BRIEF ARTICLE

Age-related variance in decisions under ambiguity is explained by changes in reasoning, executive functions, and decision-making under risk

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ABSTRACT

Previous literature has explained older individuals’ disadvantageous decision-making under ambiguity in the Iowa Gambling Task (IGT) by reduced emotional warning signals preceding decisions. We argue that age-related reductions in IGT performance may also be explained by reductions in certain cognitive abilities (reasoning, executive functions). In 210 participants (18–86 years), we found that the age-related variance on IGT performance occurred only in the last 60 trials. The effect was mediated by cognitive abilities and their relation with decision-making performance under risk with explicit rules (Game of Dice Task). Thus, reductions in cognitive functions in older age may be associated with both a reduced ability to gain explicit insight into the rules of the ambiguous decision situation and with failure to choose the less risky options consequentially after the rules have been understood explicitly. Previous literature may have underestimated the relevance of cognitive functions for age-related decline in decision-making performance under ambiguity.

Over the whole life span many decisions have to be made under conditions of ambiguity. In such conditions, no explicit information about the rules for the occurrence of positive and negative consequences is provided (Bechara & Damasio, 2005). Therefore, decision-makers have to learn the consequences of the options by processing feedback from previous decisions (Bechara, Damasio, Damasio, & Anderson, 1994). The somatic marker hypothesis suggests that rewarding and punishing feedback triggers emotional reactions including changes in somatic activation (e.g. small muscle contractions, sweat production, and visceral changes) elicited via limbic loops on the brain level (Bechara & Damasio, 2005). These changes in somatic activity can be re-triggered in an anticipatory phase before the next decision and may thereby bias the choice. Somatic markers can remain unconscious but may also be experienced as feelings for options as well as hunches and guesses. Somatic markers were suggested to be based on emotion-associated neural circuits including the ventromedial prefrontal cortex, the amygdala, and the orbitofrontal cortex (Bechara & Damasio, 2005). The Iowa Gambling Task (IGT; Bechara et al., 1994) is frequently used as a measure of decision-making under ambiguity. In the task, four decks of cards to choose from are presented. Participants only know that there are better and worse decks and are not informed about the fact that choosing the decks A and B leads to high fictitious monetary gains but occasionally to very high losses, making these decks disadvantageous in the long run. The decks C and D lead only to small gains, and occasionally to smaller losses, making these two decks advantageous in the long run. Given that gains and losses and their heights occur relatively unsystematically, individuals cannot infer the probabilities of gains and losses.
Learning to prefer the advantageous decks over the course of the task is associated with somatic activity changes mirrored by increased skin conductance response (e.g. Bechara, Damasio, Tranel, & Damasio, 1997, and many more) during feedback presentation and during the anticipatory phase preceding the decisions. These somatic activity changes potentially even guide behaviour before explicit knowledge about the decks has been acquired (Bechara et al., 1997) but there is literature criticising the IGT and the somatic marker hypothesis, e.g. Dunn, Dalgleish, & Lawrence, 2006).

Performance in the IGT may be linked to ageing, because ageing is associated with structural and functional changes in brain systems connected to the development of somatic markers (e.g. Mu, Xie, Wen, Weng, & Shuyun, 1999) and to an altered sensitivity to reward and punishment during learning (Eppinger, Hämmerer, & Li, 2011). Not all but several studies found reduced decision-making performance in high age in the IGT (see Mata, Josef, Samanez-Larkin, & Hertwig, 2011).

Using the IGT, Denburg et al. (2007) showed that individuals above 56 years of age had a reduced ability to learn to prefer advantageous options compared with younger adults. In line with the somatic marker hypothesis, the older individuals who were impaired in the IGT (about 35–40%) had reduced somatic activity changes in the anticipatory phase before the decisions. Impaired and unimpaired older individuals did not significantly differ with respect to performances in tests of working memory and executive functions (Denburg et al., 2007; Denburg, Tranel, & Bechara, 2005). Thus, it seems that age-related variance in decision-making under ambiguity is explained by a reduced ability to produce emotional somatic biases prior to the decisions.

However, there are arguments to assume that aspects of cognitive control are associated with age-related variance in IGT performance. Controlled cognitive processes as mediated by the dorsolateral prefrontal cortex may also play an important role. Brand, Recknor, Grabenhorst, and Bechara (2007) reported that performance in the last 60 trials of the IGT was correlated with executive functions, while in the first 40 trials it was not.

Ageing is associated with reduced resources and capabilities in executive functions, speed of processing, working memory, reasoning, and learning (Craik & Salthouse, 2011). On the one hand, several studies have reported no relationships between IGT performance and tasks assessing cognitive abilities, such as working memory or executive functions (find overview in Toplak, Sorge, Benoi, West, & Stanovich, 2010). On the other hand, studies have found that deficits in working memory or lesions in the dorsolateral prefrontal cortex (involved in executive functions and working memory) are connected to decision-making impairments (Bechara & Martin, 2004). The somatic marker hypothesis itself and a model of decision-making under ambiguity (Bechara et al., 1997) do not suggest that somatic markers alone determine decisions under ambiguity but that they bias cognitions during decision-making.

There are at least two reasons for assuming a role of cognitive functions for decision-making in the IGT. First, persons with good cognitive functions may do better in learning from reward and punishment and in finding out (i.e. gaining insight) which decks are more profitable. The second reason can be seen after this insight has been gained. For participants who have become aware that decks A and B involve a high risk while C and D are comparably safe, the situation begins to become less ambiguous and to resemble a decision situation under risk conditions (Brand et al., 2007). In decisions under risk, explicit rules for options’ probabilities and their potential consequences are provided (Brand, Labudda, & Markowitz, 2006). Performance in this type of decision is associated with working memory, executive functions and reasoning because in these decisions, it seems to be useful to integrate the available information, control impulses, and develop, apply, and monitor long-term strategies (see Schiebener & Brand, 2015).

A task frequently used to measure decisions under risk is the Game of Dice Task (GDT; Brand et al., 2005). In the GDT participants bet on the outcomes of 18 die throws. They can choose between several options with positive and negative prospects that can be inferred by making use of explicit information provided about possible gains and losses as well as the rules for their occurrence. Decision-making in the GDT is associated with working memory performance, executive functioning and reasoning abilities (Schiebener & Brand, 2015), and with activation in the dorsolateral prefrontal cortex (Labudda et al., 2008). GDT performance in high age is reduced particularly in persons with very low executive functions (measured by the Modified Card Sorting Test; MCST) and very low reasoning abilities (measured by the LPS4, i.e. the subtest “logical reasoning” of a German intelligence test battery; Brand & Schiebener, 2013).
The main commonality between decisions under explicit risk in the GDT and the later trials in the IGT may be that many participants have access to explicit information/knowledge about the rules. Using this information they can principally predict which outcomes could be expected (although with a given uncertainty). Therefore, comparable cognitive processes and the cognitive abilities linked to these processes may be involved in IGT and GDT. Indeed, IGT performance in the last 60 trials, but not the first 40 trials, was correlated with GDT performance (Brand et al., 2007). Thus, approximately after the first 40 trials, the IGT may become less ambiguous to many participants.

Consequently, age-related changes in decision-making in the IGT, particularly in its last 60 trials, may be related to reductions in certain cognitive abilities. We suggest that age-related reductions in cognitive abilities may be related to impairments in decision-making under risk (as measured by the GDT). These impairments in decisions under risk may then explain disadvantageous decision-making in the last 60 trials of the IGT. In other words, the age-related variance in the last 60 trials of the IGT may be mediated by cognitive functions and by decision-making under risk (mediation model is shown in Figure 2). In contrast, there should not be age-related variance in the first 40 trials, because the early trials of the IGT seem unrelated to cognitive functions (Brand et al., 2007) and somatic responses occurring in early trials do not yet translate to improvements in decision-making behaviour (Bechara et al., 1997).

Regarding cognitive abilities we concentrated on the cognitive processes of reasoning (i.e. determining a rule from given information) and executive functions (i.e. cognitive processes implementing controlled, flexible, and goal oriented cognition and behaviour). These two functions may be involved in forming concepts about a situation, making sense of feedback, categorising alternatives, and consistently applying rules/strategies. As an indicator of reasoning we used the LPS4 and we used the MCST as an indicator of executive functions. These tasks were correlated with decision-making in the GDT in earlier studies and explained age-related variance in GDT performance (Brand & Schiebener, 2013). In the mediation model, we joined the two within one latent dimension to grasp the common variance of these cognitive abilities that were relevant to age-related variance in decision-making with explicit rules in an earlier study (Brand & Schiebener, 2013). If performance in the last 60 trials of the IGT is affected by the cognitive aspects of acquiring rules and/or with decision-making under risk, it should be correlated with these two functions.

With the design of the current study, we cannot assess whether the potential role of these cognitive abilities for IGT performance is due to their involvement in learning the rules of the task or due to their involvement in decision-making with explicit knowledge about task rules (i.e. decision-making under risk). Nevertheless, if the relation between age and cognitive performance on the last 60 IGT-trials is indeed mediated by GDT performance, this may be seen as a preliminary hint that the latter explanation should (beside the former explanation) be taken into consideration when interpreting age-related variance in the IGT.

Beyond testing the mediation model, we also aimed at comparing different age groups’ IGT performance in order to depict the development of decision-making abilities in the IGT over the adult life span. Furthermore, we aimed to compare older adults who were impaired in the IGT with older adults who were unimpaired (in order to compare the results with Denburg et al., 2007).

**Method**

**Participants**

We combined data from two published studies: Brand and Schiebener (2013; n = 221; mean age 39.62, SD = 16.46, range 18–80 years; 103 males, 118 females) and Schiebener et al. (2014; n = 152; mean age 38.67, SD = 16.42, range 18–75 years; 66 males, 86 females) which have used (among other cognitive tasks) the instruments described below, but concentrated on decision-making in the GDT as dependent variable (not on the IGT as in the current manuscript). In this sample 36 participants were above 60. We aimed to achieve at least 40 participants above 60. Therefore, we additionally advertised for older individuals and could investigate further 9 participants, 6 of them 60 or older (n = 9; mean age 64.67, SD 13.98, range 45–86 years).

As a result, we had 42 participants who were 60 years or older in the combined data set. We aimed at a balanced age distribution. Thus, we used the SPSS function “complex samples” to randomly choose 42 participants from each of five predefined age groups (18–29, 30–39, 40–49, 50–59, 60 +). The final data set is described in Table 1. (We confirm that we reported how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study.)
Instruments

Decisions under ambiguity: IGT
In the IGT (Bechara et al., 1994) four decks of cards are presented (decks A, B, C, and D). Participants are asked to select one of the four card decks in each trial and that they may switch between decks at any time. They are told that some of the decks are better than others and that in order to win money they will have to avoid the bad decks. The task consists of 100 trials, which is unknown to the participants. After each choice for a deck an amount of fictitious money is won. In addition, at certain times, losses of different amounts can occur. The decks A and B lead to high gains but at unpredictable times very high losses occur. Overall, the losses are higher than the gains that can be gathered. Decks A and B are therefore considered to be disadvantageous in the long run. Decks C and D lead to small gains and even smaller losses at certain times. Overall, the gains that can be gathered are higher than the accumulated losses. Therefore, these two decks are advantageous in the long run.

Following the convention we analysed IGT performance by net scores (number of choices from advantageous decks - number of choices from disadvantageous decks). Higher net scores indicate higher preference for the advantageous decks. For analyses, we used the overall net score (all 100 trials), net scores of 5 blocks of 20 decisions, and separate net scores of the first 40 and the last 60 trials.

Cognitive abilities
We operationalised cognitive abilities by the number of correct responses in the LPS4 (Horn, 1983) and the number of non-perseverative errors in the MCST (Nelson, 1976).

Decisions under risk: GDT
The GDT is a computerised task assessing decisions under risk conditions. It provides explicit rules for gains and losses, and the probabilities for their occurrence can be calculated from the very beginning (Brand et al., 2005). The rules remain stable over all 18 trials of the task. Participants start with a capital of €1000. Their aim is to win as much money as possible and to lose as little of it as possible. They are also informed that they can carry on playing when their capital falls below zero. In each trial, participants have to guess which number will occur on top of the die in the next throw. Participants can bet on one single number or a combination of numbers. They win an
amount of fictitious money when the number or one of the numbers in the chosen combination is thrown, but the same amount is subtracted from their capital if a different number is thrown. Participants can choose a single number (possible gain/loss = €1000, winning probability = 16.67%), a combination of two numbers

Figure 1. The figure shows, separated by age group, the performances in (a) the Iowa Gambling Task, (b) the Game of Dice Task (GDT; net score), (c) the subtest reasoning of the “Leistungsprüfsystem” (LPS4; correct responses), and (d) the Modified Card Sorting Test (MCST; number of nonperseverative errors).

Figure 2. The figure shows the results of the main mediation model. The results of additional mediation models can be found in the supplementary material. Abbreviations: IGT = Iowa Gambling Task; GDT = Game of Dice Task; MCST = Modified Card Sorting Test; LPS = Leistungsprüfsystem [German intelligence test battery].
Before starting the game, participants are informed about these rules and examples are presented. All options, possible gains and losses, the overall capital, and the number of remaining rounds are permanently displayed during the task. After each decision feedback is provided: the throw of the die is shown by a video and the resulting gain or loss is displayed. Winning probabilities are not presented but may be calculated by the participants.

Following the convention we analysed GDT performance by the net score and the number of decisions for the most risky (disadvantageous) option, one single number. The net score is calculated by subtracting the number of decisions for high risk options (one and two numbers: leading to many losses because of winning probabilities below 34%) from the number of low risk options (three and four numbers: leading at least to retaining the starting capital because of winning probabilities of 50% and 66.67%). Thus, higher net scores represent a higher preference of the low risk options, which are favourable with respect to the underlying probabilities.

Statistical analyses
We used IBM SPSS Statistics 21.0 and Mplus 6 for the analyses. Several methods for outlier detection (studentised t, leverages, regression with a random variable, visual plausibility check, and tentative removal of cases at the edges of the distribution) revealed no outliers that substantially affected correlations or the results of the mediation models. Age as a biological organism variable cannot be affected by any of the other variables. Thus, the mediation hypotheses are directed (age affects the other variables) and must be tested one-tailed.

Results
Descriptive results and group comparisons
Figure 1 depicts the differences between the age groups in the test battery. Figure 1(a) illustrates the age-groups’ performances in the IGT. Descriptive statistics on the first 40 and last 60 IGT-trials can be found in Table 1. There was a significant effect of age group on performance in the last 60 trials of the IGT, $F(4, 205) = 4.41, p = .002$, partial $\eta^2 = .08$, but no effect on the first 40 trials, $F(4, 205) = 1.37, p = .245$, partial $\eta^2 = .03$.

There were significant effects of age on GDT net score, $F(4, 205) = 2.67, p = .034$, partial $\eta^2 = .05$, on the number of nonperseverative errors in the MCST, $F(4, 205) = 6.35, p < .001$, partial $\eta^2 = .11$, and on the number of correct responses in the LPS4, $F(4, 205) = 12.64, p < .001$, partial $\eta^2 = .20$.

As known from the literature male participants performed significantly better in the IGT (last 60 trials: $t(208) = 2.58, p = .011, d = .36$), but the age effect on the last 60 IGT trials remained stable when controlling for gender.

In order to compare the findings with those of Denburg et al. (2007) we compared older participants who were impaired in the IGT with older participants who were unimpaired in the IGT. Following the procedure used by Weller, Levin, and Bechara (2009) and Denburg et al. (2007) we applied the binomial test to classify the participants in the 60+ group as significantly impaired (IGT net score $\leq −18; n = 8$) or significantly unimpaired (IGT net score $\geq +18; n = 8$). Replicating the results by Denburg et al. (2005) these two groups did not differ with respect to age or the cognitive abilities ($ps > .382$) and neither GDT net score ($p = .699$). Given that the two groups were very small we repeated the analysis by collapsing the two oldest age groups (50–59 and 60+; $n = 84$, age 50–86, $M = 60.84$, $SD = 8.05$ years). In these participants, $n = 9$ were significantly impaired (age: $M = 66.44$, $SD = 7.37$ years) and $n = 21$ significantly unimpaired (age: $M = 58.76$, $SD = 7.61$ years). Impaired older participants were significantly older, $t(28) = 2.56, p = .016, d = 1.03$, had lower scores in the LPS4, $t(28) = −2.72, p = .011, d = 1.02$, but did not significantly differ from unimpaired older adults in GDT or MCST, $ps > .326, ds < 0.41$.

Hypothesised mediation model
The hypothesised mediation model was tested with structural equation modelling. The model fit was very good: $\chi^2 (N = 210, df = 2) = 0.43, p = .80; \text{SRMR} \leq 0.01; \text{CFI} = 1.00; \text{TLI} = 1.06; \text{RMSEA} < 0.01$. The model, the regression weights, and the results of the mediation analyses can be found in Figure 2.

Overall 14% of the variance in the last 60 trials of the IGT were significantly explained by the predictors. The hypothesised mediation effect was small but
significant. One of the main results is that after controlling for the effects of cognitive performance and GDT there was no longer a significant direct effect of age on the last 60 trials of the IGT.

To test the individual contribution of age-related variance in the GDT net score to the last 60 trials, we calculated an additional mediation without cognitive abilities as mediator. The effect of age on the last 60 trials was significantly mediated by GDT net score, $\beta = -.04$, $p = .015$.

In order to test for a relationship between age and the first 40 trials of the IGT, we also calculated the mediation model with the first 40 trials as dependent variable: The net score in these trials remained unexplained by age and the other predictors, $R^2 < .01$, $p = .737$.

We calculated several additional analyses to control the results against potential biases and to test concurrent hypotheses. The results of the additional analyses all support the findings reported above (see supplementary material).

**Discussion**

We found a small relationship between increasing age and less advantageous decision-making under ambiguity, measured by the IGT. Age-related reductions in decision-making only occurred with respect to the last 60 trials of the IGT in which many participants have probably acquired explicit knowledge about the rules of the decision situation (Bechara et al., 1997; Brand et al., 2007). These reductions were significantly mediated by age-related changes in performance in cognitive tasks (associated with executive functions and reasoning) and their relationship with decision-making under explicit risk conditions. In contrast, in the first 40 trials of the IGT, that is, when the decision situation is most ambiguous for the participants, there was no age-related variance. Thus, the current results imply that age-related decreases in decision-making performance in IGT are indeed associated with age-related reductions in cognitive abilities (Brand & Schiebener, 2013; Craik & Salthouse, 2011).

One potential explanation can be seen in the decline of age-sensitive cognitive abilities and their impact on reductions in the ability to decide advantageously in situations with explicit rules, as measured by the GDT (Brand & Schiebener, 2013). This ability seems also to be involved in the last trials of the IGT when the rules of the situations have potentially become explicit to many participants (Brand et al., 2007). On this basis it appears plausible that cognitive processes guiding decisions under risk may as well be involved in decision-making in the last trials of the IGT.

From the perspective of theoretical models of decision-making under risk (Brand et al., 2006; Schiebener & Brand, 2015), the cognitive abilities measured in the current study (executive functions and reasoning) are relevant for controlling impulses towards immediate rewards that are associated with high risk, for integrating information about the decision options into the development of strategies, and for regulation of behaviour in accordance with strategies.

However, the finding that the mediation excluding the GDT (i.e. age → cognitive abilities → IGT last 60 trials) had a somewhat larger effect size and reached significance, suggests that the role of cognitive abilities in age-related variance in the last 60 trials of the IGT may have facets beyond their involvement in decision-making under risk. One of these facets is that cognitive abilities may be important for generating/acquiring the explicit knowledge about the IGT-decks’ attributes (i.e. to gain insight into the rules; Bagneux, Thomassin, Gonthier, & Roulin, 2013).

In comparison to the results by Denburg et al. (2007) the current findings shed new light on age-related variance in the IGT. Denburg et al. (2007) concentrated on older adults only and found no significant differences in cognitive abilities when comparing impaired and unimpaired older decision-makers (a result which was replicated in our study). Only reduced anticipatory bodily reactions could be found as a reason for impaired decision-making in age. In contrast, the main result of the current study was that reductions in cognitive abilities and in decision-making under explicit risk are related to age effects in the IGT. Most strikingly, after controlling for the effects of cognitive abilities and decision-making under risk, no age-related variance in decision-making in the IGT was left. (Please note once more: in the first 40 trials there was no age-related variance anyway).

Thus, while unimpaired decision-making in the IGT in higher age may be connected to the successful creation of somatic markers (Denburg et al., 2007), it seems that changes in IGT performance during the adult life span are closely associated with decline in cognitive abilities. The current study was no replication study and the findings do not necessarily contradict the observations by Denburg et al. (2007).
However, our findings would suggest that future studies and theoretical models will be required to better describe the relationship between ageing, somatic markers, and/or cognitive control functions in guiding decision-making under ambiguity in different phases. Existing models of decision-making already suggest that cognitive as well as emotional processes can be involved in the decisions from the beginning and in interaction (Bechara, 2005; Schiebener & Brand, 2015; Stocco, Fum, & Napoli 2009). However, the role of age for the contributions and interactions of cognitive functions and somatic markers in explaining decision-making performance needs to be tested in future studies.

Finally, three weaknesses of the current study should be mentioned: first, we did not assess whether and in what form individuals have developed explicit knowledge about the IGT's contingencies. Second, we have not investigated the role of other cognitive abilities (e.g. working memory or attention) on IGT performance, although different abilities may contribute individually to various phases of the task (Gansler, Jerram, Vannorsdall, & Schretlen, 2011). Third, we used a cross-sectional design. Cross-sectional mediation designs in ageing research have been criticised because longitudinal change in mediators is not always related to cross-sectional change in dependent variables (Lindenberger, von Oertzen, Ghisletta, & Hertzog, 2011).

In summary, the current results suggest that the role of cognitive abilities for age-related decline of decision-making performance as measured by the IGT has often been underestimated. Thus, it may be possible that the decline in brain areas associated with cognitive control, such as fronto-striatal loops, are more important than has been suggested before for decisions under conditions which are ambiguous in the beginning.

Disclosure statement
No potential conflict of interest was reported by the authors.

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