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# Decision-making and ageing: everyday life situations under risk and under ambiguity

Fanny Gaubert<sup>1</sup> , Céline Borg<sup>2,3,4</sup>, Jean-Christophe Roux<sup>5</sup> and Hanna Chainay<sup>1</sup> 

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## Abstract

Cognitive modifications during ageing can affect decision-making competence (DMC). As this ability is central to the preservation of autonomy, our study aims to investigate how it changes in elderly adults and to determine whether such changes are linked to the deterioration of executive functions and working memory. To this end, 50 young adults and 50 elderly adults were assessed with executive, working memory, and DMC tasks. The latter comprised the Iowa Gambling Task (IGT) and a scenario task based on situations inspired by everyday life, under conditions of both risk and ambiguity. The results revealed lower performances in old than in young adults for the updating, inhibition, and working memory tasks. The IGT failed to distinguish between the two age groups. However, the scenario task did permit such a distinction, with young adults seeking more risky and ambiguous choices than elderly adults. Moreover, updating and inhibition capacities appeared to influence DMC.

## Keywords

Ageing; decision-making; under risk; under ambiguity; executive function; working memory

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## Introduction

### *Decision-making during the ageing process: impairment to ability*

The presence or absence of an impairment to the decision-making competence (DMC) in healthy elderly subjects is still a matter of debate. DMC can be involved in two kinds of situations: under ambiguity or under risk. When the possible outcomes and their probability of occurrence are uncertain, the decision-making context is considered to be ambiguous. However, the decision is deemed to be at-risk when the decision-maker is able to estimate the probability of occurrence of all the possible outcomes (Brand et al., 2007; Levy et al., 2009). In normal ageing, DMC under risk appears to divide the scientific community, sometimes being described as similar to that of young adults (Dror et al., 1998; Zamarian et al., 2008) and sometimes as modified (Deakin et al., 2004). In the case of situations under ambiguity, by contrast, researchers agree on the presence of changes in DMC in late adulthood (Fein et al., 2007; Zamarian et al., 2008). To our knowledge, only one study has compared the ability to make decisions in the two situations with the same elderly participants (Zamarian et al., 2008). The authors reported no difference in performance between old and young adults on the

Probability-Associated Gambling (PAG) task (i.e., decisions under risk), but found that the elderly group made more disadvantageous choices in the Iowa Gambling Task (IGT) (i.e., decisions under ambiguity).

### *Decision-making impairment during the ageing process: factors involved*

Decisional strategies may vary across the life span (Johnson, 1990; Mata et al., 2007, 2015; Zamarian et al., 2008). Healthy elderly participants appear to rely on simpler strategies than young adults, thereby reducing

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cognitive load (Johnson, 1990; Mata et al., 2007, 2015), and find it more difficult to keep to the same stable plan (Zamarian et al., 2008). When there is no choice other than to use complex strategies, elderly persons make more errors in their execution (Mata et al., 2015). This point is of particular interest in the present study, which aims to systematically investigate (1) DMC deficit in ageing and (2) the links between this deficit and deficits in executive functions (EFs) and working memory (WM).

EFs and feedback processing seem to play an important role in the ability to take advantageous decisions in ageing (Brand & Markowitsch, 2010). Under ambiguity, decisions seem to be based more on feedback (i.e., a factor that is dependent on both emotional processes and cognitive aptitudes). Under risk, cognitive functions seem to be involved in a more general way, starting with the EFs and WM (Labudda et al., 2008). Difficulties in adapting decisions to the context have also been reported by Deakin et al. (2004), with the elderly always betting similar amounts of money, regardless of the probability of winning. The authors also reported that older adults spend longer deliberating than their younger counterparts. Based on socioemotional selectivity theory (SST), McCarrey et al. (2010) suggested that their main goal is well-being, meaning that elderly participants might avoid soliciting functions associated with a high cognitive load, which could be potentially problematic, and favour functions with a low cognitive load. As the deployment of functions which have become degraded with age can lead to failure and frustration, older adults might change their decision-making strategy, even if this modification gives rise to other choices. They might therefore rely more on their personal experience than on environmental information, that is to say, more on a heuristic strategy (i.e., effortless, fast, emotional, etc.) than on an analytical strategy (i.e., slow, deliberative, controlled, etc.). Deakin et al. (2004) used the Cambridge Gambling Task (CGT), which is a laboratory gambling task designed to assess decision-making under risk. We can assume that the heuristic strategy might not be appropriate for this situation, thus obliging participants to adopt an analytical approach. As older adults do not appear to want to mobilise this second kind of strategy, the observed lengthened deliberation time might reflect the associated difficulties. According to Schiebener and Brand (2017), the performances in the last 60 trials of the IGT would be partially explained by reasoning, EF, and the performances obtained at the Game of Dice Task (GDT), the task that measure DMC under risk.

Finally, modifications in the use of EFs occur with age and these changes are very likely to impact DMC in late adulthood. Finucane et al. (2002) supported the idea that memorising the relevant information would be one of the cornerstones of DMC. They showed that elderly participants were more inconsistent and made more errors than

younger adults due to an incorrect understanding of the situation. The findings of Fein et al. (2007) have corroborated this idea by revealing that disadvantageous choices were correlated with immediate memory capacity in older adults, and WM capacity in younger adults (Finucane et al., 2002). Numerous studies have demonstrated modifications in memory function (i.e., WM, episodic encoding, and retrieval) in older adults at both the behavioural and neuronal levels. In particular, they suggest that to maintain the same level of performance as younger adults, older adults need to recruit more areas of the brain, most especially in contralateral regions and in the prefrontal cortex (PFC; Cabeza et al., 2004; Gutchess et al., 2005). Lee et al. (2008) studied DMC under risk and also found that, compared with younger adults, older adults activated contralateral prefrontal areas and overactivated the right insula. These different findings support the idea that memory and DMC impairment are closely linked.

In sum, ageing brings about modifications in cognition that affect DMC. However, these findings should be considered with caution in the light of studies that have revealed heterogeneous results among groups of elderly participants (Brand & Schiebener, 2013; Denburg et al., 2007; Hess et al., 2012). Indeed, greater age might not be responsible for decision-making impairment per se, but could be one element in a combination of responsible factors. If this is the case, then individual characteristics would appear to play a major role.

### *Decision-making impairment during the ageing process: the results of interacting factors*

The second question concerning DMC during the ageing process relates to the presence of a general decision-making deficit in late adulthood, that is to say, a deficit that affects all elderly participants. Brand and Schiebener (2013) refined their initial model (Brand & Markowitsch, 2010) by showing that the correlation between age and performances in the GDT was moderated not only by EFs but also by logical thinking. Other authors have found that poor DMC was correlated with the combination of advanced age, poor cognitive abilities, and low level of education (Hess et al., 2012). It therefore seems that ageing does not systematically involve DMC impairment, but rather that decision-making deficits emerge when greater age is combined with other factors. These findings in the decision-making field seem to be consistent with the scaffolding theory of ageing and cognition (STAC) (Park & Reuter-Lorenz, 2009). This posits that secondary circuits are recruited to compensate for the structural modifications that the brain undergoes with ageing and to preserve cognitive performances at the highest possible level for as long as possible. These secondary neural networks mainly appear to involve the contralateral hemisphere and the

PFC, which appears to be the most versatile brain area. For instance, Rogalsky et al. (2012) found that older adults with bilateral vm-PFC activations achieved significantly better performances in the IGT than older adults with only right vm-PFC activations. While cerebral changes appear to be dependent on the individual (i.e., genetic factors, chronic illnesses, etc.), so, too, does the deployment of the scaffolding framework (Park & Reuter-Lorenz, 2009). Some characteristics appear to enhance its efficiency, such as physical fitness or being accustomed to cognitive tasks, especially when they are challenging (i.e., new or very difficult). In other words, cognitive performances in late adulthood would be the result of a combination of structural degradation and the ability to build compensatory networks. Because the DMC seems to be dependent on different cognitive functions, it would be impacted by the combination of these two processes.

In sum, changes in DMC occur frequently in late adulthood and appear to have multiple causes. It seems that several cognitive functions, such as WM or EFs, are involved in the elderly's ability to make decisions. However, to our knowledge, no study has deliberately and precisely examined the links between DMC under risk and under ambiguity and cognitive competences in ageing. In addition, most studies have used the IGT or other laboratory tasks that are largely unrelated to everyday life to investigate the DMC. Thus, the present study aims to adopt a systematic approach in order to investigate the DMC of older adults under risk and under ambiguity by means of tasks which are, unlike the IGT, based on everyday life situations and also to examine the relationship between DMC and the efficiency of other cognitive functions. We also used the IGT because it allows (1) to compare our results with the ones described the most frequently in the literature, and (2) to assess DMC in both conditions, under ambiguity (i.e., with the first blocks) and under risk (i.e., with the last blocks) (Buelow & Suhr, 2009). Although we cannot consider our experimental tasks to be ecological, we hoped that the participants' responses would be closer to real-life than responses collected with a gambling task. Some behavioural differences may emerge between the two kinds of tasks, because they are different in terms of construct, especially because IGT involves learning throughout the trials, which is not the case with the scenario task. However, we cannot as yet say what form these differences might take. Our first prediction is that, with ageing, DMC under ambiguity will be more impaired than DMC under risk. Our study will also examine how EFs (updating, mental set shifting, and the inhibition process) and WM are correlated with DMC in older, compared with younger adults. We predict that, in line with the STAC, the regressions will be stronger for the elderly than for their younger counterparts, and that the correlations will be proportional to the extent of the cognitive impairment. Among the EFs, the inhibitory process should be particularly highly involved, as it is used to

mask non-pertinent information and is known to become degraded with ageing. Concerning WM, we know of no findings that provide us with a possible basis for making precise predictions about the involvement of maintenance or manipulation process impairment in DMC. However, as the hippocampus appears to be frequently atrophied in late adulthood, we can assume that maintenance will be impaired in elderly adults. While prefrontal activations compensate for the deficit, we might, at the least, observe manipulation impairments in older adults sooner than in younger adults, probably due to overactivation in prefrontal regions.

## Method

### Participants

Two groups of participants were included in the study: a group of 50 older adults (29 women and 21 men) and a group of 50 younger adults (34 women and 16 men). The elderly adults were aged between 62 and 87 years ( $M=71.8$ ,  $SD=5.7$ ) and the young adults between 18 and 32 years ( $M=26.3$ ,  $SD=3.5$ ). The proportions of men and women were comparable in the two groups,  $\chi^2(df=1, N=100)=1.07$ ,  $p=.30$ . Education level was assessed on a 5-point scale (i.e., 1 = no education, 2 = primary school, 3 = first half of secondary school, 4 = secondary school leaving certificate or equivalent, 5 = higher education). The young adults ( $M=4.98$ ,  $SD=0.14$ ) had a higher educational level than the elderly adults ( $M=4.16$ ,  $SD=0.96$ )  $\chi^2(df=1, N=100)=31.84$ ,  $p<.001$  (there was no participant with education Level 1).

**Neuropsychological examination.** The elderly participants underwent a brief neuropsychological assessment consisting of the Mini Mental State Examination (MMSE), which indicated preserved global mental status ( $M=29.2$ ,  $SD=0.97$ ) (Folstein et al., 1975; French version: Hugonot et al., 2008), and the brief frontal efficiency battery (*Batterie Rapide d'Efficiency Frontale*, BREF) ( $M=17.4$ ,  $SD=0.73$ ) (Dubois et al., 2000). For the purposes of another study, they also completed the Revised Observed Tasks of Daily Living (OTDL-R) ( $M=41.1$ ,  $SD=2.2$ ) (Diehl et al., 2005) and Quality of Life in Alzheimer's Disease (QoL-AD) ( $M=38$ ,  $SD=5.69$ ) (Logsdon et al., 1999) assessments. The OTDL-R assesses the level of autonomy using objects from everyday life (e.g., telephone, medicines, etc.). Due to time constraints, we had to shorten this test and used only three items from the healthcare field, one from the communications field, and two from the finance field. The QoL-AD assesses quality of life.

All the participants completed the South Oaks Gambling Screen (SOGS) (Lesieur & Blume, 1987). This is an instrument used to identify pathological gamblers and allowed

us to exclude these participants from the study. None of them had a pathological gambling profile. The older adults completed the Hospital Anxiety and Depression Scale (HADS) and the younger adults completed the Spielberg State-Trait Anxiety Inventory. In addition, the participants' mood was assessed with the Brief Mood Introspection Scale (BMIS) (Mayer & Gaschke, 1988).

### Experimental tasks

All the tasks apart from the Stroop tests were programmed and run with the E-Prime 2.0 software (Psychology Software Tools Inc.) on a Dell laptop with azerty keyboard.

Each task began with instructions, an example to illustrate them, and practice trials. The instructions were written on the screen and were also always given verbally by the experimenter. Before starting the experiment, the participants were asked to explain what they had understood in their own words.

This study used many tasks to assess EFs, WM, and decision-making. As a detailed description would be very long, we provide only brief explanations here. However, all the details are provided in the supplemental material section.

**EF assessment.** To assess EFs, we used the classification proposed by Miyake et al. (2000) as a basis. According to these authors, the executive system is not unitary and its various components are not completely independent. Their assessment of EF focuses on updating, mental set shifting, and inhibition functions and they suggest assessing each function with three different tasks. To simplify our protocol for the present study, which takes several hours of testing, we chose to reduce the number of tasks from 3 to 2 for each function.

#### Updating process

**Letter memory:** updating span task during which participants had to remember the last two letters of sets of consonants containing between 2 and 5 items.

**N-back:** A 3-level N-back ( $N=1, 2,$  and  $3$ ) task was administered during which participants had to compare the consonant displayed on the screen with the consonant that had appeared  $N$  steps earlier, depending on the level.

**Mental set shifting.** The following two tasks were created based on the study by Friedman et al. (2008).

**Number-letter:** in this task, the participants had to alternate between a parity decision and a vowel/consonant decision depending on the location on the screen (i.e., at the top or at the bottom) of a number/letter pairing (e.g., 7G).

**Category switch:** the participants had to classify words into one of two categories (i.e., “does the target word fit into a shoebox?” vs. “is the target word made by humans?”) depending on a visual cue (i.e., drawing of a shoebox vs. hand).

#### Inhibition

**Stop signal:** during a learning phase, the participants had to indicate the location of a pink triangle (i.e., on the left or right) as quickly as possible. During the test phase, the same instruction was given, with the difference that participants had to withhold their answer when they heard a beep. The stop signal reaction time was calculated as in the horse-race model.

A *Stroop test* was used to assess interference suppression. We used the Victoria Stroop version (Bayard et al., 2009) for the elderly control adults and the standard test (Golden, 1975) for the young adults.

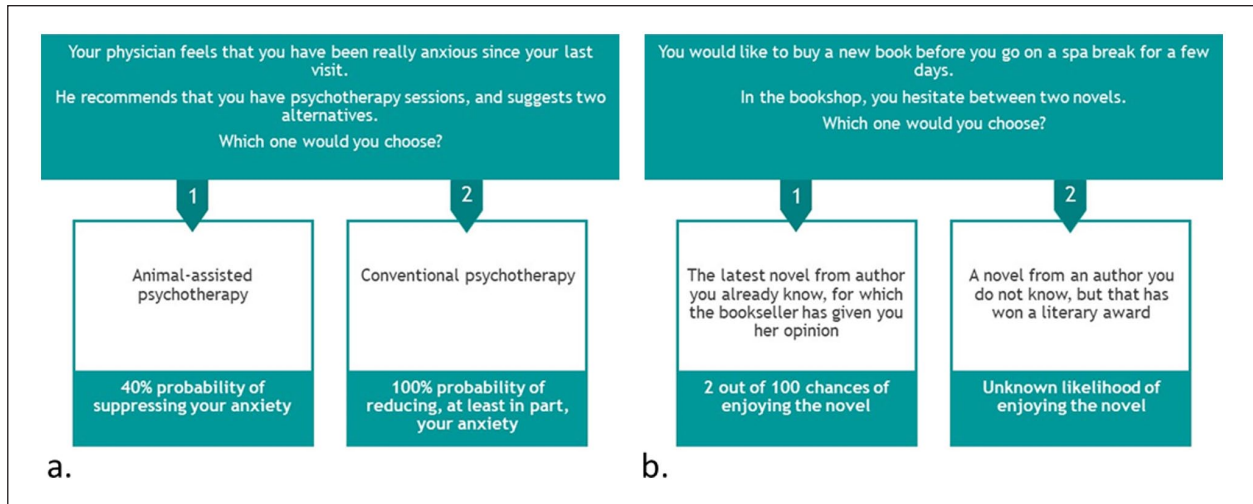
**WM tasks.** To assess WM, we used the time-based resource sharing (TBRS) model (Camos & Barrouillet, 2014). This functional model assumes that the maintenance and processing components of WM are both dependent on the same limited resource, namely, attention, which moves from one to the other quickly and continuously. When the attentional focus is on the processing component, the memory trace of the information to be maintained is thought to be degraded. However, to avoid decay, it is necessary to refresh the information by refocusing attention on this information (Barrouillet et al., 2004).

In order to study these two components of WM, we programmed three complex span tasks drawn from the protocol used by Barrouillet et al. (2004). In all the tasks, the participants had to remember consonant sets. The three tasks shared the same design and differed only in the processing phase. This took the form of an interfering subtask displayed between each letter to be remembered. In the first complex span task, the participants had to repeat “baba” syllable sets, in the second they had to perform a reading operation task (e.g.,  $8/+1/9/-2/7$ . . .), and in the last one they had to perform a continuous operation task (e.g.,  $8/+1/response/-2/response$ . . .).

Before the participants performed the three complex span tasks, they were asked to complete forward and backward digit span tasks. Both were composed of 16 spans, with the forward spans being between 2 and 9 digits long and the backward spans between 2 and 8 digits long. The task was stopped when the participant failed twice on the same span length.

#### Decision-making tasks

**IGT (Bechara et al., 2000).** The participants performed the traditional IGT (Bechara et al., 2000), which requires



**Figure 1.** (a) Example of scenario under risk on the left, and (b) under ambiguity on the right.

them to maximise an initial amount of money by selecting decks of cards. Each selection causes them to lose or gain money. Two decks are considered advantageous and two disadvantageous (for more details, see the online Supplementary Material).

*Experimental task based on everyday life situations.* The experimental task consists of two subtasks: one assessing decisions under ambiguity and the other assessing decisions under risk. It is based on two protocols used in two different studies: Lauriola and Levin (2001), and Lauriola et al. (2007).

Each subtask consists of 36 short scenarios based on everyday life situations (see Figure 1 for examples). For each trial, the context is described in two or three sentences in the top part of the screen. Below, two boxes labelled with the number 1 (i.e., on the left-hand side) or 2 (i.e., on the right-hand side) propose two possible options. The participants are instructed to read all the information and to select their preferred option by pressing the 1 key or the 2 key. The context and the options remain continuously visible. The next trial appears once the participants have pressed one of the two keys (i.e., 1 or 2). In the under-risk condition, the participants are required to choose between one safe option (100% probability of occurrence) and a risky one ( $x\%$  likelihood of occurrence). Half the scenarios involve a loss versus a smaller loss, or a gain versus a bigger gain. In the under-ambiguity condition, the 36 scenarios consist of the same 4 stories repeated with 9 different probabilities. The participants are required to choose between an unambiguous option ( $x\%$  likelihood of occurrence) and an ambiguous one (unknown % likelihood of occurrence). In both subtasks,  $x$  can take the value of 2%, 10%, 20%, 40%, 50%, 60%, 80%, 90%, and 98% likelihood. In one half of the scenarios, the numerical information is given as a percentage (e.g. 2% likelihood of making

up lost time) while, in the other half, it is given as a frequency (2 chances out of 100 of making up lost time). Both the location of the numerical information and the location of the two options are counterbalanced. In the under-risk condition, the order of the scenarios is randomised. In the under-ambiguity condition, the order of the scenarios is semi-randomised. The number of risky and ambiguous decisions was counted: in total (i.e., under risk and under ambiguity separately, with a maximum of 36 for each), per percentage of certainty and per context (i.e., gain or loss, for the under-risk condition only, with a maximum of 18).

### Procedure

The participants were first contacted by e-mail with an information letter and the experimenter's contact details (i.e., e-mail and phone number) attached. If they were interested in the study, a phone call was scheduled with the experimenter in order to explain the procedure better, answer any questions, and schedule the meetings.

The study consisted of three sessions. The first was dedicated to assessing EFs, the second to assessing WM, and the third to assessing decision-making competence. The first two lasted approximately 1.5 hr and the third approximately 1 hr. The sessions were separated by 1-week intervals and took place in the laboratory.

The first session commenced with a reminder of the purpose, organisation of the study, and the signature on the informed consent form. After the participants had completed the neuropsychological tests and questionnaires, the six executive tasks were proposed in a random order. Participants were allowed a 5-min break after each task.

The second session commenced with the anxiety scales (i.e., HADS for the older adults and Spielberger State-Trait Anxiety Inventory for the younger adults).

The three WM tasks were then performed, always in the same order: the baba span, the reading operation task, followed by the counting operation span. A cut-off criterion was applied for the last two tasks: the participants could choose to stop the task after making consecutive errors. The main reason for this cut-off was to avoid unnecessary effort that could impact performance in the last task. If the participants made more than four errors in a row but were enjoying the challenging situation, the experimenter let them finish.

The last session again commenced with the anxiety scales, to which the BMIS (i.e., a mood scale) was added. The three decision-making tasks (i.e., IGT and the two experimental subtasks) and the OTDL-R were performed. The order of the tasks was counterbalanced, but the two experimental tasks (i.e., with everyday life scenarios) were never presented immediately after one another. This was to avoid potentially reducing the participants' interest as the two tasks were quite similar. Because of the COVID-19 pandemic, the scenario task was adapted to be performed remotely by the young adults and was therefore programmed not with E-Prime but with PsyToolkit (Stoet, 2010, 2017).

The experimental manipulation was primarily administered by one experimenter (i.e., the PhD student who had programmed the tasks). Three other experimenters (i.e., Master's two students in Neuropsychology) also assisted. They had been trained in the correct administration of the tasks by the main experimenter.

### Statistical plan

We hypothesised that DMC would be impaired in older adults comparing with young adults, and even more under-ambiguity condition. We also hypothesised that performances in EFs and WM tasks would explain, at least in part, the performances in decision-making tasks. To test these hypotheses, we conducted group comparisons on the EFs and WM performances, as well as on the decision-making performances (i.e., IGT and scenarios task). Then, we conducted correlations and regressions analyses, in order to determine the impact of EFs and WM on DMC. We conducted these analyses for the participants taken all together (i.e., young and older adults), and for each group separately.

### Transparency and openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study, and we follow JARS (Kazak, 2018). Materials, data, and analysis code for this study are available on request to the first author. Data were analysed using JASP (version 0.14.0.0, JASP Team, 2022) and SPSS (version 21.0). This study's design and its analysis were not pre-registered.

## Results

### Group comparisons

*EFs and WM tasks.* Because the two groups differed significantly in educational level, to include this factor into statistical analyses comparing the elderly participants' performances on the EF and WM tasks with those of the young adults the analysis of covariances (ANCOVAs) were conducted.

Table 1 presents the participants' results in the tasks assessing EFs and WM.

*IGT.* To test our hypothesis that DMC would be impaired in older adults comparing with young adults, and especially in the under-ambiguity condition, the repeated-measures ANCOVAs were performed on the number of advantageous choices (i.e., selection of decks C and D) per blocks (i.e., 5 blocks of 20 trials) and per half (i.e., two halves of 50 trials) and on the number of strategy switches (i.e., from advantageous to disadvantageous choices, and vice versa) per blocks. Thus, the ANCOVAs were run with within-subject factor Blocks (1st vs. 2nd vs. 3rd vs. 4th vs. 5th) or within-subject factor Halves (1st vs. 2nd) and with between-subject factor Group (young adults vs. elderly adults). These analyses were followed by post hoc comparisons.

In addition, a repeated-measures ANCOVA with Blocks (1st vs. 2nd vs. 3rd vs. 4th vs. 5th) as within-subject factor and Group (young adults vs. elderly adults) as between-subject factor, and with education level as a covariate was performed on a net score, which was calculated by subtracting the number of disadvantageous deck selections (A + B) from the number of advantageous deck selections (C + D). Preliminary analyses were performed to check for sphericity (Mauchly's test) or normality of distribution (Shapiro-Wilk), and homogeneity of variance (Levene's test).

A violation of sphericity was observed for the number of advantageous choices per blocks, for the net score and for the number of strategy switches. Thus, for these analyses the correction of Greenhouse-Geisser was applied. This correction modifies the degrees of liberty.

*Advantageous choices.* The repeated-measures ANCOVA did not reveal any significant effect of blocks on the number of advantageous choices,  $F(3.5, 341.8) = .97, p = .417$  (see Figure 2), and there was also no simple group effect  $F(1, 97) = 2.21, p = .14$  or group  $\times$  block interference effect  $F(3.5, 341.8) = .80, p = .512$ . As the absence of effect may be due to the introduction of education as a covariate, the ANOVA was performed for young and older adults separately in order to check whether the effect of block exists in each group taken independently. A significant effect was observed for young adults  $F(3.5, 341.8) = 9.13, p < .001, \eta_p^2 = .157$  with fewer advantageous choices being made in the 1st block than in the 3rd, 4th, and 5th blocks and fewer in the 2nd block than in the 4th block (all  $p < .05$ ). The effect of block did not reach significance for older adults  $F(4, 196) = 2.35, p = .055, \eta_p^2 = .046$ .

**Table 1.** Results for executive function and working memory tasks and t-test comparisons for old and young adults.

|                                       | M (SD) OA       | M (SD) YA      | Statistic       | p     |
|---------------------------------------|-----------------|----------------|-----------------|-------|
| Updating ability                      |                 |                |                 |       |
| Letter memory score                   | 11.22 (1.23)    | 11.86 (0.35)   | $F(1, 96)=3.16$ | .078  |
| 1-back score                          | 10.84 (3.39)    | 13.84 (1.39)   | $F(1, 97)=25.7$ | <.001 |
| 2-back score                          | 6.20 (3.94)     | 9.74 (3.59)    | $F(1, 97)=20.4$ | <.001 |
| MRT 1-back                            | 645.52 (92.38)  | 528.67 (78.05) | $F(1, 97)=29.9$ | <.001 |
| MRT 2-back                            | 630.41 (192.45) | 617.54 (96.22) | $F(1, 97)=.051$ | .822  |
| Updating composite score              | 0.93 (0.43)     | 0.44 (0.28)    | $F(1, 97)=33.9$ | <.001 |
| Switching ability                     |                 |                |                 |       |
| Switching cost on errors (FlexiCat)   | 0.34 (0.80)     | 0.28 (0.93)    | $F(1, 97)=.297$ | .587  |
| Switching cost on errors (FlexiPaire) | -0.34 (0.96)    | 0.08 (0.63)    | $F(1, 97)=8.38$ | .005  |
| Switching composite score             | -0.00 (0.03)    | 0.01 (0.04)    | $F(1, 97)=5.72$ | .019  |
| Inhibition ability                    |                 |                |                 |       |
| SSRT stop-signal                      | 225.41 (96.93)  | 209.34 (80.27) | $F(1, 97)=1.57$ | .212  |
| Stroop score (interference board)     | 0.86 (0.23)     | 1.37 (0.27)    | $F(1, 97)=66.6$ | <.001 |
| Working memory ability                |                 |                |                 |       |
| Digit span forward                    | 6.34 (1.38)     | 6.84 (0.27)    | $F(1, 97)=.18$  | .672  |
| Digit span backward                   | 5.06 (1.19)     | 5.98 (1.35)    | $F(1, 97)=5.03$ | .027  |
| Complex span—baba                     | 4.86 (1.13)     | 5.52 (0.61)    | $F(1, 97)=2.32$ | .13   |
| Complex span—reading operation        | 3.90 (1.33)     | 4.76 (1.92)    | $F(1, 97)=1.32$ | .25   |
| Complex span—continuous operation     | 3.42 (1.21)     | 4.30 (1.83)    | $F(1, 97)=3.02$ | .085  |
| Working memory composite score        | 0.67 (0.14)     | 0.79 (0.15)    | $F(1, 97)=3.72$ | .056  |
| Mood before IGT                       |                 |                |                 |       |
| BMIS: Good/bad                        | 55.32 (4.52)    | 51.27 (5.06)   | $F(1,95)=11.1$  | <.001 |
| BMIS: Aroused/Calm                    | 27.58 (3.76)    | 27.63 (3.19)   | $F(1,95)=.199$  | .656  |
| Mood before scenarios                 |                 |                |                 |       |
| BMIS: Good/bad                        | 55.32 (4.52)    | 49.51 (5.82)   | $F(1, 94)=19.8$ | <.001 |
| BMIS: Aroused/Calm                    | 27.58 (3.76)    | 27.26 (3.58)   | $F(1, 97)=.001$ | .988  |

IGT: Iowa Gambling Task; BMIS: Brief Mood Introspection Scale; OA: Old Adults; YA: Young Adults; MRT: Mean Response Time; SSRT: Stop Signal Reaction Time.

For switching scores, the higher the scores, the less flexible the participants were. For the updating scores, the higher the scores, the more efficient the updating skills were. For inhibition ability, the higher the SSRT, the more impulsive the participants were, and the higher the Stroop z-score, the more efficient the interference suppression skills were. For working memory, the higher the scores, the more efficient the working memory skills were. For the good/bad mood scale and the arousal/calm scale, the higher the scores, the more pleasant and aroused the participant's mood was.

There was no significant effect of halves (trials 1–50 vs. trials 51–100),  $F(1, 97)=.48$ ,  $p=.48$  (see Figure 3a), and no significant group effect  $F(1, 97)=2.21$ ,  $p=.14$  nor a group  $\times$  halves interference effect  $F(1, 97)=2.54$ ,  $p=.11$ . As previously, the ANOVA was performed for young and older adults separately. A significant effect was observed for young adults,  $F(1, 49)=791$ ,  $p<.001$ ,  $\eta_p^2=.94$ , but also older adults,  $F(1, 49)=579.0$ ,  $p<.001$ ,  $\eta_p^2=.922$ , with fewer advantageous choices being made in the 1st half than in the 2nd half in both groups.

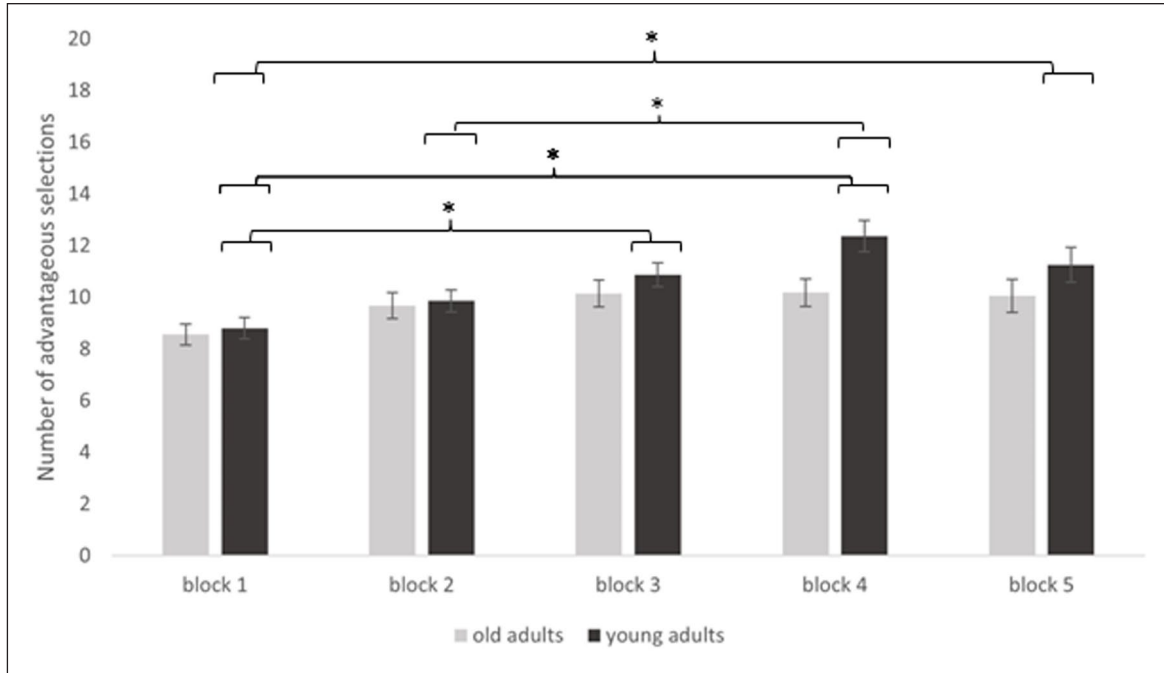
**Strategy switching.** A repeated-measures ANCOVA showed a significant effect of blocks,  $F(3.45, 335.1)=9.04$ ,  $p<.001$ ,  $\eta_p^2=.08$ , on the number of switches (see Figure 4). The post hoc analyses showed significant differences in the number of switches between the 1st, 2nd, 3rd, 4th, and 5th blocks; between the 2nd and 3rd blocks, the 4th and 5th blocks; and between the 3rd, 4th, and 5th blocks (all  $p<.05$ ). The participants switched less often between

the two kinds of decks as the task progressed. Neither a simple effect of group,  $F(1, 97)=.002$ ,  $p=.96$ , nor a group  $\times$  block interaction effect,  $F(3.45, 335.1)=0.28$ ,  $p=.86$ , was observed on the number of switches.

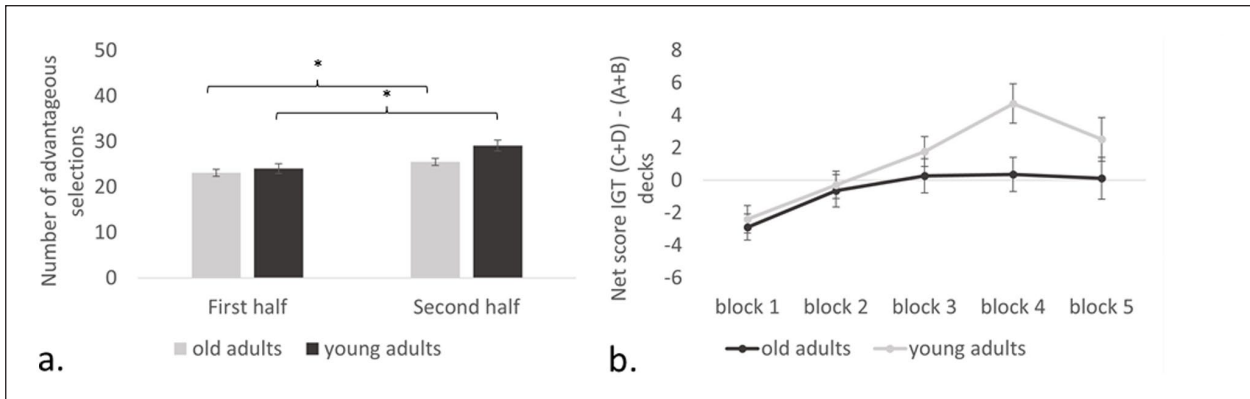
**Net score.** As far as the net score is concerned, there was no significant effect of block,  $F(3.52, 341.8)=.97$ ,  $p=.42$ , no simple group effect,  $F(1, 97)=2.21$ ,  $p=.14$ , and no group  $\times$  block interference effect,  $F(3.52, 341.8)=.80$ ,  $p=.52$ , (see Figure 3b).

**Scenario task.** The number of risky and ambiguous decisions (i.e., under-risk and under-ambiguous conditions, respectively) was used for the statistical analysis. Preliminary analyses were performed to check for normality of distribution (Shapiro–Wilk) and homogeneity of variance (Levene's test). To provide a global comparison of young and older adults' decision-making, repeated-measures ANCOVAs were first performed on the total risky decisions and the total





**Figure 2.** Mean number of advantageous selections in IGT blocks (max=20) in old and young adults (bars represent standard errors).



**Figure 3.** (a) Mean number of advantageous selections in IGT halves in old and young adults. (b) IGT net score, corresponding to (C + D)-(A + B) deck selections. Bars represent standard errors.

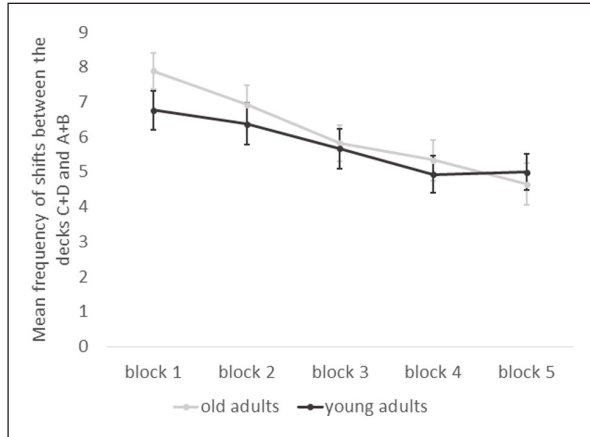
ambiguous decisions independently, with Group (young adults vs. elderly adults) as between-subject factor and Condition (under risk, under ambiguity) as within-subject factor. These analyses were then run on the number of risky decisions and on the number of ambiguous decisions separately, with Group as between-subject factor and first Context (gain vs. loss, for the under-risk condition only) and then Numerical presentation (percentage vs. frequency) as within-subject factor. Education was included as covariate in all the analyses. These analyses were followed by post hoc comparisons.

*Under risk task.* In the risk condition, the ANCOVA showed a significant group effect  $F(1, 97) = 11.14, p < .001, \eta_p^2 = .103$  but no context effect,  $F(1, 97) = .37, p = .542,$

with the young adults taking more risks overall ( $M = 18.86, SE = 0.52$ ) than the elderly adults ( $M = 15.86, SE = 0.44$ ) (see Figure 5a). More importantly, a significant group  $\times$  context interaction effect,  $F(1, 97) = 17.74, p < .001, \eta_p^2 = .109,$  was observed. Both groups took more risks in the loss than in the gain context. In the gain context, young adults took significantly more risks than elderly adults (respectively,  $M = 8.10, SE = 2.40; M = 4.32, SE = 2.42 (p < .001)$ , but in the loss context, both groups took a similar number of risks (respectively,  $M = 10.76, SE = 4.55; M = 11.54, SE = 2.35; t(98) = 1.27, p = .21$ ) (see Figure 5b).

A second ANCOVA, with percentages of certainty as within-subject factor, showed neither a percentage-of-certainty effect  $F(6.82, 661.82) = .595, p = .765,$  nor a

group  $\times$  certainty interaction effect  $F(6.82, 661.82)=1.28$ ,  $p=.255$  (see Figure 6). Supplementary ANCOVAs were performed for the two contexts (i.e., gain and loss) independently. In the gain context, no significant effect of the percentage of certainty  $F(8, 776)=1.44$ ,  $p=.177$  was observed. However, a significant simple effect of the group  $F(1,97)=68.81$ ,  $p<.001$ ,  $\eta^2=.098$  and a significant group  $\times$  certainty interaction effect  $F(8, 776)=7.84$ ,  $p<.001$ ,  $\eta^2=.056$  were observed. The post hoc analyses showed that the two groups took comparable risks for all the percentages of certainty (all  $p_{\text{bonf}}>.151$ ), except for 2% ( $t(98)=-10$ ,  $p_{\text{bonf}}<.001$ ) and 60% ( $t(98)=-5$ ,  $p_{\text{bonf}}<.001$ ). In both cases, young adults took more risks than elderly adults (see Figure 6a). In the loss context, significant effects of the percentage of certainty  $F(8, 776)=2.35$ ,  $p=.017$ ,  $\eta^2=.016$ , of the group  $F(1,97)=7.45$ ,  $p=.008$ ,  $\eta^2=.018$ , and a group  $\times$  certainty interaction



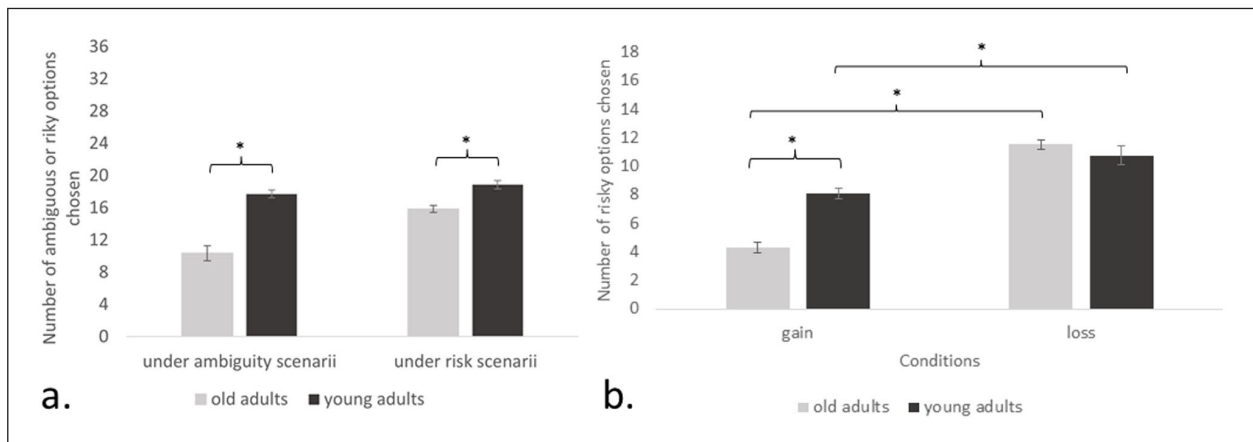
**Figure 4.** Mean frequency of switches between advantageous (C + D) and disadvantageous decks in IGT (bars represent standard errors).

effect  $F(8, 776)=11.78$ ,  $p<.001$ ,  $\eta^2=.078$  were observed. The post hoc analyses revealed that the number of risks differed between the two groups only for 2% certainty  $t(98)=8.78$ ,  $p_{\text{bonf}}<.001$ , with more risks being taken by the elderly adults (see Figure 6b).

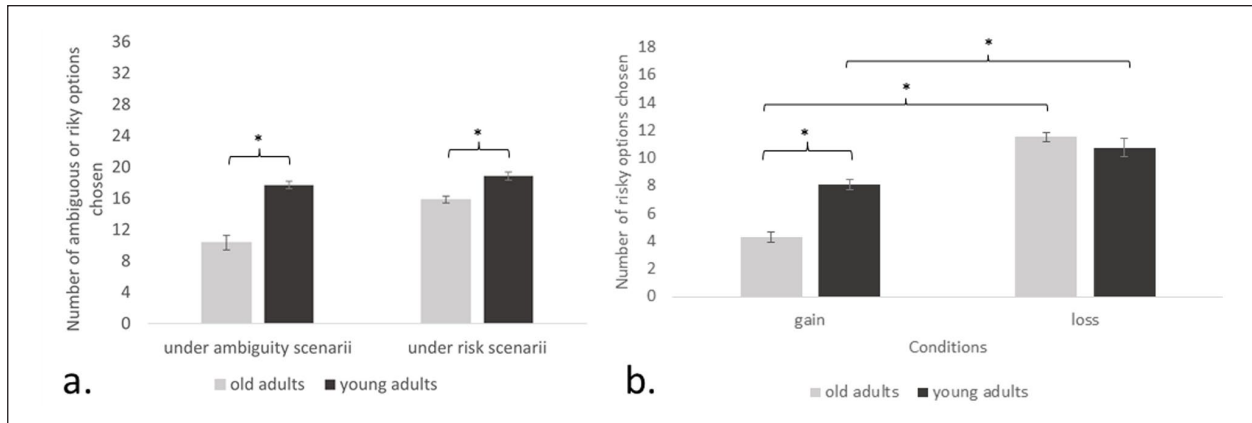
The correlation analysis showed no relation between the percentage of certainty and the number of risky options selected by the young adults in the gain context ( $r=-.09$ ,  $p=.064$ ). However, in the loss context, the higher the percentage of certainty was, the more likely the young adults were to select the risky option ( $r=.26$ ,  $p<.001$ ). The elderly adults took more risks in the gain context when the percentage of certainty was high ( $r=0.19$ ,  $p<.001$ ), but fewer risks in the loss context when the percentage of certainty was high ( $r=-0.11$ ,  $p=.023$ ).

In both conditions, under risk and under ambiguity, half of the trials expressed the numerical information in frequencies and the other half in percentages. In the under-risk condition, the simple effect of numerical presentation,  $F(1, 97)=.12$ ,  $p=.73$  was not significant and there was no significant group  $\times$  numerical presentation interaction effect,  $F(1, 97)=.18$ ,  $p=.66$ .

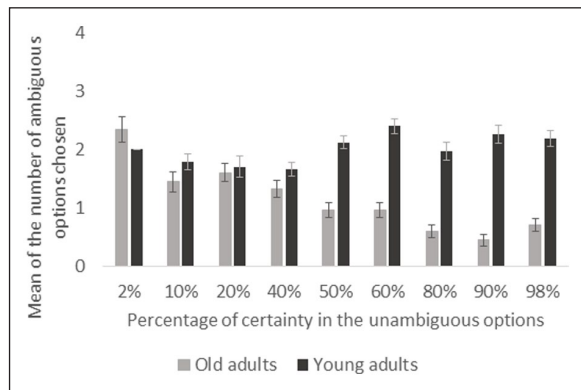
**Under ambiguity task.** In the under-ambiguity condition, the ANCOVA run with the group and percentage of certainty factors showed a significant effect of the group,  $F(1,97)=33.18$ ,  $p<.001$ ,  $\eta_p^2=.255$ , with older adults selecting significantly fewer ambiguous options ( $M=10.36$ ,  $SE=0.93$ ) than young adults ( $M=17.72$ ,  $SE=0.48$ ). The group  $\times$  certainty interaction was also significant  $F(5.62, 545.44)=14.92$ ,  $p<.001$ ,  $\eta_p^2=.133$  (see Figure 7). After Bonferroni correction, the post hoc analysis showed significant differences between young and elderly adults for the 50%, 60%, 80%, 90%, and 98% certainty conditions (all  $p<.001$ ), with older adults choosing fewer ambiguous options than young adults. There were no significant differ-



**Figure 5.** (a) Mean selections of less advantageous choices: ambiguous in under-ambiguity scenarios and risky in under-risk scenarios. (b) Mean selections of risky options in under-risk scenario depending on the context, that is, gain or loss. Bars correspond to standard errors.



**Figure 6.** Mean number of risky options selected depending on the percentage of certainty of these options, (a) in gain context and (b) in loss context. Bars correspond to standard errors, maximum choice of ambiguous options per percentage = 2.



**Figure 7.** Mean number of ambiguous options selected depending on the percentage of certainty of the unambiguous options. Bars correspond to standard errors, maximum choice of ambiguous options per percentage = 4.

ences between different percentages of certainty in young adults. After Bonferroni correction, the elderly adults chose significantly fewer ambiguous options in the 2% condition than in any other condition, except for 20%; in the 10% condition, they chose significantly fewer such options than in the 80%, 90%, and 98% conditions; in the 20% condition significantly fewer than in the 50%, 60%, 80%, 90%, and 98% conditions; and in the 40% condition significantly fewer than in the 90% condition. The correlation analyses showed opposite decisional strategies in the young and elderly adults. In young adults, the higher the percentage of certainty was, the more ambiguous options they selected ( $r = .105, p < .001$ ). By contrast, in the case of the elderly adults, the higher the percentage of certainty was, the smaller the number of ambiguous options selected ( $r = -.444, p < .001$ ).

In the under-ambiguity condition, the simple effect of numerical presentation was not significant,  $F(1, 97) = .016, p = .90$ , and there was no significant group  $\times$  numerical presentation interaction effect  $F(1, 97) = .002, p = .96$ .

### Correlation and regression analyses run on EF and WM tasks

**Correlations.** We started by analysing the correlations between the results of the EF tasks (i.e., the updating composite score, the switching composite score, the Stroop score, and the SSRT) and the WM composite score, and the results of the decision-making tasks for the two groups taken together. The correlation analysis was then performed for each group (i.e., older adults and young adults) separately.

Preliminary analyses were run to check for normality of the distribution (Shapiro–Wilk). Pearson’s  $r$  coefficient was used, except in the case of a deviation from normality, in which case Spearman’s rho was used instead.

**Global correlations.** No correlation was found between the cognitive task scores and the number of advantageous choices in the IGT. However, the strategy changes during the IGT (i.e., number of switches between good and bad decks) correlated with the Stroop score ( $\rho = -0.22, p = .026$ ; see Figure 8).

For the scenario tasks, the updating composite score ( $r = -.428, p < .001$ ), the WM composite score ( $r = .245, p = .014$ ), and the Stroop score ( $r = .435, p < .001$ ) correlated with the total number of ambiguous options chosen in the under-ambiguity condition (see Figure 9). The updating composite score ( $r = -.315, p < .001$ ) and the Stroop score ( $r = .382, p < .001$ ) correlated with the total number of risky options chosen in the under-risk condition (see Figure 10).

In the case of the scenarios under risk, the updating composite score ( $r = -.423, p < .001$ ) and the Stroop score ( $r = .480, p < .001$ ) correlated with the number of risky options chosen in the gain context (see Figure 10). No other correlation was significant in either the gain or the loss context.

**Correlations for young and older adults.** Significant correlations (see Table 2) were observed for the older adults between the switching strategy at the IGT and the Stroop score, and for the young adults between the SSRT on one hand, and both the total ambiguous decisions and the risky decisions in gain context, on the other.

**Regressions.** To analyse the involvement of EFs and WM in the decision-making competency, multiple regression analysis was performed by entering—for each analysis—one of the decision-making ratings (i.e., advantageous decisions during the IGT, number of switches during the IGT, total risky choices in the scenario task under risk, total ambiguous choices in the scenario task under ambiguity) as dependent variable and the updating composite score, the WM composite score, the switching composite

score, the Stroop score, and the SSRT of the Stop Signal task (SST) as predictors. The analysis was first performed on all the results taken together without distinguishing between young and elderly adults, and then, on the two groups taken separately. Only the significant models are reported in Table 3.

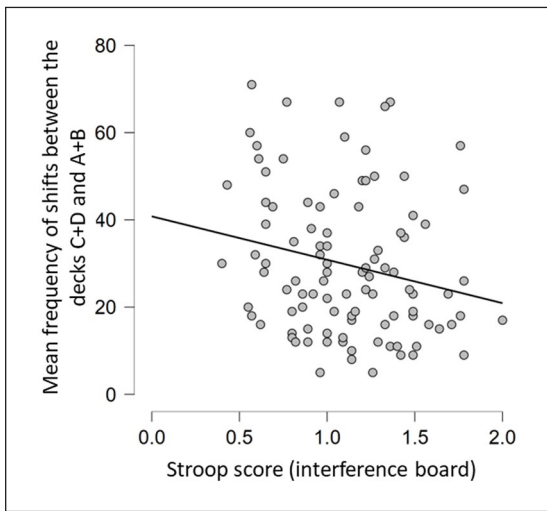
Regarding the number of shifts between the advantageous and the disadvantageous decks during the IGT, one model indicated that the Stroop score explained 3.6% of the variance. Two models were identified for the total number of ambiguous choices in the under-ambiguity condition of the scenario task. The most robust models, including the Stroop score and the updating composite score, explained 21.3% of the variance. For the total number of risky choices in the under-risk condition of the scenario task, one model indicated that the Stroop score explained 14% of the variance. The analysis performed for each context (i.e., gain vs. loss) separately showed that the Stroop score explained 22% of the variance in the gain context. However, no significant model was identified for the loss context.

Concerning the older adults, the Stroop score explain for 14.7% of the variance of the IGT strategy switching. Concerning the young adults, the SSRT explain for 6% of the variance of the number of ambiguous choices.

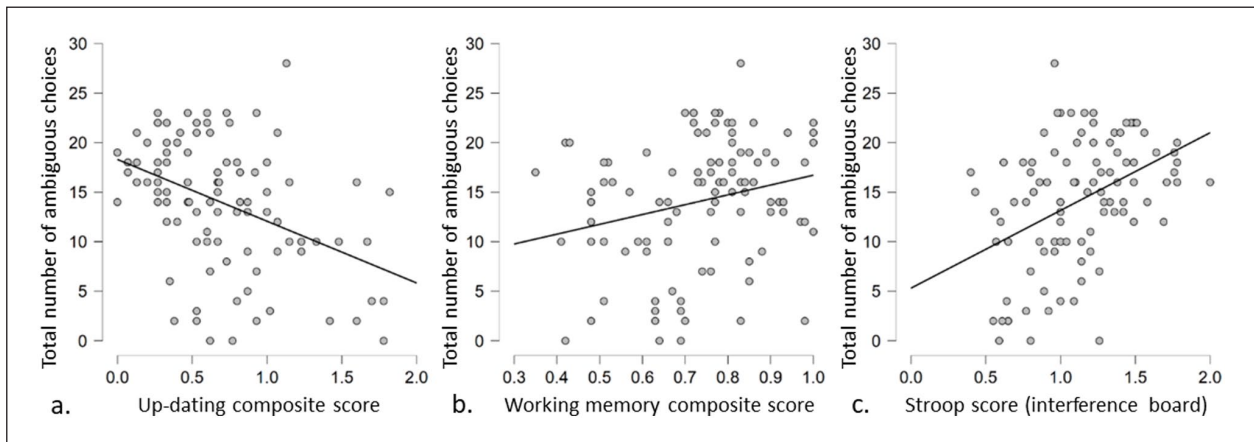
**Discussion**

This study aimed to investigate the differences in DMC between young and elderly adults under risk and under ambiguity. To this end, both tasks based on everyday life situations and the traditional IGT were used. This study also examined how EFs (updating, mental set shifting, and the inhibition process) and WM impact DMC in older compared with younger adults.

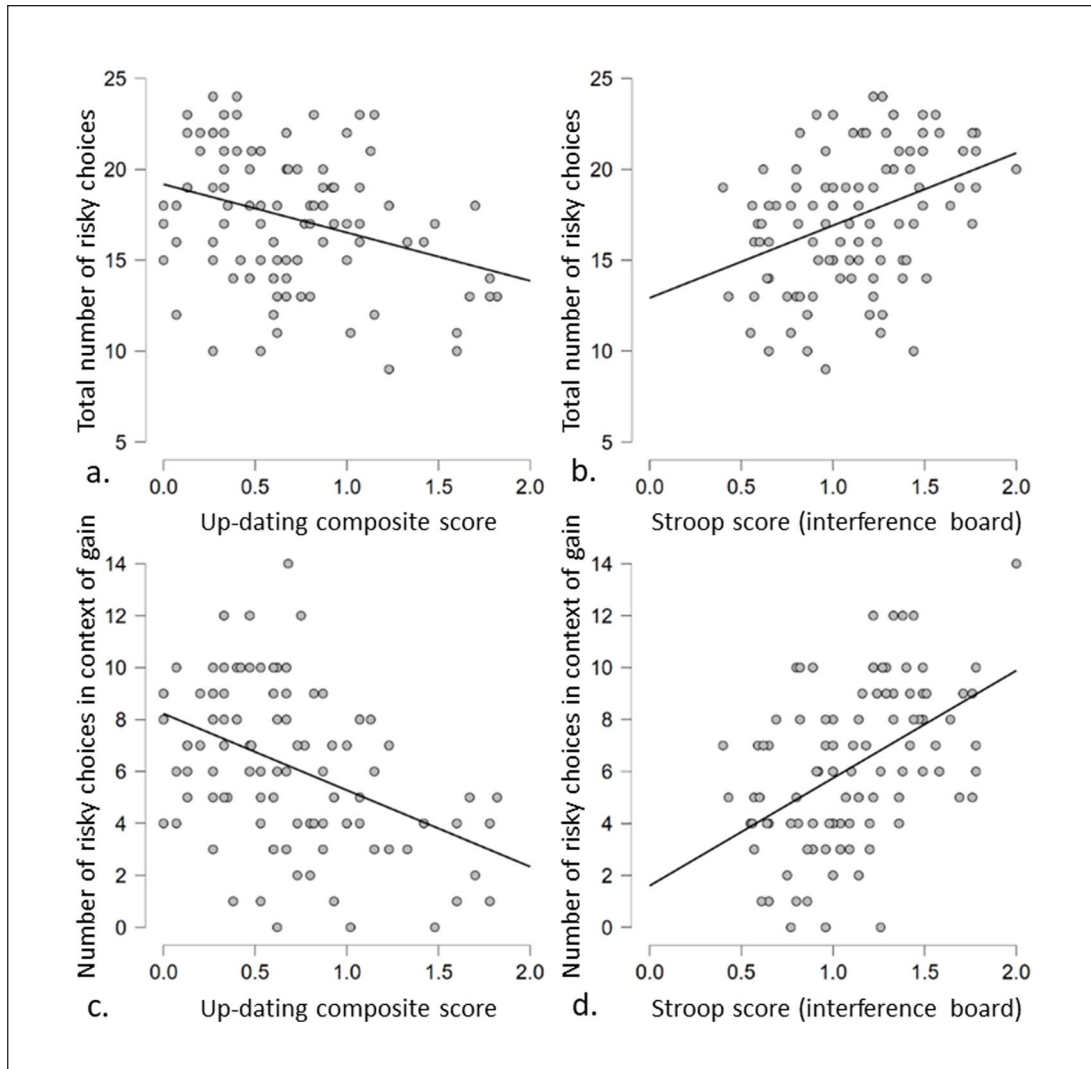
The results of the decisional tasks will be discussed first and the performances of the young and elderly adults will



**Figure 8.** Correlations between the number of switches during the IGT and the Stroop score, with the maximum number of switches being 99.



**Figure 9.** Correlations between the total number of ambiguous options (max=36) chosen in the under-ambiguity condition and the (a) updating composite score, (b) working memory composite score, and (c) Stroop score.



**Figure 10.** Correlations between the total number of risky options (max=36) chosen in the under-risk condition; and the (a) updating composite score and (b) Stroop score; and between the number of risky options chosen in the gain context (max=18), the (c) updating composite score and the Stroop score.

be compared, before describing the results of the cognitive function tasks and then turning to the correlation and regressions analyses that examined the relationships between cognitive functions and DMC for all participants taken together.

### Decision-making competence and ageing

In this study, two tasks were used to assess decision-making competence (DMC): the IGT and a scenario task with two decision-making conditions: under risk and under ambiguity.

*The IGT.* No measurement in the IGT showed a difference between the two groups. First, both groups improved as the task progressed, with more advantageous selections

and higher net scores being observed at the end of the game. However, analyses of each group taken separately revealed a significant increase in the number of advantageous choices made by the young adults over the task, something that was not observed in the elderly adults. Contrasting results are reported in the literature, with some studies observing no age effect on the net score over the five blocks (Wood et al., 2005; Zamarian et al., 2008), some studies indicating that elderly adults achieve a lower net score over the task than young adults (Fein et al., 2007), and others describing heterogeneous results, with only a subset of participants in the older group showing impaired performances (Denburg et al., 2007; Wood et al., 2005; Zamarian et al., 2008). However, when discussing the results, it is important to remember that the definition of the age ranges for young and elderly adults differed

**Table 2.** Correlations between the results in the decision-making tasks and the results in executive and working memory tasks for high and low performers independently.

|                                | Advantageous decisions IGT | Strategy switching IGT | Total risky decisions | Total ambiguous decisions | Risky decisions in gain context | Risky decisions in loss context |
|--------------------------------|----------------------------|------------------------|-----------------------|---------------------------|---------------------------------|---------------------------------|
| Switching composite score      |                            |                        |                       |                           |                                 |                                 |
| Older adults                   | rho=-0.26,<br>p=.068       | rho=-0.11,<br>p=.45    | rho=0.05,<br>p=.741   | rho=-0.03,<br>p=.819      | rho=-0.02,<br>p=.870            | rho=0.12,<br>p=.416             |
| Young adults                   | rho=0.22,<br>p=.125        | rho=-0.14,<br>p=.319   | rho=-0.04,<br>p=.871  | rho=0.03,<br>p=.832       | rho=-0.10,<br>p=.499            | rho=-0.03,<br>p=.827            |
| Updating composite score       |                            |                        |                       |                           |                                 |                                 |
| Older adults                   | rho=0.14,<br>p=.349        | r=0.16,<br>p=.28       | r=-0.20,<br>p=.168    | r=-0.19,<br>p=.197        | r=-0.20,<br>p=.170              | r=-0.06,<br>p=.682              |
| Young adults                   | r=-0.17,<br>p=.242         | rho=-0.04,<br>p=.785   | r=-0.02,<br>p=.900    | r=-0.07,<br>p=.646        | rho=0.09,<br>p=.560             | r=-0.2,<br>p=.914               |
| Stroop score                   |                            |                        |                       |                           |                                 |                                 |
| Older adults                   | rho=-0.14,<br>p=.331       | r=-0.41,<br>p=.003**   | r=0.04,<br>p=.808     | r=0.09,<br>p=.549         | r=-0.04,<br>p=.805              | r=-0.08,<br>p=.564              |
| Young adults                   | r=0.23,<br>p=.110          | r=-0.11,<br>p=.466     | r=0.22,<br>p=.127     | r=-0.03,<br>p=.818        | r=0.15,<br>p=.286               | r=0.10,<br>p=.514               |
| SSRT                           |                            |                        |                       |                           |                                 |                                 |
| Older adults                   | rho=0.187,<br>p=.194       | r=0.04,<br>p=.77       | rho=-0.07,<br>p=.826  | r=-0.14,<br>p=.329        | rho=0.07,<br>p=.640             | r=-0.10,<br>p=.474              |
| Young adults                   | r=0.05,<br>p=.748          | rho=0.22,<br>p=.127    | rho=0.15,<br>p=.284   | rho=0.29,<br>p=.038*      | rho=-0.33,<br>p=.018*           | rho=0.26,<br>p=.071             |
| Working memory composite score |                            |                        |                       |                           |                                 |                                 |
| Older adults                   | rho=-0.20,<br>p=.155       | r=-0.22,<br>p=.125     | r=0.09,<br>p=.523     | r=0.10,<br>p=.480         | r=-0.07,<br>p=.621              | r=0.20,<br>p=.172               |
| Young adults                   | r=0.01,<br>p=.964          | r=-0.04,<br>p=.772     | rho=-0.02,<br>p=.871  | rho=-0.15,<br>p=.285      | r=-0.12,<br>p=.390              | rho=0.04,<br>p=.794             |

IGT: Iowa Gambling Task; SSRT: Stop Signal Reaction Time.

\* < .05, \*\* < .01.

considerably between the studies and that this might have impacted the results.

In our study, the number of shifts between advantageous and disadvantageous decks was also analysed. Both groups switched more often between the decks at the beginning of the exercise (i.e., Blocks 1 and 2) than at the end (i.e., Blocks 4 and 5). According to Zamarian et al.'s (2008) results, elderly adults changed strategy significantly more often and adapted their behaviour significantly less often during the task than young adults. For their part, Wood et al. (2005) found that decisions made by elderly adults were based as much on the gains as the losses, whereas young adults' decision-making was more sensitive to the losses. Older adults deck selections were also highly dependent on recent outcomes, unlike those of the young adults, who selected the decks independently of this characteristic.

There are several causes that might explain this divergence in the data. First, the ages of the participants in the different groups, and especially in the young adults group, differed between the studies. In the present study, the average age of the young group was at least 10 years younger than in Zamarian et al. (2008), Denburg et al. (2007) or Fein et al. (2007). The brain undergoes modifications over

time and performances in cognitive tasks can therefore be modulated even among a population of young adults. For example, the increase in white matter reaches its peak at around 37 years of age, and then decreases at a slower rate than it has developed (Lebel et al., 2012). Recent studies have specifically described links between white matter integrity and fluid intelligence (Chen et al., 2020; J. Li et al., 2020). The IGT, at least in the initial stages, is thought to require fluid intelligence (D. Li et al., 2017). A first hypothesis could be that fluid intelligence is less mature in a group with an average age of 26 years than in groups with an average age of 36 years or more. Finally, the lack of maturity in the young group could have had the same consequences for IGT performances as the deterioration that impacts elderly adults. This could explain why we did not find any difference between our two age groups, even though such differences have been identified in other studies. A second hypothesis is drawn from studies describing elderly adults' DMC as heterogeneous and involving other factors that can influence decision-making only when considered in combination with age. For instance, different patterns of activations in elderly adults can lead to either better or poorer performances. Indeed, bilateral activations in vm-PFC or peak amplitudes in anticipatory

**Table 3.** Multiple regressions with the decision-making tasks as criterion and the executive and working memory tasks as factor scores.

|   | $\beta$ | $t$   | $p$  |
|---|---------|-------|------|
| Older and young adults together               |         |       |      |
| “Strategy switching (IGT)”                    |         |       |      |
| Stroop score                                  | -.21    | -2.16 | .033 |
| $R^2_{adj} = .036, F(1,98) = 4.65, p = .033$  |         |       |      |
| “Ambiguous choices (scenario task)”           |         |       |      |
| Stroop score                                  | .28     | 2.40  | .018 |
| Updating composite score                      | -.26    | -2.24 | .028 |
| $R^2_{adj} = .213, F(2,97) = 14.39, p < .001$ |         |       |      |
| “Risky choices (scenario task)”               |         |       |      |
| Stroop score                                  | .38     | 4.09  | .000 |
| $R^2_{adj} = .14, F(1,98) = 16.72, p < .001$  |         |       |      |
| “Risky choices in context of gain”            |         |       |      |
| Stroop score                                  | .48     | 5.42  | .000 |
| $R^2_{adj} = .22, F(1,98) = 29.35, p < .001$  |         |       |      |
| Older adults only                             |         |       |      |
| “Strategy switching (IGT)”                    |         |       |      |
| Stroop score                                  | -.41    | -3.07 | .003 |
| $R^2_{adj} = .147, F(1,48) = 9.45, p = .003$  |         |       |      |
| Young adults only                             |         |       |      |
| “Ambiguous choices (scenario task)”           |         |       |      |
| SSRT  | .28     | 2.03  | .048 |
| $R^2_{adj} = .06, F(1,48) = 4.12, p = .048$   |         |       |      |

IGT: Iowa Gambling Task; SSRT: Stop Signal Reaction Time.

skin conductance responses before picking a card from advantageous decks were related to better performances in the elderly adults (Denburg et al., 2007; Rogalsky et al., 2012). Without objective measures, some characteristics of the decision process in elderly adults may remain unidentified. It is possible that, for some random reasons, the elderly adults included in the present study were better able to compensate, resulting in behaviours similar to those of the young adults.

*The under-risk condition of the scenario task.* In the under-risk condition, young adults selected more risky options (i.e., options with a percentage of certainty less than 100) than elderly adults. These results corroborate those of Deakin et al. (2004) and Lee et al. (2008). Using the Game of Dice Task (GDT), Deakin et al. (2004) showed that elderly adults also took more time to deliberate than young adults. In the present study, the deliberation time could not be analysed as the response time was also dependent on the reading speed.

Interestingly, the decision-making context (i.e., gain or loss) may influence the decision depending on age. In the present study, both groups took similar risks in the loss context but young adults took more risks than elderly adults in the gain context. This tendency to avoid risk in a gain context and, on the contrary, to prefer it in a loss context has been described in the Prospect Theory proposed

by Kahneman and Tversky (1979). This posits that two mathematically equivalent problems can be influenced by information that is irrelevant from a rational perspective and therefore leads to different decisions (Gollier et al., 2003). Thus the young and elderly adults in the present study were sensitive to the overall context (i.e., to the frame effect), albeit to a lesser extent in the younger than the older group, especially in the case of the gain context. These results corroborate those of Kim et al. (2005) who, based on the resource allocation hypothesis (Hess et al., 2001), suggested that elderly adults are more inclined to rely on the heuristic mode to perform highly complex tasks, even though this is less suitable for making decisions in risk conditions (McCarrey et al., 2010). In accordance with STT (Agustí et al., 2017; Carstensen et al., 1999, 2003; Spreng & Turner, 2019), because elderly adults are more interested in their well-being, they prefer to avoid risk in a gain context (i.e., in order to obtain a smaller but certain gain), and seek it in a loss context (i.e. to try to avoid a certain loss). By contrast, young adults' actions are directed by the pursuit of new knowledge and they therefore take more risks than elderly adults in a gain context, because this is more conducive to the acquisition of new knowledge. Despite this operating mode, they are still influenced by the context, and generally tend to avoid risky options in order to obtain a gain rather than to prevent a loss. Their choices therefore seem to be guided by their search for knowledge and their estimation of their survival chances. Interestingly, when two groups of adults, one being younger than the other (i.e., young elderly adults vs very elderly adults), were compared on healthcare scenarios, the opposite effect was observed, with the eldest choosing more disadvantageous options than the younger elderly adults (Pertl et al., 2017). According to the authors, impaired EFs are the cause here.

The number of risks taken depending on the percentage of certainty and the context (i.e., gain or loss) differed considerably between the two groups for 2% certainty, with the old and young adults exhibiting opposite response patterns. Indeed, in a gain context, young adults almost always chose the risky options, whereas the elderly adults almost never did so. In a loss context, young adults never selected the risky options, whereas elderly adults usually chose them. The elderly adults' response pattern seems to be quite logical in the light of their global answering strategy. However, the explanation for the young adults' behaviour is less clear. In the gain context, it is possible that the very low percentage of certainty overly stimulates their desire for novelty, causing them to prefer the risky option. With regard to the loss context, we do not know how to interpret their risk avoidance. It might be due to a random effect and therefore have to be re-investigated in future studies. Furthermore, the results of the correlation analyses seem to be consistent with the SST. Indeed, the elderly

adults adopted a strategy that favoured their well-being, by taking higher risks with a higher percentage of certainty in the gain context, but lower risks with a higher percentage of certainty in the loss context. By contrast, the young adults adopted a strategy that satisfied their curiosity, at least in the loss context, during which they took an increasing number of risks as the percentage of certainty increased.

Another factor that may influence decision-making is the type of numerical presentation (i.e., frequency vs percentage). In the present study, no effect of numerical presentation was observed. After an earlier study had shown that ratio processing predicts decision-making under risk (Brand et al., 2014), Pertl et al. (2017), nevertheless, found that the frequency format was the hardest for the eldest participants to process when compared with younger participants. In the light of these two pieces of information, we might have expected the decisions to be less advantageous when the relevant information was given in frequencies.

*The under-ambiguity condition of the scenario task.* With regard to the under-ambiguity condition of the scenario task, the young adults selected significantly more ambiguous options (i.e., with unknown percentage of certainty) than the elderly adults. It is possible that, as in the case of decision-making under risk, young adults selected more ambiguous options than elderly adults because this approach was more consistent with their goals, that is, the quest for knowledge. Tannou et al. (2020) observed that ageing is very clearly associated with slower speed processing in decision-making under ambiguity. However, decisions based on personal experience and with no major temporal constraints appeared to be little impacted by ageing. It should therefore be very easy for elderly participants to succeed in our task, which is based on everyday life situations and has no time restrictions.

Whereas young adults selected equal proportions of ambiguous options for all the certainty percentages of the unambiguous options, elderly adults globally selected fewer ambiguous options as the percentage of certainty of the unambiguous options increased. To our knowledge, no other study has used scenarios inspired by everyday life to assess decision-making under ambiguity in a population of elderly adults. However, Lauriola et al. (2007) proposed a similar exercise, which focused on healthcare situations and was addressed to young adults only. Their results showed a general trend to avoid ambiguity, even among the participants considered as “ambiguity seeking.” Using Ellsberg’s task, they also showed that the higher the probability of the unambiguous urn was, the more frequently the participants selected it instead of the ambiguous urn. This is precisely what we observed in the elderly adults in the present study, but not in their younger counterparts. However, some studies that used tasks equivalent to Ellsberg’s with young and older adults did not find an

effect of age, at least when no feedback was given (Sproten et al., 2018). The emotional state of the young adults included in the present study could be responsible for these differences. The young adults’ data were collected remotely during the COVID-19 pandemic. This context might have triggered some level of stress in the young adults and this could have impacted their decisions. It does indeed appear that decision-making under ambiguity is more vulnerable to stress-inducing situations than decision-making under risk (Cano-López et al., 2016).

### *EFs and WM during ageing*

The present results revealed significant differences between the performances of young and elderly adults in cognitive tasks. Indeed, the elderly participants obtained lower scores than their younger counterparts in the tasks assessing updating, inhibition, and WM abilities. These results corroborate anterior studies. Indeed, the updating deficit in older adults, measured using the *n*-back task, has been previously reported (Bherer et al., 2004; Bopp & Verhaeghen, 2018; Najberg et al., 2021), with response times increasing and the number of hits decreasing with ageing. Regarding inhibition ability, both groups performed comparably in the SST, but young adults performed better than old adults in the Stroop test. The findings reported in the literature are quite contradictory. Bherer et al. (2004) and Troyer et al. (2006) suggested that the interference suppression component is particularly vulnerable to ageing. However, according to Rey-Mermet and Gade (2018), it remains intact, although they described deficits in tasks requiring motor inhibition (e.g., the SST). Finally, the WM composite score shows that the old and young adults performed comparably, although *p* was very close to the significance threshold. However, the older adults performed significantly worse than young adults in the backward digit span task. This latter result is consistent with the meta-analysis of Bopp and Verhaeghen (2005), which found an effect of age on several span tasks (i.e., short-term memory, reordering, and WM spans), with young adults consistently performing better.

### *Cognitive implications in decision-making competence*

Another aim of our study was to investigate the links between EF (i.e., updating, inhibition, and mental flexibility processes), WM, and decision-making in ageing.

A few of the correlations were significant and, even then, mainly when all the participants’ data were included in the analysis. The strategy changes (i.e., the number of switches between advantageous and disadvantageous decks) correlated with the Stroop score. In fact, the better the Stroop score was, the less participants shifted between decks. According to the regression analysis, the Stroop



score explained 3.6% of the variance in strategy changes. This general result was also, and only, observed in the older adults group, with the Stroop score explaining almost 15% of the variance in strategy changes. To our knowledge, very few studies have investigated the links between IGT performances and EF or WM in elderly adults. Using the Iowa Scale of Personality Change (ISPC), Nguyen et al. (2013) showed an impact of executive personality, and in particular of the impulsivity component, on IGT performances. Wood et al. (2005) showed that the young adults in their experiment owed their good IGT performances to their ability to learn and memorise, whereas the elderly adults relied on their affective reactions. Both groups probably resorted to inhibitory abilities, but not in the same way. The young adults might have deployed a long-term inhibitory strategy (i.e., they first tried to understand the task and then inhibited the disadvantageous decks), while the elderly adults might have deployed a short-term inhibitory strategy (i.e., they adapted their selections more or less trial-by-trial). One argument in favour of the hypothesis that inhibitory ability contributes to accurate IGT performances comes from Schmicker et al.'s (2019) study. These authors showed that elderly adults trained with a selective attention task (involving some inhibitory processing) improved their IGT performances but did not do so when trained with a short memory task. To sum up, the inhibitory ability seems especially useful for performance on the IGT.

Updating and inhibition (i.e., the Stroop score only) were particularly highly involved in the scenario task. Under ambiguity, these two functions explained part of the decision-making performance (i.e., 21%). Under risk, only the Stroop score explained part of the decision-making performance (i.e., 14%). WM was also linked to decision-making under ambiguity, but no causal relation was found. The present study showed that updating (i.e., updating in WM) was particularly highly involved in the scenario task. These results are consistent with those of a previous study using the *N*-back task (Rönnlund et al., 2019). When faced with a situation that requires a decision, memories of similar decision-oriented circumstances are activated to guide the new decision and have to be maintained in WM (Schiebener & Brand, 2015). To increase efficiency, the decision-maker has to focus on the relevant information and therefore to suppress the distracting information. Consequently, only the inhibitory process is involved.

Only one correlation emerged when the two groups were considered separately. This was for young adults and it was between the SSRT (i.e., an indicator of impulsivity) and the number of ambiguous choices. The more impulsive the young adults were (i.e., the higher their SSRT), the more likely they were to seek ambiguity. The regression analysis showed that the SSRT explained 6% of the variance in the ambiguous choices. The scenario task was not designed to demand rapid responding. Considerable

information was given and no time limit was set, meaning that the participants could detect what was relevant, process it, and make the decision they felt was best. Impulsive young participants probably did not take the time to understand what they read and could therefore not process it properly, leading to a more frequent selection of ambiguous options. Indeed, as these options offered the opportunity to achieve bigger gains, they maximised the potential for attentional capture, in particular in impulsive participants and irrespective of the likelihood of winning. According to the SST (Carstensen et al., 1999), as young adults are more sensitive to novelty in order to build new knowledge, they might be more likely to let their DMC be modulated by their impulsivity. In contrast, older adults, who seek to maximise well-being, would be less likely to let impulsivity guide their decisions.

### Limitations

Our study presents some limitations. First, the tasks were programmed to be doable by patients with Alzheimer's disease. It is therefore possible that some of them (i.e., the two tasks assessing mental flexibility and the SST) were too easy to reveal any significant differences between the two age groups. Second, we included 50 participants in each group. Although this is a large number of participants for inferential analyses, it is rather small when conducting robust correlation and regression analyses for each group separately. Unfortunately, the pandemic context meant that we were not able to include more old participants. That is the reason why we preferred to conduct these analyses on all the participants taken together. In future studies, it would be interesting to test the hypothesis that holds that cognitive functions are directly involved in DMC in an age-dependent way. Finally, whereas the elderly adults performed the scenario task in the laboratory, the pandemic required us to modify the task for the young adults, who performed it at home during the lockdown. The mode of administration may have interacted with the performances.

### Conclusion

Compared with young adults, elderly adults showed impaired performances in the majority of the cognitive tasks. There was no difference between the two age groups on the IGT. However, the scenario task revealed higher levels of risk and ambiguity seeking in young than in older adults. Surprisingly, this observation was especially marked under risk condition in the gain context. The SST could provide a satisfactory explanation: elderly adults avoid risk and ambiguity to maximise their well-being, while young adults seek risk and ambiguity in their quest for knowledge. Inhibition and updating would seem to be particularly highly involved in the DMC, whatever the

condition (i.e., under risk or under ambiguity). Decisions in the older adults were more sensitive to interference suppression, particularly in the IGT. In contrast, the young adults were more sensitive to motor inhibition, particularly in the scenario task.

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### Author contributions

F.G., C.B., and H.C. made substantial contributions to the design of the work. F.G. designed the tasks and performed data acquisition, most of the analyses, and interpretation of the data. She was also a major contributor during the writing of the manuscript. H.C. contributed to the data analyses, in particular with regard to the regressions. C.B. and H.C. also contributed significantly to revising the work. All the authors read and approved the final manuscript.

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### Ethics approval and consent to participate

The study was approved by the ethical committee of Comité de Protection des Personnes Ile de France XI and was assigned No. 19031-57438. All the participants received and signed an informed consent form and consent was also explained orally.

### Consent for publication

Not applicable.

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### Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

### Supplementary material

The supplementary material is available at [qjep.sagepub.com](http://qjep.sagepub.com).

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