise, require adherence and investment of effort. The benefits, for example, a decreased probability of a vascular disease (King et al., 2007) or better cognitive functioning (Baumgart et al., 2015), occur only after a time delay. There is mixed evidence about whether aging leads to a better or worse consideration of delayed outcomes in decision making. Löckenhoff et al. (2011) showed that older adults were more patient than younger adults in intertemporal choices - choice with outcomes that occur after different temporal delays. However, subsequent studies have also demonstrated that older adults were more likely than younger adults to select immediate but lower rewards in monetary intertemporal choices (Göllner et al., 2018) as well as in decisions with social and health rewards (Seaman et al., 2016).

Intertemporal decision making of older adults can potentially benefit from prospection – the ability to construct mental representations of future events. Episodic future thinking (EFT) has received considerable interest as one form of prospection (Schacter et al., 2017). Constructive episodic simulation hypothesis conceptualizes EFT as a process of retrieval and recombination of episodic information that allows future events to be imagined (Schacter et al., 2007). In the current study we addressed the potential benefit of EFT for supporting future-oriented decisions of older adults by decreasing the rate at which they discount future rewards (temporal discounting).

A typical EFT paradigm consists of an interview in which participants engage in future thinking – they vividly imagine and describe personal events that can likely happen in several specified future time periods, for example, in a month from study participation (Daniel et al., 2013; Stein et al., 2016). These events are then used as cues to prompt EFT during trials of a task with intertemporal choices – a delay discounting (DD) task. If these decisions are presented with cues for future events, participants demonstrate a lower rate of discounting future rewards and an increased consideration of future outcomes, which is also referred as a "tag effect" (Peters & Büchel, 2010). It has been suggested that the tag effect works by expanding the time period for which participants evaluate subjective benefits of alternatives (Stein et al., 2018) and thus it increases the values of delayed options. EFT procedures with future event cues decreased cigarette self-administration (Stein et al., 2016) and initial alcohol consumption in a hypothetical alcohol purchase task (Snider et al., 2016). EFT cues also decreased calorie consumption in a subsequent meal for overweight or obese participants who wanted to improve their dietary habits (Daniel et al., 2013; O'Neill et al., 2016). These findings indicated that an EFT intervention can increase consideration of future health-related outcomes of decisions, including food choice. Hollis-Hansen and colleagues (2019) have also demonstrated that EFT leads to a decrease in caloric values of products purchased in an online grocery shopping task, which is indicative of decisions more considerate of future outcomes.

Past research has assessed the EFT ability in older adults and has described age-related differences, as well as parallels between memory and EFT (for a review, see Schacter et al., 2013). During the generation of hypothetical future events, older adults tend to produce fewer episodic details about their events (Lapp & Spaniol, 2017), but more semantic details. This is relevant for the effectiveness of the EFT intervention because higher vividness of generated events is related to the size of the tag effect (Peters & Büchel, 2010). Although older adults' ability to vividly imagine specific future episodes may be decreased, they can still potentially engage in future thinking. However, there is only limited existing research on the effect of the EFT procedure on decision making of older adults, as compared to younger adults. A study by Hu et al. (2017) compared the tag effect between a group of middle to older age participants (*n* = 20, mean age = 68.29) who self-reported subjective cognitive decline and a control group of healthy participants (*n* = 24, mean age = 66.49) For each participant, discounting rate in the episodic condition was compared to the discounting rate in the control condition with no episodic cues. The findings indicated that the control group benefited from the EFT procedure, whereas the group with the subjective cognitive decline did not. A study by Sasse et al. (2017) did not establish a significant beneficial effect of including EFT cues in a DD task in a group of 22 older adults. However, the findings indicated that the executive functioning of older adults correlated with a decrease of discounting in trial blocks when EFT cues were included, as compared to control trials. Accordingly, analysis of the fMRI data from that study demonstrated that a stronger cognitive control was related to increased subjective value signals in the hippocampus, the anterior cingulate cortex, and the coupling between the hippocampus and the striatum in the EFT trials.

Taken together, these studies indicate that older adults could potentially benefit from EFT similarly to younger adults, but the effect may depend on their cognitive abilities, such as executive function. Decreasing temporal discounting could help older adults maintain their long-term goals and improve adherence to healthy lifestyle. Therefore, the tag effect, as well as its predictors and limitations in older adults, are relevant for research on decision making in aging.

Current study

In the current study we investigated whether EFT would influence decision making of older adults in two types of decisions. Based on the reviewed literature, we considered that EFT could facilitate consideration of future outcomes by older adults in a monetary DD task and increase consideration of healthiness of food products during food choice. To address this, we used an approach with an established self-guided online EFT procedure (Stein et al., 2017, 2018; Sze et al., 2017). This procedure offers several potential advantages over the previously used interview-based EFT interventions. It allows participants to generate personal episodic event cues using a uniform event cue generation task in a format that does not rely on an interviewer and remains identical across participants. Additionally, this procedure is potentially more feasible as an intervention for promoting EFT since it does not require conducting an in-person interview. Previous research examined the use of information and communication technology by older adults and demonstrated their overall perception of the technology as easy to use and useful (Pauly et al., 2019). This further bolsters the feasibility of a self-guided EFT procedure administered online to older adults. In addition to that, we aimed to compare the effect of the EFT in older adults to the effect in younger adults.

In order to provide a control group for testing the effects of EFT, we planned to compare the EFT group of older adults to the episodic recent thinking (ERT) condition. The control ERT condition, like EFT, involves imagination about specific and positive personal events, but instead of anticipating future events, it involves remembering past events (Stein et al., 2017; Stein et al., 2018; Sze et al., 2017). Consistently with these previous studies, we assume that ERT involves episodic thinking, and the task performed by participants in the comparison group differs from the one presented to the EFT group predominantly with respect to time orientation.

To assess the potential benefit of EFT for food choice, we asked participants to complete a hypothetical food choice task with a design similar to the task from a neuroimaging study by Hare et al. (2011) that assessed effects of attentional conditions on choice. The study demonstrated an effect of focusing on the perceived healthiness of food products, as compared to a control attention condition. In our study, participants were presented with food choices paired with their self-generated episodic cues. This would allow us to compare the EFT and the ERT conditions in older adults. We anticipated that an effect of the EFT procedure on choice could be influenced by an age-related decline of executive function of older adult participants. The importance of executive function for the EFT processes (Sasse et al., 2017) is relevant for research on EFT in older age because of a possible age-related decline of executive function (Fjell et al., 2016). In order to test the potential link between executive function and the efficiency of the EFT procedure, we administered a brief inventory Adult Executive Functioning Inventory (ADEXI; Holst & Thorell, 2017). ADEXI has been previously administered in a sample of older adults (Thorell et al., 2019), and it has an advantage of being self-administered, and therefore suitable for an application within an online study or an online-based intervention. Since depression may lead to lower cognitive performance (Rock et al., 2014) and decrease positive prospective thinking (Thimm et al., 2013), we additionally administered a German version of the shorter Geriatric Depression Scale (GDS; Brink et al., 1982).

Hypotheses

Based on the previous research we formulated several hypotheses. First, we predicted that older adults in the EFT group would demonstrate a stronger tag effect than older adults in the ERT group (H1), similar to previous results in younger adults (Schacter et al., 2017). Since participants' baseline delay discounting rates can differ, we administered the DD task twice – before the episodic thinking task and then after it. The tag effect was measured as a difference between the delay discounting rates from the second monetary DD task which included self-generated episodic thinking cues (EFT or ERT) and from the baseline monetary DD task. Confirmation of this hypothesis would provide evidence for efficacy of the self-guided online EFT intervention in older age.

Additionally, we tested several predictions with respect to choices of “healthy” and “unhealthy” food depending on their group. Specifically, we predicted that participants in the EFT group would choose “healthy” but “untasty” food more often than participants in the ERT group (H2). Additionally, we predicted that participants in the EFT group would choose “unhealthy-tasty” food less frequently than those in the ERT group (H3). Both of these effects would be separately indicative of the potential practical usefulness of the EFT procedure. We also tested whether participants in the EFT group would place higher importance on the healthiness characteristic of the products (H4). This analysis would indicate whether thinking about future events increases the extent to which participants take into account long-term consequences of food choices that are represented by the healthiness ratings. Another hypothesis that we tested was that the self-reported executive function would interact with the healthiness ratings in a model predicting food choice in the EFT group of older adults (H5). We expected that a higher executive function score would be related to a stronger effect of healthiness ratings on the choice variable indicating how much a participant wants to consume a given food product. Finally, we tested whether older adults would show a smaller decrease of delay discounting in the EFT condition, than younger adults (H6). This analysis allowed us to test whether the EFT intervention was relatively less efficient in the older age group consistently with prior research (Sasse et al., 2017).

3.3.3. Method

All participants provided informed consent before taking part in the study. We conducted an a priori power analysis based to determine the sample size. Previous studies reported medium to large effect sizes for the EFT tag effect (for example, Hu et al., 2017; Stein et al., 2016; Sze et al., 2017). Using G*Power 3.1.9.2 software (Faul et al., 2007) we calculated sample size required to detect a medium effect size of d = .5 in a one-sided t-test with α = .05 with power = .9 which indicated that we required at least 70 participants in each group – EFT and ERT. Therefore, sample sizes of 75 participants per group were planned. The study was approved by the ethics committee of the University of Bonn.

Data collection

Overall, 181 older adults and 75 younger adults completed the study. The task was hosted on Qualtrics and participants were recruited using the panel service Toluna. Participants were German and all instructions, materials and tests were administered in the German language. Participants were informed that their choices in monetary delay discounting tasks and in the food choice task were hypothetical. We pre-registered hypotheses and analysis plan after collecting data from an initial sample of the EFT group of younger adults at the Open Science Framework (https://osf.io/jdxfs?view_only=705b9d78272f4c2e8e653fd7c8ae578b).

Procedure

Participants were randomly invited to participate in the EFT or in the ERT version of the study. At first, participants were informed about the procedure in the study and then they indicated their agreement to participate. Participants then provided age and gender. Next, to control for potential age-related decreases of executive function, we administered a German translation of ADEXI (Holst & Thorell, 2017). It consists of 14 items, each with five possible answers from "definitely untrue" to "definitely true". ADEXI reflects deficits in inhibitory control and working memory. We also administered a German translation of the GDS (Brink et al., 1982). It includes 15 items in which participants indicate whether they agree with the statements describing various aspects of mood. We used the threshold of 10 points as an exclusion criterion to rule out the possibility of depressive symptoms. After that, participants completed the baseline monetary DD task. Then they rated healthiness and taste of food products that would later be presented in the food choice task. The EFT group then performed the self-administered EFT event generation procedure, whereas the ERT group performed the ERT procedure. As a next step, both groups completed the monetary DD task and the food choice task, which both included self-generated event cues.

EFT event generation procedure

The procedure for generating future events and promoting EFT during decision making was similar to the previously established online EFT procedure (Stein et al., 2017, 2018; Sze et al., 2017). Participants were asked to describe three positive personal events that they expected to happen at three specific time frames in the future (1 month, 2-6 months, 7-12 months). Consistent with previous research (Daniel et al., 2013), we elicited positive events because earlier findings indicated that participants pre-experience positive events more vividly than negative (D'Argembeau & van der Linden, 2004). In the beginning of the event generation trial participants were presented with the time period for which an event should be imagined. To help participants visualize the time frames we presented specific dates ranges for the events and also included a calendar; the order of time frames was randomized. Participants were asked to select an event for that time frame that they could visualize vividly and then imagine it as if it was actually happening. Additionally, it was emphasized that the event should be personal and specific; however, participants were also instructed not to enter any sensitive or identifying information. Then participants were asked to describe the event in 2-5 sentences.

To guide the event generation process, we included an example of an ill-suited event which was negative and not specific, as well as an example of a suitable specific and positive event. Additionally, we included a checklist at the bottom of the web form to make sure that the selected event met key criteria. In the next form participants entered shorter names (1-3 words) for each event. We then asked further specific pointed questions about episodic details surrounding the imagined event to prompt more detailed episodic thinking (in German): "What will you do at the event?", "Where will the event that you imagined take place?", "Who will be with you?", "How will you feel?", "What will you see?" and "What will you hear?". Similarly to the previous studies administering the EFT task online (Stein et al., 2017; Sze et al., 2017), we asked participants to provide ratings of vividness and valence of the event that they imagined on 5-point scales in order to promote their thinking about details of each event. Self-generated cues and event descriptions were later used to promote episodic thinking in the trials of the DD task and the food choice task.

ERT event generation procedure

The ERT event generation procedure administered to the control group was analogous to the EFT procedure, but the time periods for generated events corresponded to the recent past (1 day ago, 2-6 days ago and 7-12 days ago), rather than future. Therefore, the ERT also involved autobiographical episodic thinking and the main difference between the task variants was the future focus for the EFT group.

Delay discounting task

We used an adjusting-amount task to evaluate delay discounting of participants (Stein et al., 2017). Our task had six different time delays – 1 week, 1 month, 3 months, 6 months, 1 year and 2 years. Participants made six choices for each delay period. First trial was always between 50 Euros for the immediate option and 100 Euros for the delayed option with the respective delay. Then, depending on the choice, the value of the immediate option was gradually adjusted to estimate the approximate indifference point. Participants completed the delay discounting task twice. First, we administered the task after the questionnaires to assess the baseline performance. Then, after the EFT or the ERT event generation, the delay discounting task was administered the second time, now with the event cues (Figure 7). Event cues included the name of the event and the description of the event as provided by the participant. During every trial, participants were prompted to imagine their episodic events. Episodic thinking cues were approximately matched with the time frames for the discounting task (e.g. events that occur earlier matched with delay discounting trials with earlier delayed rewards, and events that occur later matched with delay discounting trials with later rewards).

Food choice task

Food choice task was constructed similarly to the one used in the study by Hare et al. (2011). After the baseline delay discounting task, participants rated healthiness and taste of a set of 20 food products, consisting of 10 healthy food items and 10 less healthy items (Figure 7, part A). We used stimuli from the database of food pictures by Blechert et al. (2014), and additional pictures of regular food products from a supermarket. The order of rated properties – healthiness or taste – was randomized between participants. After the second delay discounting task, we asked participants to rate how much they would like to consume each of previously rated food products on a four-point scale ("would not like at all", "would not like", "would like" and "would like a lot"; see Figure 7, part C). Order of products was randomized. In each trial we included a cue for a random event and a prompt for participant to engage in event imagination before choice. For the EFT group we included cues for future self-generated events and for the ERT group we included cues for recent events.

Data analysis approach

We calculated area under the curve (AUC) as a measure of delay discounting in monetary DD tasks. An advantage of this measure is that it is independent of assumptions about discounting function (Myerson et al., 2001). Using logistic regressions, we obtained approximate indifference points for each delay period corresponding to the monetary reward at which the participant would have 50% chance of picking either alternative. We then calculated AUC as a sum of trapezium areas between the indifference points. In case participant selected only immediate smaller reward values for a specific time period, AUC of 0 would be assumed. These AUC values were then divided by the maximum possible AUC, which was in turn estimated as the difference between the longest delay (2 years, or 730 days) and the shortest delay (7 days), multiplied by the highest possible reward (100 Euros). The maximal possible value of the resulting AUC index was thus 1, and the lowest – 0. The main outcome measure was the change in the AUC index, calculated as a difference between the AUC index from the second delay discounting task and the AUC index from the first delay discounting task.

For hypotheses H1-H4 we compared the EFT and the ERT groups of older adults. We tested the H1 by conducting regression analysis with the change in the AUC index as a dependent variable and the group as a predictor variable. Similarly to the study done by Hare et al. (Hare et al., 2011), we tested the H2 and the H3 by comparing proportions of positive answers ("would like" or "would like a lot") for each of four possible combinations of food characteristics ("healthy-tasty", "healthy-untasty", "unhealthy-tasty", "unhealthy-untasty") between the EFT and the ERT groups. We also analyzed the food choice task performance using repeated measurement regression models. We tested the H4 by conducting regression analysis predicting the choice variable from an interaction between the group dummy variable and the healthiness ratings as well as from an interaction between the group dummy variable taste ratings. Healthiness ratings were centered.

We tested the H5 in the EFT group of older adults by specifying a regression model similar to the H4, with an interaction between healthiness ratings and the ADEXI score as a predictor variable. This analysis allowed us to test whether the self-reported executive function predicted how strongly participants took healthiness of food products into account. Healthiness ratings and ADEXI scores were centered before inclusion in analysis. Finally, to test the hypothesis H6, we compared EFT groups of older and younger adults by specifying a model similar to the H1 with the change in the AUC index as a dependent variable and the age group as a predictor variable. Reported linear repeated measurement regression models were fit by the restricted maximum likelihood (REML) and associated *t*-tests used Satterthwaite approximations for degrees of freedom.

3.3.4. Results

The summary of demographic properties of participants and collected measures is presented in the Table 18. Due to a high influx of recruited participants in the EFT group of older adults near the end of data collection, more participants completed the survey in this group than originally planned (89 included in analysis, as compared to 75 planned).

Table 18. Characteristics of the EFT group of younger adults, and the EFT and the ERT groups of older adults.

Group	EFT group of older adults	ERT group of older adults	EFT group of younger adults
n	89	55	39
Age (SD)	68.6 (3.9)	69.8 (4.1)	28.6 (4.9)
Gender, % female	49.4%	47.3%	61.5%
ADEXI score (SD)	28.1 (8.2)	29.1 (7.2)	29.6 (8.2)
Cue imagery ratings	4.53 (0.47)	4.29 (0.62)	4.38 (0.58)

Note. ADEXI - Adult Executive Functioning Inventory, EFT – episodic future thinking, ERT – episodic recent thinking. Mean values for age, ADEXI score and cue imagery ratings are presented with standard deviation in parentheses.

Data exclusion

We excluded participants who only selected shorter timeframes in all delay discounting trials (n = 4), since it likely indicated a lack of engagement with the task. We also excluded participants with GDS scores exceeding 10 (n = 17). We also excluded participants who explicitly stated that there were no personal events corresponding to the specified future or past time period or entered meaningless symbol entries (n = 49). Some participants included time periods in their descriptions of future or past personal events that deviated from the time frames required by the instructions (n = 24). For example, a participant could describe a future event in 6 months, instead of the requested period of 7-12 months. Such event cues with time periods outside the requested time frames could potentially decrease the efficiency of EFT and could lead to an underestimation of the effect of the EFT procedure in decision trials. Excluding those participants from analysis did not change the general pattern of results, therefore, we are reporting results from the more inclusive sample. This sample included 89 older adults in the EFT group, 55 older adults in the ERT group and 39 younger adults in the EFT group.

Imagery ratings

To check for a potential effect of vividness of imagination on delay discounting, in exploratory analysis we evaluated a relationship between averaged ratings of cue imagery during event generation and the change in the AUC index in EFT and ERT groups of older adults using Kendall's rank correlation. We did not establish a significant relationship between the measures (Kendall's τ = -0.005, z = -0.09, p = 0.93), which indicated that the observed results were likely not driven by engagement in imagination.

Delay discounting

We first tested whether the EFT group of older adults showed a stronger increase of the AUC index between the baseline and the task including the episodic event cues, as compared to the ERT group of older adults (the tag effect). The EFT group of older adults demonstrated a significantly higher change in the AUC index, than the ERT group of older adults (Table 19) confirming the H1. We also compared the tag effect between older adults and younger adults in the EFT groups (H6). We did not find a significant difference between the age groups with respect to the effect of the EFT condition on the change in the AUC index (Figure 12).

Table 19. Regression models predicting change in the AUC index, proportions of "healthy-untasty" and "unhealthy-tasty" choices.

Hypothesis	H1		H2		H3		H6	
	Change in the AUC index		Proportion of "healthy-untasty" choices		Proportion of "unhealthy-tasty" choices		Change in the AUC index	
	Estimate	*t*-statistic	Estimate	*t*-statistic	Estimate	*t*-statistic	Estimate	*t*-statistic
Intercept	0.009	0.398	0.077	1.855	0.607***	15.297	0.093**	3.172
EFT condition	0.077**	2.647	0.069	1.29	0.035	0.696		
Age group							-0.007	-0.189
Observations	144		108		140		128	

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. Models testing H1, H2 and H3 were specified in the EFT and the ERT groups of older adults. Model testing H6 was specified in the EFT group of older adults and the EFT group of younger adults.

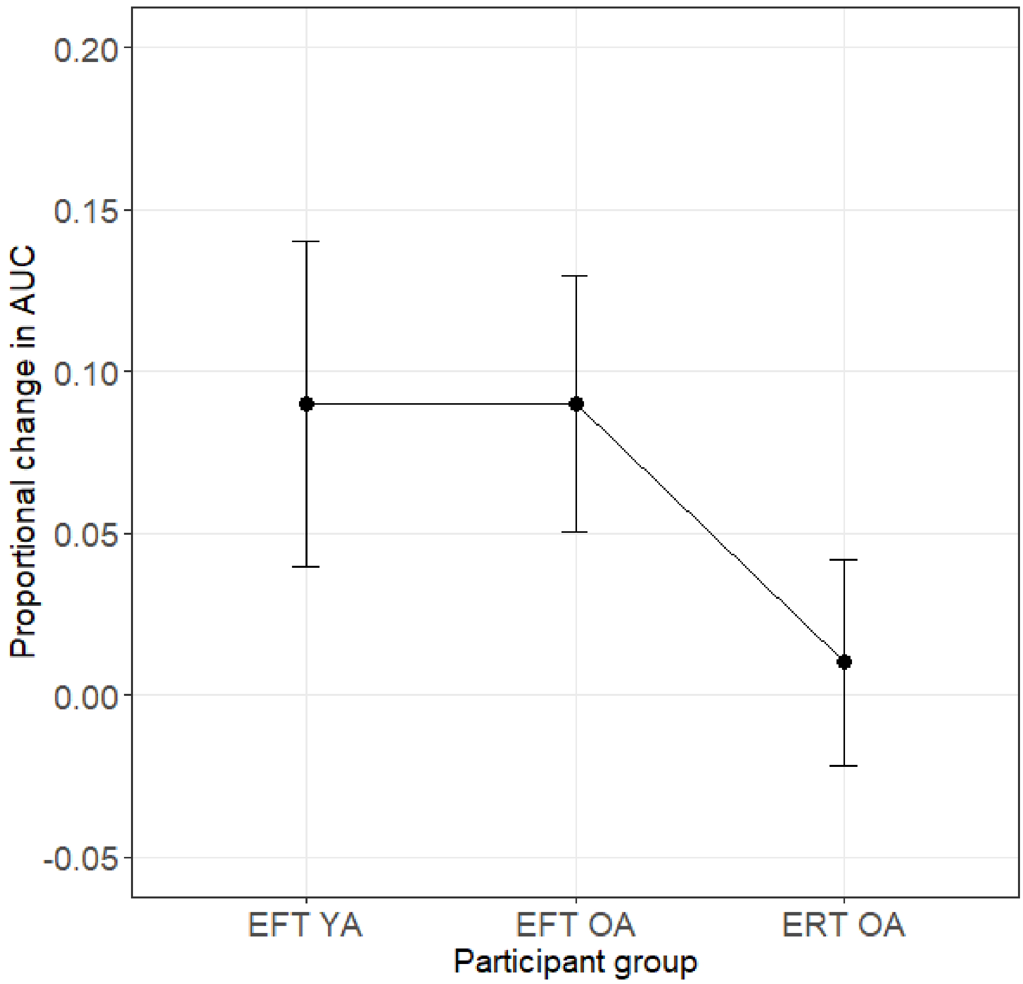

Figure 12. Change in the AUC index across groups of participants. Average change in the AUC index from the baseline DD task to the DD task using respective episodic thinking cues across the EFT group of younger adults, the EFT group of older adults and the ERT group of older adults. Error bars represent 95% confidence intervals.

Food choice

We assessed the potential effect of EFT on food choice. First, we verified assumptions that healthiness and taste ratings of products, as well as rating delay discounting rates at baseline, were predictive of food choices. We specified a regression model with choice as a dependent variable with healthiness and taste ratings as independent variables (Table 20). Both taste and healthiness ratings significantly predicted choices, which confirmed that participants made choices considering product characteristics. We also specified a model predicting choice variable from interactions between the AUC index at baseline with healthiness and taste ratings as independent variables (Table 20). Higher AUC index at baseline was associated with a higher importance of healthiness ratings when choosing food products which confirmed the assumption of the link between rates of delay discounting and consideration of health outcomes during food choice.

In confirmatory results, we did not establish significant differences between proportions of “healthy-untasty” products selected (H2) or between proportions of “unhealthy-tasty” products selected (H3; Table 19). Next, we tested whether the EFT group took healthiness food products into account during choice more strongly, than the ERT group (H4). Healthiness ratings predicted choice; however, we did not observe differences of importance of healthiness ratings between the EFT and the ERT groups (see Table 21). After that, we tested whether self-reported executive function measured with ADEXI interacted with the healthiness ratings to predict food choice in the EFT group of older adults (H5); however, we did not establish a significant effect.

Table 20. Mixed effects regression models predicting choices in the food choice task by healthiness and taste ratings, AUC index at baseline and their interactions.

	Choice			
	Simple model		With AUC index at baseline	
	Estimate	*t*-statistic	Estimate	*t*-statistic
Intercept	0.17***	4.492	0.169***	4.459
Healthiness rating	0.129***	11.505	0.129***	11.538
Taste rating	0.701***	48.051	0.7***	47.996
AUC index at baseline			-0.025	-0.177
Healthiness rating × AUC index at baseline			0.124**	2.971
Taste rating × AUC index at baseline			-0.124*	-2.202
Observations	3660		3660	

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. AUC index at baseline, healthiness and taste ratings were centered. Random intercepts for participants are included to account for multiple measurements.

Table 21. Mixed effects regression models predicting choices in the food choice task by interaction between healthiness ratings and the EFT condition, and between healthiness ratings and ADEXI scores.

Hypothesis	H4		H5	
	Choice variable		Choice variable	
	Estimate	*t*-statistic	Estimate	*t*-statistic
Intercept	0.058	0.813	0.259***	4.513
Healthiness rating	0.343***	13.757	0.321***	16.215
EFT condition	0.198*	2.174		
Healthiness rating × EFT condition	-0.022	-0.699		
ADEXI score			-0.004	-0.616
Healthiness rating × ADEXI score			-0.002	-0.632
Observations	2880		1780	

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. For the interaction between the healthiness ratings and the EFT condition, the ERT condition acts as a reference. Healthiness ratings and ADEXI scores were centered. Random intercepts for participants are included to account for multiple measurements. Model testing H4 was specified in the EFT and ERT groups of older adults, model testing H5 was specified in the EFT group of older adults.

3.3.5. Discussion

The current study assessed the effect of EFT on decision making of older adults. We used a previously established approach for promoting thinking about positive future events to influence the rate of delay discounting in an online decision task. We assessed the effect of EFT on two types of behavior – monetary choice and food choice. Results suggested that EFT decreased the rate of delay discounting in monetary choices of older adults.

Earlier research used analogous tasks in younger adults and demonstrated their potential utility as interventions for decreasing the rate of delay discounting and modifying health-related behavior (Stein et al., 2017, 2018; Sze et al., 2017). Past literature has also addressed the efficiency of EFT in older adults using choices between delayed monetary rewards. The study on EFT in individuals with subjective cognitive decline (Hu et al., 2017) reported an increase of the AUC measure in the EFT condition in a DD task, as compared to a control condition, in the healthy control group of older adults. We extended these previous findings in several ways. We demonstrated a larger increase of the AUC from baseline to the EFT condition than from baseline to the ERT condition in older adults. This comparison of these episodic thinking conditions allowed to isolate the effect of thinking about future events from the general effect of episodic thinking. Self-reported ratings of cue imagery during event generation were not significantly correlated with the change in the AUC, indicating that the observed effect was likely not due to the vividness of imagination of events. In addition to that, no significant difference between the change in the AUC index in the EFT group of older adults and in the

EFT group of younger adults was established. Overall, these findings demonstrate that older adults can engage in EFT, which then benefits their intertemporal choices.

Additionally, current study assessed the potential effect of EFT on healthiness of food choices of older adults. The EFT condition did not increase the importance of the healthiness characteristic of food products during choice. Correspondingly, we did not observe differences between the EFT and the ERT conditions in selection of "healthy" and not "tasty" products, or "unhealthy-tasty" products. We confirmed the link between participants' ratings of healthiness of products and their reported preferences, which ruled out a potential explanation that participants did not pay attention to health properties of presented options during choice. We also found an indication that participants who were more patient at baseline took healthiness of food products into account to a greater extent during choice which supported the assumption that lower temporal discounting of participants would be related to a stronger consideration of healthiness of food products. Another potential explanation for the lack of the effect of EFT on food choice could be that participants did not sufficiently link the future health outcomes of food choice to their EFT cues. A review by Zhou et al. (2018) considered a potential benefit of educational interventions for promoting healthy eating in older adults. Combining the EFT intervention with education about healthy nutrition could inform older adults about potential future benefits of healthier food choice and thus allow to link them to future timepoints.

We also investigated a possible contribution of the executive function to decisions in the food choice task. Executive function decreases in healthy aging (Fjell et al., 2016), and we predicted that it would moderate the beneficial effect of EFT on food choice; however, we did not establish such a relationship. The measure of the executive function was lower in older adults, but the difference was not significant. The administered measure of executive function was not performance-based, but rather based on self-report, which could have potentially decreased its accuracy. Another potential explanation is that in our study older adults were as capable of engaging in EFT as younger adults, which could have potentially decreased the effect of the executive function heterogeneity on performance in the food choice task. Finally, since participants in our study were recruited online, there is a possibility of a selection effect in which older adults with higher executive function were more likely to take part in the study. One interesting topic for the future research addressing factors underlying EFT in older population could be an interplay between EFT, executive function and also episodic memory performance.

Conclusion

In the current study we demonstrated the effect of a self-guided online-based EFT task on temporal discounting of older adults. The stronger valuation of future rewards supported by EFT could have a beneficial effect on a range of health-related behaviors, and therefore is important in the context of research on aging. Previous literature has demonstrated the benefit of EFT for various health-related behaviors, including food choice. However, we did not observe an effect of EFT on the healthiness of food choices. Further research is required to establish specific conditions and prerequisites, such as personal dietary goals or cognitive abilities that might determine the effect of EFT on food choice of older adults.

4. General discussion

This dissertation investigated the effects of age-related changes in cognitive abilities on decision making. Specifically, the three empirical studies included in this dissertation investigated effects that have potential to influence value construction processes relevant to value-based decision making in older adults, as suggested by previous research.

4.1. Overview of key results of the three studies

Study 1, conducted in a laboratory setting, addressed the link between a decline in episodic memory performance in older age and consistency of value-based decision making. Results indicated that memory performance in older age is related to value-based decision making and likely contributes to the value construction process. Therefore, an age-related decline in episodic memory could be considered a relevant topic for further research on decision making in older age.

Study 2 was conducted online via web browser. It investigated the possible influence of age-related positivity effect on information search and, consequently, on decision making quality. The possibility of an adverse effect of selective attention on decisions due to the positivity effect has been mentioned in the literature (Carstensen & DeLiema, 2018). However, the link between the positivity effect and decision making quality has not been systematically investigated. Contrary to the registered hypothesis, older adults did not demonstrate a higher positivity bias compared to younger adults. Decision making quality in choice trials was not linked to the positivity bias in information search. Decision quality also did not significantly differ between age groups. Apart from that, the results confirmed the expected link between higher positivity in decision trials and the resulting higher decision satisfaction. Overall, the findings suggest the need for future research to investigate conditions under which the positivity effect influences decision making.

Study 3 was also conducted online, and it tested whether decision making of older adults would benefit from episodic future thinking. Results suggested that episodic future thinking can decrease the rate of delay discounting of older adults in a task with monetary rewards. Still, it did not increase consideration of healthiness of products in a food choice task. Together, the findings suggest a preserved episodic future thinking ability in older adults, as well as a potential utility of episodic future thinking as an intervention to promote future-oriented decision in older age. However, further research is required to investigate factors underlying its effect on food choice.

The next sections overview and summarize combined findings from the studies. Then, several aspects of research on aging and decision making relevant to the studies are highlighted and discussed. After that, I discuss the overall combined results from the three studies, directions for future research, practical implications of the findings and make a general conclusion.

4.2. Cognitive aging and decision making outcomes

One topic addressed by the empirical studies within this work was whether aging is associated with a decrease in decision making quality due to limitations in examined cognitive abilities. The results provided partial support for the hypothesized links between cognitive abilities and lowered quality of decisions made by older adults.

The focus of the first study was on the contribution of episodic memory to value-based choices in older age. The results confirmed the link between memory performance and several relevant characteristics of value-based choice in this sample. Specifically, lower episodic memory was related to a decreased accuracy of choice, measured as consistency with previously stated preferences for food products. In contrast, we did not observe an association between memory scores and performance on a control number comparison task in which participants were required to simply select a larger number. This supported the assumption that differences in decision making were not due to a decrease in the ability to make simple comparisons, but rather likely due to differences in cognitive performance.

Lower memory was also associated with longer decision times, as would be expected if a decline in episodic memory would lead to less efficient retrieval of value-relevant information. In decisions with higher difficulty in which choice options were relatively similar, older adults were more likely to make an error and had longer decision times. This supported hypothesized links between observed errors, reaction times and construction of value during choice. These findings are in line with the framework proposed by Shadlen and Shohamy (2016) suggesting that differences in subjective valuations of food products would act similarly to the strength of evidence considered in the sequential sampling models. Choices between clearly bad and clearly good options are expected to be relatively easy. As a result, they would be quicker and would less likely result in a selection of the less preferable alternative. A choice between products that differ only slightly would require more time to retrieve enough information about options from memory. Decisions between such choices would also be more susceptible to stochastic errors. These findings indicate that a decline in cognitive performance in older age – as demonstrated with episodic memory – can adversely influence processes contributing to value-based decision making.

Episodic future thinking was investigated in the third study as a mechanism for improving consideration of future rewards in decision making of older adults. In everyday life, future thinking is important for planning and decisions about the future (Li et al., 2015; Zaval et al., 2015). A decline in the effectiveness of episodic future thinking could therefore lead to a lower decision quality in relevant choice contexts.

In the current results, groups of older and younger adults demonstrated similar effects of episodic future thinking on decision making, indicating that this cognitive ability remained preserved, unlike in the findings by Sasse et al. (2017). The results suggested that under the examined conditions, older adults were able to engage in episodic future thinking, and that it could provide benefit for their future-oriented decisions if administered in form of an intervention. The lack of significant difference between older and younger adults seems at odds with previous findings that indicated a decline of this function in aging (Addis et al., 2008). This suggests the need to further investigate concrete limitations in episodic future thinking of older adults and whether these limitations are relevant for real-life decision making. It is also possible that a more specific assessment of generated details of imagined future events, such as used by Addis and colleagues (2008), could be more sensitive to age differences in episodic future thinking and thus could more reliably indicate differences in episodic future thinking.

4.3. Positivity effect and decision making

The main focus of the second study in the current dissertation was the potential influence of the positivity effect on decision making in older adults. Previous studies discussed the possibility that a stronger focus on positive information by older adults could have an adverse effect on their decisions, for example, in some situations in which consideration of negative information is important for an optimal choice (Carstensen & DeLiema, 2018; Reed & Carstensen, 2015). The results of this study did not provide support for the positivity effect. Unexpectedly, younger adults on average showed a higher positivity bias measure than older participants. The positivity effect could also be statistically rejected by equivalence testing. A reconciliation of these findings with the previous literature would likely require follow-up research examining conditions necessary for observing the positivity effect.

The results also did not confirm the hypothesized link between the measure of bias towards any specific valence (bias index) and the resulting decision quality. One plausible explanation for this could be an insufficient difference in the positivity bias between the age groups, which was in turn linked to the measure of bias index. The confirmatory analysis established the expected link between higher positivity and decision satisfaction, which reflects a subjective assessment of decision outcomes. In addition to the positivity effect, the study also aimed at testing the evidence for the loss prevention orientation of older adults; however, the findings did not provide support for it.

The results indicate the need to re-examine the positivity effect and the factors that may influence it. A stronger focus on positive information by older adults could make them more likely to ignore negative information related to choice alternatives in favor of positive (Reed & Carstensen, 2015). As one possible real-life outcome, Carstensen and DeLiema (2018) suggested that the positivity effect could increase vulnerability of older adults to fraud. However, the findings appear to suggest that in the studied decision context, older adults are not showing a higher positivity bias compared to younger adults. Additionally, the age groups did not significantly differ with respect to decision quality.

4.4. Combining conclusions from the three studies

The empirical studies in the current dissertation addressed several different aspects of cognitive aging and decision making. The investigated effects that can occur in aging – decline in episodic memory and positivity effect – were expected to adversely affect processes of value construction during decision making and lead to worsened outcomes of value-based decisions. Additionally, the third study tested episodic future thinking in older adults and whether it was less efficient than in younger adults. The first study provided evidence for the hypothesis that decision quality of older adults can decline due to lower episodic memory. However, the second and the third study produced findings that support a more optimistic view of decision making in aging. In the second study, older adults had, on average, a slightly lower decision making quality, but the effect was not significant. Importantly, we did not find evidence for a higher positivity bias and an effect of the bias index on decision quality. Overall, the findings indicate that the positivity effect would likely not lead to decreased decision quality in older age. In the third study older adults were able to engage in episodic future thinking, which positively influenced their intertemporal decisions. This finding suggests that older adults may have a preserved episodic future thinking ability that can be leveraged by prospective behavioral interventions designed to support decision making.

Consistent with past research on cognitive aging and decision making, the three studies within this dissertation provide a complex picture of changes in cognitive abilities and decision making in older age. Findings from the first study aligned with previous research demonstrating inter-individual heterogeneity in a decline of cognitive abilities in older age, specifically episodic memory performance (Nyberg et al., 2012). Likewise, older adults showed heterogeneity in resulting decision making. Overall, results from empirical studies suggested that while efficiency of decision making processes may decline in some decision contexts, it remains preserved in others – older adults searched for positive and negative information similarly to younger adults in the second study and benefited from episodic future thinking in the third study. Combined with results from previous studies indicating compensatory mechanisms in decision making of older adults (Strough, Parker, et al., 2015), this emphasizes the need for future research to account for likely compensatory mechanisms and investigate decision making processes in realistic contexts. For example, an older decision maker engaging in consumer choice in a familiar situation could more likely leverage accumulated experience to achieve better decision making outcomes (Li et al., 2015; Zaval et al., 2015). Additionally, if an intervention is designed to improve specific aspects of decision making, it may need to account for inter-individual differences in decision making.

4.5. Potential limitations

The current dissertation evaluated decision making in groups of older and younger adults by administering decision tasks similar to those used in past research. There are several considerations with respect to the methodological approaches used that can be relevant to the interpretation of findings. One such consideration is the realism of the used decision making tasks. As discussed in the previous section, assessing decision making in real life or in tasks closely resembling it could be important for an accurate evaluation of decision making (Strough, Parker, et al., 2015).

The first study was conducted in the laboratory and represented a choice situation that an aging decision maker could be confronted with, for example, in a supermarket, when choosing among food products. However, the design of the computer-based task and the lab environment do not perfectly represent a typical grocery shopping trip or the process of ordering food in a restaurant. This possible limitation could be addressed in the future research by constructing a more realistic decision task for assessing the relationship between memory and choice.

The second and the third study were conducted online. Decision tasks administered in these studies resembled plausible situations in which a decision maker uses a web browser to make choices with respect to monetary rewards, food products or makes a charitable donation online. Individuals can be confronted with similar decisions in real life, such as online shopping or charitable giving using websites. Assuming an increasing relevance of online shopping (Lim et al., 2015), the studies within the current dissertation could therefore be broadly representative of a growing sphere of consumer behaviors relevant to older and younger adults.

Another potential limitation is that, like many previous studies on aging and decision making, current studies assessed decisions of older adults at one timepoint and did not collect longitudinal data. Evaluating performance at baseline and at one or more follow-ups similar to longitudinal studies on cognitive functions (for example, Wilson et al., 2002) could provide stronger evidence for a gradual change in decision making of older adults. It could also offer an estimate of the rate of change. Alternatively, it would also eliminate such a longitudinal change for aspects of decision making that remain stable. An assessment of decision making paired with cognitive evaluations within a longitudinal cohort study is a promising topic for further research. However, it is complicated by the need to collect the data over a long period of time and also by the need to design decision tasks with no or minimal training effect.

4.6. Potential directions for future research

Presented studies offer several directions for the research on decision making in aging as well as on value-based decision making in general. The findings highlighted the contribution of episodic memory to value-based decisions in older age. One future direction with respect to this research is a more nuanced approach that would allow to link learning and forgetting of option values to quality of choices. This would also address the contribution of episodic memory function to learning from feedback during decision making. Further research could also clarify the practical consequences for decision making in episodic memory decline – both in healthy older adults as well as in older adults with a subjective cognitive decline or a mild cognitive impairment.

The lack of observed positivity effect highlighted the need to further address conditions under which it can occur, and which factors decrease the age difference in positivity bias. Findings demonstrate that, while older and younger adults could likely share similarities with respect to positivity bias, both age groups could likely be attentive to information highlighting positive nutritional characteristics of healthy food products. However, this assumption would benefit from testing in more realistic environments such as a virtual reality supermarket (Waterlander et al., 2011) or by using wearable eye-tracking during food choice in a more familiar setting.

The relationship between the bias towards any valence and the decision quality was not established. Research may address this relationship under conditions that promote a stronger heterogeneity within the study samples with respect to bias towards a specific valence. Findings indicated the effect of positivity bias on decision satisfaction. A related prospective research topic could investigate whether systematically biased subjective assessments of decisions could influence learning from choice outcomes and impact future choices.

The findings from the third study demonstrate that episodic future thinking can decrease the rate of delay discounting of older adults. However, episodic future thinking did not raise the likelihood of selecting healthier products. Future research can further investigate the role of episodic future thinking in different contexts, including adherence to healthy nutrition and other health-related behaviors.

4.7. Implications for applied spheres

The studies within the current dissertation addressed scientific questions related to specific effects that may influence the processes of value-based decision making. Apart from a contribution to research on aging and decision making, current studies could also be informative for more applied spheres.

Previous literature on decision making has considered benefits of designing consumer information in a way that increases saliency of important attributes. Enax et al. (2016) showed an increase in attention of younger adults to nutritional characteristics of food products in decisions where products were labeled with salient nutrition information. The results of first study within this dissertation indicated that an age-related decrease of episodic memory performance could lead to a higher likelihood of stochastic errors in food choice. Consumer information constructed in a way that emphasizes key attributes of options, such as nutritional information, could make it easier for older adults to compare properties of various choice options and thus compensate for the decrease in choice accuracy.

A different area that could be informed by the current findings is a design of a potential intervention aimed at supporting adherence of older adults to a healthy lifestyle, for example by promoting exercise or healthy eating. These health-related behaviors with long-term consequences could benefit from a remotely administered self-guided paradigm for promoting episodic future thinking.

5. Summary

The current dissertation aimed to investigate the relationship between cognitive functions in older age and decision making processes. Building upon previous research, the studies carried out for this dissertation addressed several mechanisms with which age-related changes in cognitive performance could influence value-based decision making in older adults. The findings supported some hypothesized effects, such as the link between episodic memory performance and accuracy of value-based decisions. However, the results did not support hypotheses that predicted worsened decision making in older adults due to positivity effect or decreased efficiency of future episodic thinking. Taking this into account, the findings are broadly consistent with the overall picture of cognitive aging presented in the literature that shows decreases in decision quality in some contexts and maintenance or compensation in others. The current work can inform future research on decision making in older age, as well as research on value-based decision making in general. Additionally, the results can have implications for more practical spheres related to supporting optimal decision making of older adults.

6. Bibliography

Addis, D. R., Wong, A. T., & Schacter, D. L. (2008). Age-related changes in the episodic simulation of future events. Psychological Science, 19(1), 33–41. https://doi.org/10.1111/j.1467-9280.2008.02043.x

Agarwal, S., Driscoll, J. C., Gabaix, X., & Laibson, D. (2009). The Age of Reason: Financial Decisions over the Life Cycle and Implications for Regulation. Brookings Papers on Economic Activity, 2009(2), 51–117. https://doi.org/10.1353/eca.0.0067

Baltes, P. B., Staudinger, U. M., & Lindenberger, U. (1999). LIFESPAN PSYCHOLOGY: Theory and Application to Intellectual Functioning. Annual Review of Psychology, 50(1), 471–507. https://doi.org/10.1146/annurev.psych.50.1.471

Barber, S. J., Opitz, P. C., Martins, B., Sakaki, M., & Mather, M. (2016). Thinking about a limited future enhances the positivity of younger and older adults' recall: Support for socioemotional selectivity theory. Memory & Cognition, 44(6), 869–882. https://doi.org/10.3758/s13421-016-0612-0

Barron, H. C., Dolan, R. J., & Behrens, T. E. J. (2013). Online evaluation of novel choices by simultaneous representation of multiple memories. Nature Neuroscience, 16(10), 1492–1498. https://doi.org/10.1038/nn.3515

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 51. https://doi.org/10.18637/jss.v067.i01

Baumgart, M., Snyder, H. M., Carrillo, M. C., Fazio, S., Kim, H., & Johns, H. (2015). Summary of the evidence on modifiable risk factors for cognitive decline and dementia: A population-based perspective. Alzheimer's & Dementia, 11(6), 718–726. https://doi.org/10.1016/j.jalz.2015.05.016

Becker, N., Laukka, E. J., Kalpouzos, G., Naveh-Benjamin, M., Bäckman, L., & Brehmer, Y. (2015). Structural brain correlates of associative memory in older adults. NeuroImage, 118, 146–153. https://doi.org/10.1016/j.neuroimage.2015.06.002

Berkman, E. T. (2018). Value-based choice: An integrative, neuroscience-informed model of health goals. Psychology & Health, 33(1), 40–57. https://doi.org/10.1080/08870446.2017.1316847

Bickel, W. K., Mackillop, J., Madden, G. J., Odum, A. L., & Yi, R. (2015). Experimental manipulations of delay discounting & related processes: An introduction to the special issue. Journal of the Experimental Analysis of Behavior, 103(1), 1–9. https://doi.org/10.1002/jeab.133

Bjälkebring, P., Västfjäll, D., Dickert, S., & Slovic, P. (2016). Greater Emotional Gain from Giving in Older Adults: Age-Related Positivity Bias in Charitable Giving. Frontiers in Psychology, 7(JUN), 1–8. https://doi.org/10.3389/fpsyg.2016.00846

Blanchard-Fields, F., Mienaltowski, A., & Seay, R. B. (2007). Age differences in everyday problem-solving effectiveness: older adults select more effective strategies for interpersonal problems. The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 62(1), P61-64. https://doi.org/10.1093/geronb/62.1.P61

Blechert, J., Meule, A., Busch, N. A., & Ohla, K. (2014). Food-pics: an image database for experimental research on eating and appetite. Frontiers in Psychology, 5(JUN), 1–10. https://doi.org/10.3389/fpsyg.2014.00617

Bornstein, A. M., & Daw, N. D. (2013). Cortical and Hippocampal Correlates of Deliberation during Model-Based Decisions for Rewards in Humans. PLoS Computational Biology, 9(12), e1003387. https://doi.org/10.1371/journal.pcbi.1003387

Bouazzaoui, B., Fay, S., Taconnat, L., Angel, L., Vanneste, S., & Isingrini, M. (2013). Differential involvement of knowledge representation and executive control in episodic memory performance in young and older adults. Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale, 67(2), 100–107. https://doi.org/10.1037/a0028517

Bowie, C. R., & Harvey, P. D. (2006). Administration and interpretation of the Trail Making Test. Nature Protocols, 1(5), 2277–2281. https://doi.org/10.1038/nprot.2006.390

Brink, T. L., Yesavage, J. A., Lum, O., Heersema, P. H., Adey, M., & Rose, T. L. (1982). Screening Tests for Geriatric Depression. Clinical Gerontologist, 1(1), 37–43. https://doi.org/10.1300/J018v01n01_06

Brosch, T., & Sander, D. (2013). Neurocognitive mechanisms underlying value-based decision-making: from core values to economic value. Frontiers in Human Neuroscience, 7(July), 398. https://doi.org/10.3389/fnhum.2013.00398

Brown, S. B. R. E., & Ridderinkhof, K. R. (2009). Aging and the neuroeconomics of decision making: A review. Cognitive, Affective, & Behavioral Neuroscience, 9(4), 365–379. https://doi.org/10.3758/CABN.9.4.365

Brown, T. C., & Peterson, G. L. (2009). An Enquiry into the Method of Paired Comparison: Reliability, Scaling, and Thurstone's Law of Comparative Judgment. Technical Report, January, 1–104. papers3://publication/uuid/ECF401D9-8AD7-41BB-98E0-D35860AE2A42

Bruine de Bruin, W., Parker, A. M., & Fischhoff, B. (2012). Explaining adult age differences in decision-making competence. Journal of Behavioral Decision Making, 25(4), 352–360. https://doi.org/10.1002/bdm.712

Budaev, S., Jørgensen, C., Mangel, M., Eliassen, S., & Giske, J. (2019). Decision-Making From the Animal Perspective: Bridging Ecology and Subjective Cognition. Frontiers in Ecology and Evolution, 7(May), 1–14. https://doi.org/10.3389/fevo.2019.00164

Buttkus, C., & Schäffler, S. (2014). Wirkungstransparenz bei Spendenorganisationen. Retrieved from https://www.phineo.org/downloads/PHINEO_Studie_Wirkungstransparenz_2014.pdf

Cabeza, R., Albert, M., Belleville, S., Craik, F. I. M., Duarte, A., Grady, C. L., … Rajah, M. N. (2018). Maintenance, reserve and compensation: the cognitive neuroscience of healthy ageing. Nature Reviews Neuroscience, 19(11), 701–710. https://doi.org/10.1038/s41583-018-0068-2

Camille, N., Griffiths, C. A., Vo, K., Fellows, L. K., & Kable, J. W. (2011). Ventromedial Frontal Lobe Damage Disrupts Value Maximization in Humans. Journal of Neuroscience, 31(20), 7527–7532. https://doi.org/10.1523/JNEUROSCI.6527-10.2011

Carpenter, S. M., & Yoon, C. (2011). Aging and consumer decision making. Annals of the New York Academy of Sciences, 1235(1), E1–E12. https://doi.org/10.1111/j.1749-6632.2011.06390.x

Carpenter, S. M., & Yoon, C. (2015). Aging and Consumer Decision Making. In Aging and Decision Making (pp. 351–370). Elsevier. https://doi.org/10.1016/B978-0-12-417148-0.00017-0

Carstensen, L. L. (2006). The Influence of a Sense of Time on Human Development. Science, 312(5782), 1913–1915. https://doi.org/10.1126/science.1127488

Carstensen, L. L., & DeLiema, M. (2018). The positivity effect: a negativity bias in youth fades with age. Current Opinion in Behavioral Sciences, 19, 7–12. https://doi.org/10.1016/j.cobeha.2017.07.009

Carstensen, L. L., & Mikels, J. A. (2005). At the Intersection of Emotion and Cognition. Current Directions in Psychological Science, 14(3), 117–121. https://doi.org/10.1111/j.0963-7214.2005.00348.x

Castellano, C.-A., Hudon, C., Croteau, E., Fortier, M., St-Pierre, V., Vandenberghe, C., Nugent, S., Tremblay, S., Paquet, N., Lepage, M., Fülöp, T., Turcotte, É. E., Dionne, I. J., Potvin, O., Duchesne, S., & Cunnane, S. C. (2019). Links Between Metabolic and Structural Changes in the Brain of Cognitively Normal Older Adults: A 4-Year Longitudinal Follow-Up. Frontiers in Aging Neuroscience, 11(JAN), 1–11. https://doi.org/10.3389/fnagi.2019.00015

Charles, S. T., & Carstensen, L. L. (2010). Social and emotional aging. Annual Review of Psychology, 61, 383–409. https://doi.org/10.1146/annurev.psych.093008.100448

Charlton, R. A., Barrick, T. R., Markus, H. S., & Morris, R. G. (2010). The relationship between episodic long-term memory and white matter integrity in normal aging. Neuropsychologia, 48(1), 114–122. https://doi.org/10.1016/j.neuropsychologia.2009.08.018

Colsher, P. L., & Wallace, R. B. (1991). Longitudinal application of cognitive function measures in a defined population of community-dwelling elders. Annals of Epidemiology, 1(3), 215–230. https://doi.org/10.1016/1047-2797(91)90001-S

Curran, P. G. (2016). Methods for the detection of carelessly invalid responses in survey data. Journal of Experimental Social Psychology, 66, 4–19. https://doi.org/10.1016/j.jesp.2015.07.006

D’Argembeau, A., & Van der Linden, M. (2004). Phenomenal characteristics associated with projecting oneself back into the past and forward into the future: Influence of valence and temporal distance. Consciousness and Cognition, 13(4), 844–858. https://doi.org/10.1016/j.concog.2004.07.007

Daniel, T. O., Stanton, C. M., & Epstein, L. H. (2013). The future is now: Comparing the effect of episodic future thinking on impulsivity in lean and obese individuals. Appetite, 71, 120–125. https://doi.org/10.1016/j.appet.2013.07.010

de Leeuw, J. R. (2015). jsPsych: a JavaScript library for creating behavioral experiments in a Web browser. Behavior Research Methods, 47(1), 1–12. https://doi.org/10.3758/s13428-014-0458-y

De Wit, A., & Bekkers, R. (2017). Government support and charitable donations: A meta-analysis of the crowding-out hypothesis. Journal of Public Administration Research and Theory, 27(2), 301–319. https://doi.org/10.1093/jopart/muw044

Del Missier, F., Mäntylä, T., & Bruin, W. B. (2012). Decision-making Competence, Executive Functioning, and General Cognitive Abilities. Journal of Behavioral Decision Making, 25(4), 331–351. https://doi.org/10.1002/bdm.731

Del Missier, F., Mäntylä, T., Hansson, P., Bruine de Bruin, W., Parker, A. M., & Nilsson, L.-G. (2013). The multifold relationship between memory and decision making: An individual-differences study. Journal of Experimental Psychology: Learning, Memory, and Cognition, 39(5), 1344–1364. https://doi.org/10.1037/a0032379

Del Missier, F., Mäntylä, T., & Nilsson, L.-G. (2015). Aging, Memory, and Decision Making. In Aging and Decision Making (Vol. 1235, pp. 127–148). Elsevier. https://doi.org/10.1016/B978-0-12-417148-0.00007-8

Demos, K. E., Kelley, W. M., & Heatherton, T. F. (2011). Dietary restraint violations influence reward responses in nucleus accumbens and amygdala. Journal of Cognitive Neuroscience, 23(8), 1952–1963. https://doi.org/10.1162/jocn.2010.21568

Denburg, N. L., & Hedgcock, W. M. (2015). Age-Associated Executive Dysfunction, the Prefrontal Cortex, and Complex Decision Making. In Aging and Decision Making (pp. 79–101). Elsevier. https://doi.org/10.1016/B978-0-12-417148-0.00005-4

Depping, M. K., & Freund, A. M. (2013). When choice matters: Task-dependent memory effects in older adulthood. Psychology and Aging, 28(4), 923–936. https://doi.org/10.1037/a0034520

Depping, M. K., & Freund, A. M. (2011). Normal Aging and Decision Making: The Role of Motivation. Human Development, 54(6), 349–367. https://doi.org/10.1159/000334396

Doll, B. B., Shohamy, D., & Daw, N. D. (2015). Multiple memory systems as substrates for multiple decision systems. Neurobiology of Learning and Memory, 117, 4–13. https://doi.org/10.1016/j.nlm.2014.04.014

Doya, K. (2008). Modulators of decision making. Nature Neuroscience, 11(4), 410–416. https://doi.org/10.1038/nn2077

Drolet, A., Jiang, L., Pour Mohammad, A., & Davis, C. (2018). The influence of aging on consumer decision-making. Consumer Psychology Review, (October 2018), arcp.1046. https://doi.org/10.1002/arcp.1046

Dutilh, G., & Rieskamp, J. (2016). Comparing perceptual and preferential decision making. Psychonomic Bulletin & Review, 23(3), 723–737. https://doi.org/10.3758/s13423-015-0941-1

Eberhardt, W., Bruine de Bruin, W., & Strough, J. (2019). Age differences in financial decision making: The benefits of more experience and less negative emotions. Journal of Behavioral Decision Making, 32(1), 79–93. https://doi.org/10.1002/bdm.2097

Ebner, N. C., Freund, A. M., & Baltes, P. B. (2006). Developmental changes in personal goal orientation from young to late adulthood: From striving for gains to maintenance and prevention of losses. Psychology and Aging, 21(4), 664–678. https://doi.org/10.1037/0882-7974.21.4.664

Ehrensperger, M. M., Berres, M., Taylor, K. I., & Monsch, A. U. (2010). Screening properties of the German IQCODE with a two-year time frame in MCI and early Alzheimer's disease. International Psychogeriatrics, 22(1), 91–100. https://doi.org/10.1017/S1041610209990962

Ehrensperger, M. M., & Monsch, A. U. (2016). A Validation Study of the Very Short German 7-Item Iqcode [Poster presentation]. Alzheimer's & Dementia, 12(7), P745. https://doi.org/10.1016/j.jalz.2016.06.1555

Ely, A. V., Winter, S., & Lowe, M. R. (2013). The generation and inhibition of hedonically-driven food intake: Behavioral and neurophysiological determinants in healthy weight individuals. Physiology and Behavior, 121(September 2015), 25–34. https://doi.org/10.1016/j.physbeh.2013.03.026

Enax, L., Krajbich, I., & Weber, B. (2016). Salient nutrition labels increase the integration of health attributes in food decision-making. Judgment and Decision Making, 11(5), 460–471. https://doi.org/10.1017/CBO9781107415324.004

Enax, L., & Weber, B. (2015). Marketing Placebo Effects – From Behavioral Effects to Behavior Change? Journal of Agricultural & Food Industrial Organization, 13(1), 15–31. https://doi.org/10.1515/jafio-2015-0015

English, T., & Carstensen, L. L. (2015). Does positivity operate when the stakes are high? Health status and decision making among older adults. Psychology and Aging, 30(2), 348–355. https://doi.org/10.1037/a0039121

Enkavi, A. Z., Weber, B., Zweyer, I., Wagner, J., Elger, C. E., Weber, E. U., & Johnson, E. J. (2017). Evidence for hippocampal dependence of value-based decisions. Scientific Reports, 7(1), 17738. https://doi.org/10.1038/s41598-017-18015-4

Eppinger, B., Walter, M., Heekeren, H. R., & Li, S.-C. (2013). Of goals and habits: age-related and individual differences in goal-directed decision-making. Frontiers in Neuroscience, 7(December), 1–14. https://doi.org/10.3389/fnins.2013.00253

Eramudugolla, R., Cherbuin, N., Easteal, S., Jorm, A. F., & Anstey, K. J. (2013). Self-reported cognitive decline on the informant questionnaire on cognitive decline in the elderly is associated with dementia, instrumental activities of daily living and depression but not longitudinal cognitive change. Dementia and Geriatric Cognitive Disorders, 34(5–6), 282–291. https://doi.org/10.1159/000345439

European Commission. (2018). The 2018 Ageing Report: economic and budgetary projections for the EU Member States (2016-2070). European Economy (Vol. 2). https://doi.org/10.2765/615631

Fagerlin, A., Zikmund-Fisher, B. J., Ubel, P. A., Jankovic, A., Derry, H. A., & Smith, D. M. (2007). Measuring Numeracy without a Math Test: Development of the Subjective Numeracy Scale. Medical Decision Making, 27(5), 672–680. https://doi.org/10.1177/0272989X07304449

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods, 39(2), 175–191. https://doi.org/10.3758/BF03193146

Fehr, E., & Rangel, A. (2011). Neuroeconomic Foundations of Economic Choice—Recent Advances. Journal of Economic Perspectives, 25(4), 3–30. https://doi.org/10.1257/jep.25.4.3

Fellows, L. K., & Farah, M. J. (2007). The Role of Ventromedial Prefrontal Cortex in Decision Making: Judgment under Uncertainty or Judgment Per Se? Cerebral Cortex, 17(11), 2669–2674. https://doi.org/10.1093/cercor/bhl176

Finucane, M. L., & Gullion, C. M. (2010). Developing a tool for measuring the decision-making competence of older adults. Psychology and Aging, 25(2), 271–288. https://doi.org/10.1037/a0019106

Fjell, A. M., Sneve, M. H., Grydeland, H., Storsve, A. B., & Walhovd, K. B. (2016). The Disconnected Brain and Executive Function Decline in Aging. Cerebral Cortex, 27(3), bhw082. https://doi.org/10.1093/cercor/bhw082

Fjell, A. M., & Walhovd, K. B. (2010). Structural Brain Changes in Aging: Courses, Causes and Cognitive Consequences. Reviews in the Neurosciences, 21(3), 187–221. https://doi.org/10.1515/REVNEURO.2010.21.3.187

Foerde, K., Race, E., Verfaellie, M., & Shohamy, D. (2013). A Role for the Medial Temporal Lobe in Feedback-Driven Learning: Evidence from Amnesia. Journal of Neuroscience, 33(13), 5698–5704. https://doi.org/10.1523/JNEUROSCI.5217-12.2013

Garcia-Retamero, R., & Galesic, M. (2013). Transparent Communication of Health Risks. (R. Garcia-Retamero & M. Galesic, Eds.). New York, NY: Springer New York. https://doi.org/10.1007/978-1-4614-4358-2

Gerstorf, D., Ram, N., Hoppmann, C., Willis, S. L., & Schaie, K. W. (2011). Cohort differences in cognitive aging and terminal decline in the Seattle Longitudinal Study. Developmental Psychology, 47(4), 1026–1041. https://doi.org/10.1037/a0023426

Glöckner, A., & Betsch, T. (2008). Multiple-Reason Decision Making Based on Automatic Processing. Journal of Experimental Psychology: Learning Memory and Cognition, 34(5), 1055–1075. https://doi.org/10.1037/0278-7393.34.5.1055

Gluth, S., Sommer, T., Rieskamp, J., & Büchel, C. (2015). Effective Connectivity between Hippocampus and Ventromedial Prefrontal Cortex Controls Preferential Choices from Memory. Neuron, 86(4), 1078–1090. https://doi.org/10.1016/j.neuron.2015.04.023

Göllner, L. M., Ballhausen, N., Kliegel, M., & Forstmeier, S. (2018). Delay of Gratification, Delay Discounting and their Associations with Age, Episodic Future Thinking, and Future Time Perspective. Frontiers in Psychology, 8(JAN), 1–15. https://doi.org/10.3389/fpsyg.2017.02304

Gopinath, B., Russell, J., Kifley, A., Flood, V. M., & Mitchell, P. (2016). Adherence to Dietary Guidelines and Successful Aging Over 10 Years. Journals of Gerontology - Series A Biological Sciences and Medical Sciences, 71(3), 349–355. https://doi.org/10.1093/gerona/glv189

Gupta, R., Duff, M. C., Denburg, N. L., Cohen, N. J., Bechara, A., & Tranel, D. (2009). Declarative memory is critical for sustained advantageous complex decision-making. Neuropsychologia, 47(7), 1686–1693. https://doi.org/10.1016/j.neuropsychologia.2009.02.007

Hanoch, Y., Wood, S., Barnes, A., Liu, P.-J., & Rice, T. (2011). Choosing the right medicare prescription drug plan: The effect of age, strategy selection, and choice set size. Health Psychology, 30(6), 719–727. https://doi.org/10.1037/a0023951

Hare, T. A., Malmaud, J., & Rangel, A. (2011). Focusing Attention on the Health Aspects of Foods Changes Value Signals in vmPFC and Improves Dietary Choice. Journal of Neuroscience, 31(30), 11077–11087. https://doi.org/10.1523/JNEUROSCI.6383-10.2011

Hare, T. A., Camerer, C. F., & Rangel, A. (2009). Self-Control in Decision-Making Involves Modulation of the vmPFC Valuation System. Science, 324(5927), 646–648. https://doi.org/10.1126/science.1168450

Herlitz, A., Nilsson, L.-G., & Bäckman, L. (1997). Gender differences in episodic memory. Memory & Cognition, 25(6), 801–811. https://doi.org/10.3758/BF03211324

Herlitz, A., & Rehnman, J. (2008). Sex Differences in Episodic Memory. Current Directions in Psychological Science, 17(1), 52–56. https://doi.org/10.1111/j.1467-8721.2008.00547.x

Hershey, D. A., Austin, J. T., & Gutierrez, H. C. (2015). Financial Decision Making across the Adult Life Span. In Aging and Decision Making (pp. 329–349). Elsevier. https://doi.org/10.1016/B978-0-12-417148-0.00016-9

Hollis-Hansen, K., Seidman, J., O'Donnell, S., & Epstein, L. H. (2019). Episodic future thinking and grocery shopping online. Appetite, 133(October 2018), 1–9. https://doi.org/10.1016/j.appet.2018.10.019

Holst, Y., & Thorell, L. B. (2017). Neuropsychological Functioning in Adults With ADHD and Adults With Other Psychiatric Disorders. Journal of Attention Disorders, 21(2), 137–148. https://doi.org/10.1177/1087054713506264

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. Acta Psychologica, 26, 107–129. https://doi.org/10.1016/0001-6918(67)90011-X

Hu, X., Uhle, F., Fliessbach, K., Wagner, M., Han, Y., Weber, B., & Jessen, F. (2017). Reduced future-oriented decision making in individuals with subjective cognitive decline: A functional MRI study. Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring, 6(1), 222–231. https://doi.org/10.1016/j.dadm.2017.02.005

Huettel, S. A. (2010). Ten challenges for decision neuroscience. Frontiers in Neuroscience, 4(SEP), 1–7. https://doi.org/10.3389/fnins.2010.00171

Jankovic, N., Geelen, A., Streppel, M. T., de Groot, L. C. P. G. M., Orfanos, P., van den Hooven, E. H., … Feskens, E. J. (2014). Adherence to a Healthy Diet According to the World Health Organization Guidelines and All-Cause Mortality in Elderly Adults From Europe and the United States. American Journal of Epidemiology, 180(10), 978–988. https://doi.org/10.1093/aje/kwu229

Jansen, A. P. D., Van Hout, H. P. J., Nijpels, G., Van Marwijk, H. W. J., Gundy, C., De Vet, H. C. W., & Stalman, W. A. B. (2008). Self-reports on the IQCODE in older adults: A psychometric evaluation. Journal of Geriatric Psychiatry and Neurology, 21(2), 83–92. https://doi.org/10.1177/0891988707311558

Johnson, E. J., Häubl, G., & Keinan, A. (2007). Aspects of endowment: A query theory of value construction. Journal of Experimental Psychology: Learning, Memory, and Cognition, 33(3), 461–474. https://doi.org/10.1037/0278-7393.33.3.461

Johnson, E. J., & Ratcliff, R. (2014). Computational and Process Models of Decision Making in Psychology and Behavioral Economics. Neuroeconomics: Decision Making and the Brain, 358–365. https://doi.org/10.1016/B978-0-12-416008-8.00032-2

Kable, J. W., & Glimcher, P. W. (2007). The neural correlates of subjective value during intertemporal choice. Nature Neuroscience, 10(12), 1625–1633. https://doi.org/10.1038/nn2007

Kahana, E., Kelley-Moore, J., & Kahana, B. (2012). Proactive aging: A longitudinal study of stress, resources, agency, and well-being in late life. Aging & Mental Health, 16(4), 438–451. https://doi.org/10.1080/13607863.2011.644519

Kalenscher, T. (2014). Decision-Making and Neuroeconomics. In eLS (pp. 323–328). John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470015902.a0021397.pub2

Kim, S., Healey, M. K., Goldstein, D., Hasher, L., & Wiprzycka, U. J. (2008). Age differences in choice satisfaction: A positivity effect in decision making. Psychology and Aging, 23(1), 33–38. https://doi.org/10.1037/0882-7974.23.1.33

King, D. E., Mainous, A. G., & Geesey, M. E. (2007). Turning Back the Clock: Adopting a Healthy Lifestyle in Middle Age. The American Journal of Medicine, 120(7), 598–603. https://doi.org/10.1016/j.amjmed.2006.09.020

Koffarnus, M. N., & Bickel, W. K. (2014). A 5-trial adjusting delay discounting task: Accurate discount rates in less than one minute. Experimental and Clinical Psychopharmacology, 22(3), 222–228. https://doi.org/10.1037/a0035973

Koffarnus, M. N., Jarmolowicz, D. P., Mueller, E. T., & Bickel, W. K. (2013). Changing delay discounting in the light of the competing neurobehavioral decision systems theory: A review. Journal of the Experimental Analysis of Behavior, 99(1), 32–57. https://doi.org/10.1002/jeab.2

Krajbich, I., Armel, C., & Rangel, A. (2010). Visual fixations and the computation and comparison of value in simple choice. Nature Neuroscience, 13(10), 1292–1298. https://doi.org/10.1038/nn.2635

Krajbich, I., Lu, D., Camerer, C., & Rangel, A. (2012). The Attentional Drift-Diffusion Model Extends to Simple Purchasing Decisions. Frontiers in Psychology, 3(June). https://doi.org/10.3389/fpsyg.2012.00193

Krajbich, I., & Smith, S. M. (2015). Modeling Eye Movements and Response Times in Consumer Choice. Journal of Agricultural & Food Industrial Organization, 13(1), 55–72. https://doi.org/10.1515/jafio-2015-0016

Kramer, J. H., Yaffe, K., Lengenfelder, J., & Delis, D. C. (2003). Age and gender interactions on verbal memory performance. Journal of the International Neuropsychological Society, 9(01), 97–102. https://doi.org/10.1017/S1355617703910113

Kühner, C., Bürger, C., Keller, F., & Hautzinger, M. (2007). Reliabilität und Validität des revidierten Beck-Depressionsinventars (BDI-II). Der Nervenarzt, 78(6), 651–656. https://doi.org/10.1007/s00115-006-2098-7

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest Package: Tests in Linear Mixed Effects Models. Journal of Statistical Software, 82(13). https://doi.org/10.18637/jss.v082.i13

Lakens, D. (2017). Equivalence Tests: A Practical Primer for t Tests, Correlations, and Meta-Analyses. Social Psychological and Personality Science, 8(4), 355–362. https://doi.org/10.1177/1948550617697177

Lapp, L. K., & Spaniol, J. (2017). Impact of age-relevant goals on future thinking in younger and older adults. Memory, 25(9), 1246–1259. https://doi.org/10.1080/09658211.2017.1284240

Lee, L., Amir, O., & Ariely, D. (2009). In Search of Homo Economicus: Cognitive Noise and the Role of Emotion in Preference Consistency. Journal of Consumer Research, 36(2), 173–187. https://doi.org/10.1086/597160

Li, S.-C., Lindenberger, U., Hommel, B., Aschersleben, G., Prinz, W., & Baltes, P. B. (2004). Transformations in the couplings among intellectual cognitive processes across the life span. Psychological Science, 15, 155–163. https://doi.org/10.1111/j.0956-7976.2004.01503003.x

Li, Y., Gao, J., Enkavi, a Z., Zaval, L., Weber, E. U., & Johnson, E. J. (2015). Sound credit scores and financial decisions despite cognitive aging. Proceedings of the National Academy of Sciences, 112(1), 65–69. https://doi.org/10.1073/pnas.1413570112

Lighthall, N. R., Huettel, S. A., & Cabeza, R. (2014). Functional Compensation in the Ventromedial Prefrontal Cortex Improves Memory-Dependent Decisions in Older Adults. Journal of Neuroscience, 34(47), 15648–15657. https://doi.org/10.1523/JNEUROSCI.2888-14.2014

Lim, Y. Y., Ellis, K. A., Harrington, K. D., Ames, D., Martins, R. N., Masters, C. L., … Maruff, P. (2012). Use of the CogState Brief Battery in the assessment of Alzheimer's disease related cognitive impairment in the Australian Imaging, Biomarkers and Lifestyle (AIBL) study. Journal of Clinical and Experimental Neuropsychology, 34(4), 345–358. https://doi.org/10.1080/13803395.2011.643227

Lim, Y. Y., Pietrzak, R. H., Snyder, P. J., Darby, D., & Maruff, P. (2012). Preliminary Data on the Effect of Culture on the Assessment of Alzheimer's Disease-Related Verbal Memory Impairment with the International Shopping List Test. Archives of Clinical Neuropsychology, 27(2), 136–147. https://doi.org/10.1093/arclin/acr102

Lim, Y. Y., Prang, K. H., Cysique, L., Pietrzak, R. H., Snyder, P. J., & Maruff, P. (2009). A method for cross-cultural adaptation of a verbal memory assessment. Behavior Research Methods, 41(4), 1190–1200. https://doi.org/10.3758/BRM.41.4.1190

Lim, Y. J., Osman, A., Salahuddin, S. N., Romle, A. R., & Abdullah, S. (2016). Factors Influencing Online Shopping Behavior: The Mediating Role of Purchase Intention. Procedia Economics and Finance, 35(October 2015), 401–410. https://doi.org/10.1016/s2212-5671(16)00050-2

Löckenhoff, C. E., & Carstensen, L. L. (2008). Decision strategies in health care choices for self and others: older but not younger adults make adjustments for the age of the decision target. The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 63(2), P106–P109. https://doi.org/10.1111/j.1743-6109.2009.01601.x

Löckenhoff, C. E., & Carstensen, L. L. (2004). Socioemotional Selectivity Theory, Aging, and Health: The Increasingly Delicate Balance Between Regulating Emotions and Making Tough Choices. Journal of Personality, 72(6), 1395–1424. https://doi.org/10.1111/j.1467-6494.2004.00301.x

Löckenhoff, C. E., O'Donoghue, T., & Dunning, D. (2011). Age differences in temporal discounting: The role of dispositional affect and anticipated emotions. Psychology and Aging, 26(2), 274–284. https://doi.org/10.1037/a0023280

Löckenhoff, C. E., & Carstensen, L. L. (2007). Aging, emotion, and health-related decision strategies: motivational manipulations can reduce age differences. Psychology and Aging, 22(1), 134–146. https://doi.org/10.1037/0882-7974.22.1.134

Lockhart, S. N., Mayda, A. B. V., Roach, A. E., Fletcher, E., Carmichael, O., Maillard, P., Schwarz, C. G., Yonelinas, A. P., Ranganath, C., & DeCarli, C. (2012). Episodic memory function is associated with multiple measures of white matter integrity in cognitive aging. Frontiers in Human Neuroscience, 6(March), 1–12. https://doi.org/10.3389/fnhum.2012.00056

Maruff, P., Lim, Y. Y., Darby, D., Ellis, K. A., Pietrzak, R. H., Snyder, P. J., … Masters, C. L. (2013). Clinical utility of the cogstate brief battery in identifying cognitive impairment in mild cognitive impairment and Alzheimer’s disease. BMC Psychology, 1(1), 30. https://doi.org/10.1186/2050-7283-1-30

Matsumoto, Y., Yamagishi, T., Li, Y., & Kiyonari, T. (2016). Prosocial Behavior Increases with Age across Five Economic Games. PLOS ONE, 11(7), e0158671. https://doi.org/10.1371/journal.pone.0158671

Mattson, M. P., & Arumugam, T. V. (2018). Hallmarks of Brain Aging: Adaptive and Pathological Modification by Metabolic States. Cell Metabolism, 27(6), 1176–1199. https://doi.org/10.1016/j.cmet.2018.05.011

Mikels, J. A., Shuster, M. M., & Thai, S. T. (2015). Aging, Emotion, and Decision Making. In Aging and Decision Making (pp. 169–188). Elsevier. https://doi.org/10.1016/B978-0-12-417148-0.00009-1

Milosavljevic, M., Malmaud, J., Huth, A., Koch, C., & Rangel, A. (2010). The Drift Diffusion Model Can Account for the Accuracy and Reaction Ti1me of Value-Based Choices Under High and Low Time Pressure. SSRN Electronic Journal, 5(6), 437–449. https://doi.org/10.2139/ssrn.1901533

Morrow, D., & Chin, J. (2015). Decision Making and Health Literacy among Older Adults. In Aging and Decision Making (pp. 261–282). Elsevier. https://doi.org/10.1016/B978-0-12-417148-0.00013-3

Myerson, J., Green, L., & Warusawitharana, M. (2001). AREA UNDER THE CURVE AS A MEASURE OF DISCOUNTING. Journal of the Experimental Analysis of Behavior, 76(2), 235–243. https://doi.org/10.1901/jeab.2001.76-235

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., … Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. Journal of the American Geriatrics Society, 53(4), 695–699. https://doi.org/10.1111/j.1532-5415.2005.53221.x

Nyberg, L., Lövdén, M., Riklund, K., Lindenberger, U., & Bäckman, L. (2012). Memory aging and brain maintenance. Trends in Cognitive Sciences, 16(5), 292–305. https://doi.org/10.1016/j.tics.2012.04.005

O'Neill, J., Daniel, T. O., & Epstein, L. H. (2016). Episodic future thinking reduces eating in a food court. Eating Behaviors, 20, 9–13. https://doi.org/10.1016/j.eatbeh.2015.10.002

Orquin, J. L., & Mueller Loose, S. (2013). Attention and choice: A review on eye movements in decision making. Acta Psychologica, 144(1), 190–206. https://doi.org/10.1016/j.actpsy.2013.06.003

Oud, B., Krajbich, I., Miller, K., Cheong, J. H., Botvinick, M., & Fehr, E. (2016). Irrational time allocation in decision-making. Proceedings of the Royal Society B: Biological Sciences, 283(1822), 20151439. https://doi.org/10.1098/rspb.2015.1439

Owen, M. A., Swaisgood, R. R., & Blumstein, D. T. (2017). Contextual influences on animal decision-making: Significance for behavior-based wildlife conservation and management. Integrative Zoology, 12(1), 32–48. https://doi.org/10.1111/1749-4877.12235

Padoa-Schioppa, C. (2011). Neurobiology of Economic Choice: A Good-Based Model. Annual Review of Neuroscience, 34(1), 333–359. https://doi.org/10.1146/annurev-neuro-061010-113648

Padoa-Schioppa, C., & Assad, J. A. (2006). Neurons in the orbitofrontal cortex encode economic value. Nature, 441(7090), 223–226. https://doi.org/10.1038/nature04676

Palombo, D. J., Keane, M. M., & Verfaellie, M. (2015). How does the hippocampus shape decisions? Neurobiology of Learning and Memory, 125, 93–97. https://doi.org/10.1016/j.nlm.2015.08.005

Papenberg, G., Salami, A., Persson, J., Lindenberger, U., & Bäckman, L. (2015). Genetics and Functional Imaging: Effects of APOE, BDNF, COMT, and KIBRA in Aging. Neuropsychology Review, 25(1), 47–62. https://doi.org/10.1007/s11065-015-9279-8

Park, D. C., & Reuter-Lorenz, P. (2009). The Adaptive Brain: Aging and Neurocognitive Scaffolding. Annual Review of Psychology, 60(1), 173–196. https://doi.org/10.1146/annurev.psych.59.103006.093656

Pauly, T., Lay, J. C., Kozik, P., Graf, P., Mahmood, A., & Hoppmann, C. A. (2019). Technology, Physical Activity, Loneliness, and Cognitive Functioning in Old Age. GeroPsych, 32(3), 111–123. https://doi.org/10.1024/1662-9647/a000208

Peters, E., Dieckmann, N. F., & Weller, J. (2011). Age Differences in Complex Decision Making. In Handbook of the Psychology of Aging (Seventh Ed, pp. 133–151). Elsevier. https://doi.org/10.1016/B978-0-12-380882-0.00009-7

Peters, J., & Büchel, C. (2010). Episodic Future Thinking Reduces Reward Delay Discounting through an Enhancement of Prefrontal-Mediotemporal Interactions. Neuron, 66(1), 138–148. https://doi.org/10.1016/j.neuron.2010.03.026

Philiastides, M. G., & Ratcliff, R. (2013). Influence of Branding on Preference-Based Decision Making. Psychological Science, 24(7), 1208–1215. https://doi.org/10.1177/0956797612470701

Plassmann, H., O'Doherty, J., & Rangel, A. (2007). Orbitofrontal Cortex Encodes Willingness to Pay in Everyday Economic Transactions. Journal of Neuroscience, 27(37), 9984–9988. https://doi.org/10.1523/JNEUROSCI.2131-07.2007

Polanía, R., Moisa, M., Opitz, A., Grueschow, M., & Ruff, C. C. (2015). The precision of value-based choices depends causally on fronto-parietal phase coupling. Nature Communications, 6, 8090. https://doi.org/10.1038/ncomms9090

Queen, T. L., Hess, T. M., Ennis, G. E., Dowd, K., & Grühn, D. (2012). Information Search and Decision Making: Effects of Age and Complexity on Strategy Use. Psychology and Aging, 27(4), 817–824. https://doi.org/10.1037/a0028744

Queen, T. L., & Hess, T. M. (2010). Age differences in the effects of conscious and unconscious thought in decision making. Psychology and Aging, 25(2), 251–261. https://doi.org/10.1037/a0018856

R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

RStudio Team (2015). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA. URL http://www.rstudio.com/.

Rangel, A. (2013). Regulation of dietary choice by the decision-making circuitry. Nature Publishing Group, 16(12), 1717–1724. https://doi.org/10.1038/nn.3561

Rangel, A., Camerer, C., & Montague, P. R. (2008). A framework for studying the neurobiology of value-based decision making. Nature Reviews Neuroscience, 9(7), 545–556. https://doi.org/10.1038/nrn2357

Rangel, A., & Clithero, J. A. (2014). The Computation of Stimulus Values in Simple Choice. In Neuroeconomics (pp. 125–148). Elsevier. https://doi.org/10.1016/B978-0-12-416008-8.00008-5

Rangel, A., & Hare, T. (2010). Neural computations associated with goal-directed choice. Current Opinion in Neurobiology, 20(2), 262–270. https://doi.org/10.1016/j.conb.2010.03.001

Ratcliff, R., Thapar, A., & McKoon, G. (2011). Effects of aging and IQ on item and associative memory. Journal of Experimental Psychology: General, 140(3), 464–487. https://doi.org/10.1037/a0023810

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., … Acker, J. D. (2005). Regional brain changes in aging healthy adults: General trends, individual differences and modifiers. Cerebral Cortex, 15(11), 1676–1689. https://doi.org/10.1093/cercor/bhi044

Reed, A. E., & Carstensen, L. L. (2012). The Theory Behind the Age-Related Positivity Effect. Frontiers in Psychology, 3(SEP), 1–9. https://doi.org/10.3389/fpsyg.2012.00339

Reed, A. E., Chan, L., & Mikels, J. A. (2014). Meta-analysis of the age-related positivity effect: age differences in preferences for positive over negative information. Psychology and Aging, 29(1), 1–15. https://doi.org/10.1037/a0035194

Reuter-Lorenz, P. A., & Park, D. C. (2014). How Does it STAC Up? Revisiting the Scaffolding Theory of Aging and Cognition. *Neuropsychology Review*, *24*(3), 355–370. https://doi.org/10.1007/s11065-014-9270-9

Rock, P. L., Roiser, J. P., Riedel, W. J., & Blackwell, A. D. (2014). Cognitive impairment in depression: a systematic review and meta-analysis. Psychological Medicine, 44(10), 2029–2040. https://doi.org/10.1017/S0033291713002535

Rönnlund, M., Nyberg, L., Bäckman, L., & Nilsson, L.-G. (2005). Stability, Growth, and Decline in Adult Life Span Development of Declarative Memory: Cross-Sectional and Longitudinal Data From a Population-Based Study. Psychology and Aging, 20(1), 3–18. https://doi.org/10.1037/0882-7974.20.1.3

Rosen, A. C., Prull, M. W., Gabrieli, J. D. E., Stoub, T., O'Hara, R., Friedman, L., … deToledo-Morrell, L. (2003). Differential associations between entorhinal and hippocampal volumes and memory performance in older adults. Behav Neurosci, 117(6), 1150–1160. https://doi.org/10.1037/0735-7044.117.6.1150

Rossetti, H. C., Lacritz, L. H., Cullum, C. M., & Weiner, M. F. (2011). Normative data for the Montreal Cognitive Assessment (MoCA) in a population-based sample. Neurology, 77(13), 1272–1275. https://doi.org/10.1212/WNL.0b013e318230208a

Ruff, C. C., & Fehr, E. (2014). The neurobiology of rewards and values in social decision making. Nature Reviews Neuroscience, 15(8), 549–562. https://doi.org/10.1038/nrn3776

Rung, J. M., & Madden, G. J. (2018). Experimental reductions of delay discounting and impulsive choice: A systematic review and meta-analysis. Journal of Experimental Psychology: General, 147(9), 1349–1381. https://doi.org/10.1037/xge0000462

Salthouse, T. (2012). Consequences of Age-Related Cognitive Declines. Annual Review of Psychology, 63(1), 201–226. https://doi.org/10.1146/annurev-psych-120710-100328

Salthouse, T. A. (2004). What and When of Cognitive Aging. Current Directions in Psychological Science, 13(4), 140–144. https://doi.org/10.1111/j.0963-7214.2004.00293.x

Salthouse, T. A. (2011). Neuroanatomical substrates of age-related cognitive decline. Psychological Bulletin, 137(5), 753–784. https://doi.org/10.1037/a0023262

Samanez-Larkin, G. R., Kuhnen, C. M., Yoo, D. J., & Knutson, B. (2010). Variability in Nucleus Accumbens Activity Mediates Age-Related Suboptimal Financial Risk Taking. Journal of Neuroscience, 30(4), 1426–1434. https://doi.org/10.1523/JNEUROSCI.4902-09.2010

Samanez-Larkin, G. R., & Knutson, B. (2015). Decision making in the ageing brain: changes in affective and motivational circuits. Nature Reviews Neuroscience, 16(5), 278–289. https://doi.org/10.1038/nrn3917

Sanfey, A. G., Loewenstein, G., McClure, S. M., & Cohen, J. D. (2006). Neuroeconomics: cross-currents in research on decision-making. Trends in Cognitive Sciences, 10(3), 108–116. https://doi.org/10.1016/j.tics.2006.01.009

Sasse, L. K., Peters, J., & Brassen, S. (2017). Cognitive control modulates effects of episodic simulation on delay discounting in aging. Frontiers in Aging Neuroscience, 9(MAR), 1–11. https://doi.org/10.3389/fnagi.2017.00058

Schacter, D. L., Gaesser, B., & Addis, D. R. (2013). Remembering the Past and Imagining the Future in the Elderly. Gerontology, 59(2), 143–151. https://doi.org/10.1159/000342198

Schacter, D. L., Addis, D. R., & Buckner, R. L. (2007). Remembering the past to imagine the future: the prospective brain. Nature Reviews Neuroscience, 8(9), 657–661. https://doi.org/10.1080/08995600802554748

Schacter, D. L., Benoit, R. G., & Szpunar, K. K. (2017). Episodic future thinking: mechanisms and functions. Current Opinion in Behavioral Sciences, 17, 41–50. https://doi.org/10.1016/j.cobeha.2017.06.002

Scheibe, S. (2018). Predicting real-world behaviour: Cognition-emotion links across adulthood and everyday functioning at work. Cognition and Emotion, 0(0), 1–7. https://doi.org/10.1080/02699931.2018.1500446

Seaman, K. L., Gorlick, M. A., Vekaria, K. M., Hsu, M., Zald, D. H., & Samanez-Larkin, G. R. (2016). Adult age differences in decision making across domains: Increased discounting of social and health-related rewards. Psychology and Aging, 31(7), 737–746. https://doi.org/10.1037/pag0000131

Shadlen, M. N., & Kiani, R. (2013). Decision Making as a Window on Cognition. Neuron, 80(3), 791–806. https://doi.org/10.1016/j.neuron.2013.10.047

Shadlen, M. N., & Shohamy, D. (2016). Decision Making and Sequential Sampling from Memory. Neuron, 90(5), 927–939. https://doi.org/10.1016/j.neuron.2016.04.036

Snider, S. E., LaConte, S. M., & Bickel, W. K. (2016). Episodic Future Thinking: Expansion of the Temporal Window in Individuals with Alcohol Dependence. Alcoholism: Clinical and Experimental Research, 40(7), 1558–1566. https://doi.org/10.1111/acer.13112

Soreq, L., Rose, J., Soreq, E., Hardy, J., Trabzuni, D., Cookson, M. R., Smith, C., Ryten, M., Patani, R., & Ule, J. (2017). Major Shifts in Glial Regional Identity Are a Transcriptional Hallmark of Human Brain Aging. Cell Reports, 18(2), 557–570. https://doi.org/10.1016/j.celrep.2016.12.011

Stein, J. S., Sze, Y. Y., Athamneh, L., Koffarnus, M. N., Epstein, L. H., & Bickel, W. K. (2017). Think fast: rapid assessment of the effects of episodic future thinking on delay discounting in overweight/obese participants. Journal of Behavioral Medicine, 40(5), 832–838. https://doi.org/10.1007/s10865-017-9857-8

Stein, J. S., Tegge, A. N., Turner, J. K., & Bickel, W. K. (2018). Episodic future thinking reduces delay discounting and cigarette demand: an investigation of the good-subject effect. Journal of Behavioral Medicine, 41(2), 269–276. https://doi.org/10.1007/s10865-017-9908-1

Stein, J. S., Wilson, A. G., Koffarnus, M. N., Daniel, T. O., Epstein, L. H., & Bickel, W. K. (2016). Unstuck in time: episodic future thinking reduces delay discounting and cigarette smoking. Psychopharmacology, 233(21–22), 3771–3778. https://doi.org/10.1007/s00213-016-4410-y

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. Journal of the International Neuropsychological Society, 8(3), 448–460. https://doi.org/10.1017/S1355617702813248

Stern, Y. (2012). Cognitive reserve in ageing and Alzheimer's disease. The Lancet Neurology, 11(11), 1006–1012. https://doi.org/10.1016/S1474-4422(12)70191-6

Story, G. W., Vlaev, I., Seymour, B., Darzi, A., & Dolan, R. J. (2014). Does temporal discounting explain unhealthy behavior? A systematic review and reinforcement learning perspective. Frontiers in Behavioral Neuroscience, 8(March), 1–20. https://doi.org/10.3389/fnbeh.2014.00076

Strough, J., Löckenhoff, C. E., & Hess, T. M. (2015). The Present, Past, and Future of Research on Aging and Decision Making. In Aging and Decision Making (pp. 1–14). Elsevier. https://doi.org/10.1016/B978-0-12-417148-0.00001-7

Strough, J., Parker, A. M., & Bruine de Bruin, W. (2015). Understanding Life-Span Developmental Changes in Decision-Making Competence. In Aging and Decision Making (pp. 235–257). Elsevier. https://doi.org/10.1016/B978-0-12-417148-0.00012-1

Sze, Y. Y., Stein, J. S., Bickel, W. K., Paluch, R. A., & Epstein, L. H. (2017). Bleak Present, Bright Future: Online Episodic Future Thinking, Scarcity, Delay Discounting, and Food Demand. Clinical Psychological Science, 5(4), 683–697. https://doi.org/10.1177/2167702617696511

Thimm, J. C., Holte, A., Brennen, T., & Wang, C. E. A. (2013). Hope and expectancies for future events in depression. Frontiers in Psychology, 4(JUL), 1–6. https://doi.org/10.3389/fpsyg.2013.00470

Thorell, L. B., Holst, Y., & Sjöwall, D. (2019). Quality of life in older adults with ADHD: links to ADHD symptom levels and executive functioning deficits. Nordic Journal of Psychiatry, 73(7), 409–416. https://doi.org/10.1080/08039488.2019.1646804

Tiffin-Richards, F. E., Costa, A. S., Holschbach, B., Frank, R. D., Vassiliadou, A., Krüger, T., … Reetz, K. (2014). The Montreal Cognitive Assessment (MoCA) - A Sensitive Screening Instrument for Detecting Cognitive Impairment in Chronic Hemodialysis Patients. PLoS ONE, 9(10), e106700. https://doi.org/10.1371/journal.pone.0106700

Tisserand, D. J., van Boxtel, M. P. J., Pruessner, J. C., Hofman, P., Evans, A. C., & Jolles, J. (2004). A voxel-based morphometric study to determine individual differences in gray matter density associated with age and cognitive change over time. Cerebral Cortex (New York, N.Y. : 1991), 14(9), 966–973. https://doi.org/10.1093/cercor/bhh057

Tovel, H., & Carmel, S. (2014). Maintaining Successful Aging: The Role of Coping Patterns and Resources. Journal of Happiness Studies, 15(2), 255–270. https://doi.org/10.1007/s10902-013-9420-4

Trussel, J. M., & Parsons, L. M. (2007). Financial Reporting Factors Affecting Donations to Charitable Organizations. Advances in Accounting, 23(07), 263–285. https://doi.org/10.1016/S0882-6110(07)23010-X

United Nations, Department of Economic and Social Affairs, Population Division (2015). World population, ageing. (ST/ESA/SER.A/390), 164. https://doi.org/ST/ESA/SER.A/390

Van Weert, J. C. M., Van Munster, B. C., Sanders, R., Spijker, R., Hooft, L., & Jansen, J. (2016). Decision aids to help older people make health decisions: A systematic review and meta-analysis. BMC Medical Informatics and Decision Making, 16(1). https://doi.org/10.1186/s12911-016-0281-8

von der Ahe, B., & Lüdecke, R. (2016). Wirkungstransparenz bei Spendenorganisationen. Retrieved from https://www.phineo.org/downloads/PHINEO_Studie_Wirkungstransparenz_2016.pdf

Walhovd, K. B., Fjell, A. M., Reinvang, I., Lundervold, A., Dale, A. M., Eilertsen, D. E., Quinn, B. T., Salat, D., Makris, N., & Fischl, B. (2005). Effects of age on volumes of cortex, white matter and subcortical structures. Neurobiology of Aging, 26(9), 1261–1270. https://doi.org/10.1016/j.neurobiolaging.2005.05.020

Waterlander, W. E., Scarpa, M., Lentz, D., & Steenhuis, I. H. M. (2011). The virtual supermarket: an innovative research tool to study consumer food purchasing behaviour. BMC Public Health, 11(1), 589. https://doi.org/10.1186/1471-2458-11-589

Wayde, E. N., Black, S. R., & Gilpin, A. (2017). Decision-making quality of younger and older adults in familiar and unfamiliar domains. Aging, Neuropsychology, and Cognition, 24(2), 135–157. https://doi.org/10.1080/13825585.2016.1176110

Weber, E. U., Johnson, E. J., Milch, K. F., Chang, H., Brodscholl, J. C., & Goldstein, D. G. (2007). Asymmetric Discounting in Intertemporal Choice. Psychological Science, 18(6), 516–523. https://doi.org/10.1111/j.1467-9280.2007.01932.x

Weilbächer, R. A., & Gluth, S. (2017). The Interplay of Hippocampus and Ventromedial Prefrontal Cortex in Memory-Based Decision Making. Brain Sciences, 7(1), 4. https://doi.org/10.3390/brainsci7010004

Willemsen, M. C., Böckenholt, U., & Johnson, E. J. (2011). Choice by Value Encoding and Value Construction: Processes of Loss Aversion. Journal of Experimental Psychology: General, 140(3), 303–324. https://doi.org/10.1037/a0023493

Wilson, R. S., Beckett, L. A., Barnes, L. L., Schneider, J. A., Bach, J., Evans, D. A., & Bennett, D. A. (2002). Individual differences in rates of change in cognitive abilities of older persons. Psychology and Aging, 17(2), 179–193. https://doi.org/10.1037/0882-7974.17.2.179

Wimmer, G. E., Braun, E. K., Daw, N. D., & Shohamy, D. (2014). Episodic Memory Encoding Interferes with Reward Learning and Decreases Striatal Prediction Errors. Journal of Neuroscience, 34(45), 14901–14912. https://doi.org/10.1523/JNEUROSCI.0204-14.2014

Wimmer, G. E., & Shohamy, D. (2012). Preference by Association: How Memory Mechanisms in the Hippocampus Bias Decisions. Science, 338(6104), 270–273. https://doi.org/10.1126/science.1223252

Wood, S., Hanoch, Y., Barnes, A., Liu, P. J., Cummings, J., Bhattacharya, C., & Rice, T. (2011). Numeracy and Medicare Part D: The Importance of Choice and Literacy for Numbers in Optimizing Decision Making for Medicare's Prescription Drug Program. Psychology and Aging, 26(2), 295–307. https://doi.org/10.1037/a0022028

Wruck, W., & Adjaye, J. (2020). Meta-analysis of human prefrontal cortex reveals activation of GFAP and decline of synaptic transmission in the aging brain. Acta Neuropathologica Communications, 8(1), 26. https://doi.org/10.1186/s40478-020-00907-8

Zaval, L., Li, Y., Johnson, E. J., & Weber, E. U. (2015). Complementary Contributions of Fluid and Crystallized Intelligence to Decision Making Across the Life Span. Aging and Decision Making, 149–168. https://doi.org/10.1016/B978-0-12-417148-0.00008-X

Zhou, X., Perez-Cueto, F., Santos, Q., Monteleone, E., Giboreau, A., Appleton, K., … Hartwell, H. (2018). A Systematic Review of Behavioural Interventions Promoting Healthy Eating among Older People. Nutrients, 10(2), 128. https://doi.org/10.3390/nu10020128

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Study 1. Fedor Levin, Susann Fiedler & Bernd Weber (2018): The influence of episodic memory decline on value-based choice, Aging, Neuropsychology, and Cognition, DOI: 10.1080/13825585.2018.1509939
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