# Developmental Neuroeconomics: Lifespan Changes in Economic Decision Making

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Dissertationsschrift zur Erlangung des Doktorgrades

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April 2012

- Acknowledgments -

Many people have participated in the development of this thesis, by giving me input or by supporting me otherwise during the three years since I began my Ph.D. project at the AWI. I am especially grateful for the support and fruitful input of my supervisor Prof. Christiane Schwieren, without whom this thesis never would have taken form. I also would like to thank Carsten Diener and Prof. Christian J. Fiebach for making the project possible, and for the prosperous cooperation. I am also much obliged to Gil Sharvit for teaching me how to analyse fMRI data, cooperating on our projects, and first and foremost for being a very good friend.

I am also grateful to the staff of the Alfred Weber Institute for Economics, for the possibilities to discuss my research projects and for providing a very likable work environment.

I also would like to thank the Heidelberg Graduate School for Humanities and Social Sciences, and within this especially my graduate school supervisor Daniela Jopp for the possibility to discuss my research in a highly interdisciplinary environment.

My gratitude goes also to the participants of the conferences where I presented my research, for providing me with helpful comments on the research projects.

Last but not least, I also would like to thank my wife, family, and friends, for supporting me throughout the thesis.

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# Introduction

## Demographic change

By 2050, the number of people in the world age 60 years and older will surpass the number of young people (younger than 15 years of age) for the first time in history, with the oldest old (age 80 years and older) being the world's fastest growing age group (United Nations Population Division, 2002).

According to a prognosis of the German Bureau of Statistics (Statistisches Bundesamt, 2008), a complete reversal of the German population's age structure will be observed in the century between 1950 and 2050. In 2005, 19.3% of the German population was age 65 years or above. When taking into account the actual population surplus of 100,000 people p.a., by 2050 one third of the German population will be age 65 years or above; 15.1 percent will be younger than twenty years; and 51.7 percent of the population is going to be between 20 and 65 years of age. Even if expecting a doubling of the actual immigration rate, these data will only slightly change, with 31.8 percent of the population being age 65 years and older, 15.4 percent being age 20 years and younger, and 52.8 percent in between these two age groups. To hold the actual population ratio of older to younger people constant, an unrealistic population surplus of 3,400,000 people would be needed.

Yet, as quality of life standards continue to increase, it is highly probable that people will actively contribute to society until a higher age. Therefore, from an economic as well as political and social perspective, the development of dependency ratios is of high interest. The total dependency ratio is defined as an age-population ratio of those not in the working force (the dependent part), compared to those typically working (the productive part)[1]. A decrease in these ratios is assumed to mediate a decreased burden on the productive part of the population, the latter being expected to furnish the pensions and other costs caused by those outside the working force. The German Bureau of Statistics report assumes however an increase of the dependency ratio until 2050. In a scenario with a population surplus of 100,000 p.a. the total dependency ratio will increase from 61.0 in 2000 to 77.8 in 2030 and 84.2 in 2050. The old age dependency ratio will increase from 32.6 in 2010 to 47.3 in 2030 and up to 54.5 in 2050. These data do however not assume an increase in retirement age, and "dependency" is based on a very broad definition. In fact, Klein and Unger (2002) suggest, based on

[1] The total dependency ratio is calculated by dividing the total dependent part by the productive part multiplied by 100 and can be subdivided into the child dependency ratio and the older age dependency ratio. The dependent part is in that case defined as those under the age of 20 years and those over the age of 65 years, the productive part as those from age 21 till age 64 years.

cohort-sequential analysis of data from the German Socioeconomic Panel, that an increase in life expectancy essentially implies an increase in active life expectancy, thus in the number of years of independence and self-responsibility in life. Indeed, those German men born in 1927 had, at ages 67-70, spent 81.5 percent of their life in activity, compared to 73 percent for those born ten years earlier, in 1917. A similar, but less pronounced pattern is observed in women; those born in 1927 spent on average 77 percent of their years in activity at ages 67-70, compared to 72.5 percent for those born in 1917.

Age also correlates positively with overall wealth. The risk of poverty in older adults is lower than in all other age groups, and most older Germans have access to an at least satisfactory amount of financial resources (Bundesministerium für Arbeit und Soziales, 2008). Poverty rates in Germany reach a maximum in those parts of the population younger than 20 years of age, and steadily decline afterwards. In the age group of 21 to 64 year old adults, one of the highest poverty risks is held by single parents, which have an almost three times higher poverty risk than older adults. For future times, however, the National Report on Poverty and Prosperity expects a decrease in the wealth of older adults, reflecting a curriculum of discontinuous employment and increases in unemployment.

The aging of the society also has direct impacts on financial programs such as the social security. With the experience of older people, as well as with their potential to contribute to society, aging populations hinge on the civil engagement of their older generations. Kruse and Schmitt argue that older and younger people alike are able to contribute innovations to society and sharpen its competitive edge, and that changes in age do not necessarily imply losses in economic competitiveness (Kruse & Schmitt, 2006, 2009). These scenarios anticipate that older people can be motivated to contribute their potential and strength to society (Kessler & Staudinger, 2007; Tesch-Römer, Engstler, & Wurm, 2006). Understanding and influencing older adults' motivation is one of the many research aims in economic aging research (see e.g., Sproten & Schwieren, 2012).

## The effects of aging on decision making

With a growing part of the population getting older, the potential demands of older adults put increasing strain on already-limited resources. It is therefore of crucial importance to understand the effects of aging on the maintenance of independence, with the target to facilitate and improve independent functioning. In this regard, decision making processes are, given their importance in everyday life functioning, particularly important. In addition, successful decision making has a higher impact for older than for young adults; compensation for disadvantageous judgments and decisions is in relation less demanding for young adults, as they have higher physical resiliency and more time available to cope with unfavorable decision outcomes.

The changes in population structure require people to maintain strong decision-making competence for an increasing proportion of their lifetime. Our western societies highly weight values such as independence and self-determinacy. This implies sharing in decisions with advisors rather than relying on paternalism (Zwahr, 1999). For example, within many older adults' lifetime, there was a shift from a model in which the advice of one's family doctor was never challenged towards a health care model in which patients expect to be equal partners with their doctors in decision making (Mather, 2006). As a result, those who are more able to handle such decisions are more likely to get beneficial health care.

Financial decisions also are an important domain in which older adults are required to make decisions. An increasing part of the population is relying on individual financial plans to maintain the living standard after retirement. Even those individuals that call on professionals to develop a formal financial plan need to be aware that they cannot entirely redraw from making decisions, as tax laws, market conditions, and the individual needs of the investor are constantly changing. Due to a higher life expectancy, savings and financial assets must hold longer, and high-quality decision making must be maintained. In an environment rich in information and with high uncertainty levels, this task can be difficult, even for those with experience in financial decision making. For people with (age-related) reductions in their information processing abilities, making high-quality decisions may be beyond their capabilities. Furthermore, the trends towards geographically dispersed families and single-person households limit older adults' access to support and knowledge from family members.

In studies of self-evaluation, it has been shown that older adults feel relatively confident about their ability to make decisions. This confidence however strongly contrasts with their concern about other cognitive abilities, such as memory, that are underlying decision making abilities (Hertzog, Lineweaver, & McGuire, 1999; Princeton Survey Research, 1998). The neglect of changes in decision making abilities may be due to the fact that decision making involves a large variety of subprocesses, not all of them being influenced equally by aging. Decision making involves for example the ability to think at least one step ahead to examine the consequences of the different possibilities and make the best decision, keeping multiple pieces of information in mind to decide between options, and dealing with the emotional aspects of the decision.

Hence the question to know which subprocesses underlying decision making are the most influenced by age arises. Peters and colleagues hypothesize that age has an impact on the dual processes underlying decisions (Peters, Hess, Västfjäll, & Auman, 2007). They develop three general, complementary propositions about aging and the dual processes. Firstly, aging leads to declines in the efficiency of controlled processing mechanisms associated with deliberation, such as long-term and working memory, or explicit learning. A decline of these deliberative processes may lead to an enhancement of more implicit or automatic forms of knowledge in decisions. Second, the impact of emotional knowledge on decisions may become more important with age, because of age-related changes in social goals. And third, as people age, the experience in the use of affective knowledge increases, making them more expert in the use of affective information and enhancing their ability to rely on it. These propositions have in common the suggestion that adults rely more on affective information as they age, at least in comparison to their deliberative abilities that require greater conscious effort or do not help meet social goals (Carstensen & Turk-Charles, 1994; Hess, Waters, & Bolstad, 2000; Labouvie-Vief, 1999). Hence this shift towards an increased emotional processing may constitute a response of adaption to changes in cognitive skills, life-experiences, and in the processing of goals that promote well-being (Diener & Suh, 1997).

When starting from the premise that emotion processing in older adults has a higher impact on decision making than in young adults, a wide range of consequences can be expected. In fact, in many decisions emotions play a central role (Loewenstein & Lerner, 2000; Mellers & McGraw, 2001). For example, people often take into account the emotional state they will be in after making a decision and therefore choose options minimizing the chance of feeling regret (Mellers, Schwartz, & Ritov, 1999; Ritov, 1996). Probably even more widespread and influential are the unintended influences of emotions. Judgments about the affective value of a stimulus are rapid and easily available, and can be used as guiding cues for judgments and decisions (Finucane, Alhakami, Slovic, & Johnson, 2000; Slovic, Finucane, Peters, & MacGregor, 2007). Even emotions that are in no relation to the decision at hand can influence it (Isen, 2001; Lerner, Small, & Loewenstein, 2004).

Hence, changes in emotional experience that occur with age can have an important impact on decision making. One of the most influential theories in the entire field of aging research probably is the socioemotional selectivity theory (Carstensen, Isaacowitz, & Charles, 1999). According to this theory, older adults are more likely to maintain a positive emotional state, and to generally experience less negative affect than younger adults. Older adults' negative affect also lasts for a shorter time than that of younger adults (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000; Charles, Reynolds, & Gatz, 2001). The reduction in negative affect occurs, according to socioemotional selectivity theory, because the goals of people change when approaching the end of life and perceiving limitations on their time. This shift in goals consists in a stronger focus on achieving affective satisfaction and meaning rather than on the acquisition of new information; therefore, older adults focus more on regulating emotion, causing an enhancement of their everyday emotional experience.

It has been suggested that this enhanced focus on emotion regulation influences attention and memory (Mather, 2004; Mather & Carstensen, 2003). For example, Mather and colleagues observed in older adults a disproportionately poorer memory for negative events (Charles, Mather, & Carstensen, 2003), a distortion of autobiographical memories in a positive direction (Kennedy, Mather, & Carstensen, 2004), and memory distortions that favor chosen options over rejected options (Mather & Johnson, 2000).

The changes in emotional goals can also influence the way decisions are made. For example, older adults prefer to spend time with emotionally meaningful social partners (Fung, Lai, & Ng, 2001; Lang & Carstensen, 1994), probably the ones most likely to fulfill emotional needs. In young adults, this effect appears only if they are subject to a limited time horizon (Fung, Carstensen, & Lutz, 1999). Overall, older adults were found to be more sensitive to factors of the social context, easing the integration of relevant knowledge with the social information, and by that improving the self-reported social experience (Hess, Osowski, & Leclerc, 2005).

Besides the influence of aging on affective and deliberative information processing which may rent older adults more susceptible to various biases than their younger counterparts would be, the higher experience of older adults with most decision making situations may also have a moderating or enhancing effect on decision making. For example, Dijksterhuis and colleagues pointed out that decision making in older adults can be more effective than in younger adults in choices in which past experience provides additional guidance or in which greater deliberation would hinder decision making (Dijksterhuis, Bos, Nordgren, & van Baaren, 2006). Thus, the greater expertise of older adults in some choices can be beneficial for decision making. In fact, it has been shown that older adults can behave more like experts by making decisions faster, seeking out less information and discounting irrelevant information, having a better knowledge and control over the situational variables, and arriving at decision outcomes equivalent or superior to those of younger adults (Kim & Hasher, 2005; Meyer & Pollard, 2004; Tentori, Osherson, Hasher, & May, 2001).

Recently, an additional dimension that can explain part of the age differences in decision making has been established by Ratcliff, Thapar and McKoon (2006, 2007). These authors show that the decision criteria used by older and young adults differ, with younger adults using fewer criterions to reach a decision faster, whereas older adults focus more on decision accuracy.

Hence, most of the modern literature on aging assumes age differences in emotion and deliberative information processing to be underlying changes or non-changes in decision making. However, to quote Hanoch, Wood and Rice (2007): "there are literally thousands of research papers investigating judgment and decision-making. Relatively speaking, few of them have been devoted to the study of older adults." Thus, age differences in processes involved in decision making have been reported by and large – but evidence on age differences in decision making per se is still sparse. Based on the assumption that age-related cognitive decline has negative effects on decision making, it seem fair to expect less favorable decision making in older adults. Taking into account the improvements in emotion processing, the positivity effect, and the greater life experience of older adults, these probably can compensate in part for the declines in cognitive abilities. Indeed, a number of studies have shown that older adults' decision making capabilities can match those of younger adults (Chasseigne, Grau, Mullet, & Cama, 1999; Chen & Sun, 2003; Wood, Busemeyer, Koling, Cox, & Davis, 2005). To understand the conditions allowing older adults to make decisions as good as those of their younger pairs, Simon (1956), and in Simon's tradition Gigerenzer and colleagues (Gigerenzer & Gaissmaier, 2011; Gigerenzer & Todd, 1999), argued that the study of either the environment or the mind will lead to clarifications about the underlying processes.

Based on Simon's recommendations, the aim of this thesis is to contribute to the understanding of age differences in decision making, as well by varying factors of the decision environment as by studying (indirectly) the mind through the investigation of brain mechanisms underlying age differences in decision making under uncertainty.

The common stereotype about older adults is that they are uncertainty avoidant. As emotions play a central role in uncertain choices (Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005; Loewenstein, Weber, Hsee, & Welch, 2001), the age-related changes in emotion processing possibly may influence decision making under uncertainty in older adults. It is however not trivial to make clear predictions on how age can affect uncertain decisions. In fact, positive affect remains constant or increases slightly with age (Mroczek, 2001), and it is likely that the impact of positive affect on decisions remains constant through the adult lifespan. Negative affect decreases (Charles, et al., 2001; Mroczek, 2001). However, different negative emotions have different effects on decision making under uncertainty (e.g. anger and fear); anger decreases risk aversion – fear increases it (Lerner, Gonzalez, Small, & Fischhoff, 2003; Lerner & Keltner, 2001). Both of these emotions decrease with age, but it is not known whether the effects will tend to cancel each other out, or whether one of the emotions will take the lead over the other. Numerous additional factors have also been found to influence age-related differences in decision making under conditions of uncertainty (Mata, Josef, Samanez-Larkin, & Hertwig, 2011; Mather, 2006), some of them being part of the current thesis (e.g., the moderating effects of education, whether subjects need to decide with a priori or with statistical probabilities).

When dealing with uncertain decisions between two options, in everyday life a third option often is available: not to make a decision (Anderson, 2003). This option, in young adults, gets the more attractive the more the decision is emotion laden (Beattie, Baron, Hershey, & Spranca, 1994) or the more the conflict between the available options increases (Tversky & Shafir, 1992). The nature of decision situations (i.e. the level of conflict and emotion involved) has been shown to become more salient as people age (Blanchard-Fields, Jahnke, & Camp, 1995). In the light of these results, it is not surprising to find that older adults are more likely than young adults to avoid making decisions or to delegate them (Okun, 1976). In fact, sticking with the status quo or not making a decision leads in the short term to less negative affect than choosing a conflict-laden option (Luce, 1998), and may therefore be the preferred option in older adults.

Another option that often is available in uncertain decisions is to invest some effort to learn more about the characteristics of choice options.  Due to reduced working memory capacities, holding multiple pieces of information in mind can be more difficult for older adults; this reduced memory capacity can lead older adults to seek less information than younger adults when making decisions (Meyer, Russo, & Talbot, 1995; Zwahr, Park, & Shifren, 1999). Information search strategies also differ between age groups. Due to the positivity effect, older adults spend more time than young adults examining positively valenced information, and less time examining information with a negative affective value (Mather, Knight, & McCaffrey, 2005). Older adults also tend to use, in comparison to young adults, more feature-based strategies when examining information about choice options (Johnson, 1990). That is, in comparison to young adults that examine all the information about one possible choice, then turning to the next choice, older adults tend to examine all the information corresponding to a particular dimension in each choice, before shifting to examine information about another dimension.

The goal of this thesis is to contribute to the understanding of the effects of age on decision making under uncertainty. The first three papers of this thesis will be committed to the study of age effects on decision making under uncertainty in individual decisions. More specifically, in the first paper, a group of younger and older adults will perform a task comparing behavior under risk and under ambiguity. The second paper will also compare two age groups; it aims at comparing young and older adults with respect to the effects of feedback on decision making under uncertainty, the effects of risky decisions with a priori versus statistical probabilities, and the effects of education on self-reported risk preferences. The third paper takes a different perspective. Instead of reporting purely behavioral results, it is committed at the study of brain mechanisms underlying age differences in decision making under uncertainty.

The fourth paper's goal is to develop and validate a framework for the study of decision making under uncertainty with a social dimension. In this paper, a novel task is developed; this task adds the possibility to delegate or to seek an advice in decisions under uncertainty. It is validated with a small group of young participants and expected results in an older age group are discussed.

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# Ageing and decision making: How ageing affects decisions under uncertainty

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**Abstract:**

*In an aging society, it becomes more and more important to understand how aging affects financial decision making. Older adults have to face many situations that require consequential financial decisions. In the present study, we explored the effects of aging on decisions in two important domains of uncertainty: risk and ambiguity. For this purpose, a group of young and a group of older adults played a card game composed of risky and ambiguous decisions. In the risk condition, participants knew the probabilities of winning or losing the game (i.e., they had full information), whereas in the ambiguous condition, these probabilities were unknown (thus, there was lack of information). When confronted with risky decisions, the behaviour of older and young adults did not differ. In contrast, under ambiguity, there were significant age-effects in decision making, with a higher propensity to gamble for older than for young subjects. Finally, we observe that whereas young subjects behave differently under risk and under ambiguity, older adults do not. We conclude that there exist differences in uncertainty-processing between young and older adults, and explore possible explanations of these differences.*

Keywords: Age differences, experiment, risk and uncertainty

J14, C91

# Introduction:

*The ageing population*

Though it is widely recognized that all western societies are facing an ageing population, most of the research on individual decision making relies on student populations (Henrich, Heine, & Norenzayan, 2010). While this certainly reflects some effect of subject availability, it possibly is also a consequence of the common belief that decision-making abilities may decline with age (Peters, Finucane, MacGregor, & Slovic, 2000).

Understanding how older adults make financial decisions is of great importance for social policy (Estes, 2001; Filer, Kenny, & Morton, 1993; Neugarten, 1974). Wealth tends to accumulate over the life course (Davies & Shorrocks, 2000; Jappelli & Pistaferri, 2000), and older adults have on average a greater spending power than young adults do. At the same time, in countries devoid of compulsory voting, older individuals are more likely to vote than young people are, and thus they may have high political influence (Glenn & Grimes, 1968; Strate, Parrish, Elder, & Ford, 1989). There is a shift in the demographic structure of western countries, including long-term trends like increased longevity and short-term trends with long-term outcomes (cf. the baby-boom of the 1960’s). The proportion of older and retired people is growing (Vaupel, 2010), and the need to understand the differences between young and older adults increases.

A reason to study older adults’ decision making behaviour is that they have to make many consequential decisions. Choices in the domain of health care or financial decisions are only two examples of older people’s everyday life situations in which they need to decide carefully. Should they undergo a surgery with a certain risk but possibly high benefits, or rather not take the risk (or even avoid making a decision (Mather, 2006))? Should they rather sell their house and move to an assisted living facility, or shouldn’t they? These and similar decisions not only have an immediate outcome, but possibly can also affect the individual’s future well-being. For this reason, we want to contribute to the understanding of decision making of older adults.

The remainder of this paper will be structured as follows: in a first step, we shortly introduce the topics of decision making under financial uncertainty and decision making of older adults. In the experimental section, we will describe our study and analyse the results. Finally, we will discuss the findings in the light of the current interest in age differences.

### *Uncertainty*

As by now generally accepted, humans are not fully rational decision makers (Kahneman & Tversky, 1979; Krajbich, Armel, & Rangel, 2010). Unlike subjective expected utility theory predicts, decisions often depend on the confidence in estimated probabilities[2]. In some choices, such as gambling in blackjack games, probabilities can be computed easily recurring to relative frequencies (by counting the number of played cards and similar strategies). On the other side, for situations like the outbreak of an epidemic, probabilities are based on conflicting or absent information and thus are difficult to compute. The first type of events is called *risky* in decision theory; the second type is called *ambiguous*. There is large experimental evidence that people are less willing to bet on ambiguous outcomes than on risky ones (e.g. Camerer & Weber, 1992).

The few existing studies looking at decision making in older adults are inconclusive: some state that decision making abilities decline[3] with age, while others disagree with this statement. For example, Deakin and colleagues show that risk taking decreases with age and, more generally, that age is related to “less advantageous” decision making (Deakin, Aitken, Robbins, & Sahakian, 2004). The first statement, that the willingness to take risks is negatively related to age, is supported by several other studies (Chaubey, 1974; Dohmen et al., 2005; Hallahan, Faff, & McKenzie, 2004). Yet these findings seem to be methodology or subject-group dependent: in some other studies, older participants make risk decisions equivalent to those of young adults (Dror, Katona, & Mungur, 2000).

Research by Denburg et al. and Fein et al. provides support for the second statement, i.e., “quality of decision making […] [is] reduced with age” (Denburg, Tranel, Bechara, & Damasio, 2001; Fein, et al., 2007). According to this view, normal ageing may compromise the ability to decide advantageously. This means that in a set of choices, older adults choose less often than young adults the option with the highest expected payoff. However, these results are again challenged by other studies, were the main finding is that older adults’ decision making is similar to that of young adults (Kovalchik, Camerer, Grether, Plott, & Allman, 2005).

To our knowledge, there is only one study so far looking at decision making in both risky and ambiguous conditions in healthy older adults (Zamarian, Sinz, Bonatti, Gamboz, & Delazer, 2008). The

[2] We refer the reader unfamiliar with decision theory to one of the many comprehensive articles or books on the topic (e.g. (Parmigiani & Inoue, 2009)).

[3] A “decline” in decision making abilities, also sometimes called “less advantageous” or “poor” decision making often is not well defined in the literature. It generally means making decisions with a worse overall outcome than the outcome of a control group (i.e. young adults) on the same task (e.g. (Fein, McGillivray, & Finn, 2007)).

authors found that normal ageing does not affect decision making under risk. Ageing does however affect decision making under ambiguity, and older adults showed poorer performance than young adults in the ambiguity task. While this study certainly shows an age effect, it is debated if the measure used to assess ambiguity, the Iowa gambling task, eventually not assesses other factors than ambiguity, such as risk, or “hot” and “cold” decision making (Buelow & Suhr, 2009).

As all the aforementioned studies use different methodologies, it is difficult to say if the observed differences between results are an effect of these different methodologies used. Other factors, like heterogeneity in psychophysiological ageing, could play a role too.

The goal of this study is to take another step towards a better understanding of the relationship between ageing and decision making under financial uncertainty. We report results of an experiment in which we explore behavioural differences in uncertain decisions between young and older adults.

### *Hypotheses*

The experiment aims at investigating age differences in behaviour under uncertainty. Based on the literature reviewed above, we hypothesize that:

(1) older adults have a lower propensity to gamble in risky situations than young adults have, and that

(2) differences between young and older adults also exist in the propensity to gamble in ambiguous situations.

## Methods

### *Participants*

A total of 75 adults (51 young adults, 24 older adults; cf. Table 1) participated in the experiment. All of the young adults where students at the Universities of Mannheim or Heidelberg and were on average 25.18 years old (SD = 3.45). The older adults were healthy[4] with an average age of 67.72 years (SD = 7.28, minimum age: 58 years, maximum: 88 years). The majority of the older adults held a college or university degree and were retired. We recruited them by word of mouth advertisement at an adult education centre. Thereby we generated a group of older adults not representative of the

[4] This means that participants did not report any major physiological limitations in the questionnaire, nor did they report any psychological problems.

population, but well-matched to the student sample with respect to education and cognitively active lifestyle. Moreover, we ensured that the older participants were familiar with the use of a computer.

Table 1: Participants

| | Young | Older |
|---|---|---|
| Number | 51 | 24 |
| Male/Female | 20/31 | 12/12 |
| Age (SD) | 25.18 (3.45) | 67.72 (7.28) |
| Years of education* (SD) | 12.64 (1.32) | 12.22 (1.38) |

*until graduation from school

## *Procedures*

The experiment took place at the Collaborative Research Centre 504 Lab (SFB-504) of the University of Mannheim (only young participants) and at the Alfred Weber Institute Lab (AWI-Lab) of Heidelberg University (young and older participants).

Participants were seated in computer-equipped cubicles devoid of visual access to other participants. All participants received the same instructions, which were also read aloud by the experimenter. Participants first had to fill in a general questionnaire generating their personal code and asking questions on their age, sex, health status, marital status, educational level, and professional curriculum. Subsequently, the experimental tasks by which we examined behaviour under uncertainty started.

Participants received a show-up fee of € 3. In addition, they were paid an amount of money depending on their performance in the task.

## *The task*

The risk and ambiguity task (RAT) consisted of a card game which was adapted from Hsu and colleagues (Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005). Hsu and colleagues used this paradigm in an fMRI experiment, and we made it suitable for standard computer-lab use (thus using a mouse and a keyboard).

In this task, subjects had to make continuous choices between a gamble and a sure amount of money. In half of the trials, participants were faced with risky decisions (i.e. the probabilities of winning were known), and in half of the trials, they were faced with ambiguous decisions (i.e. the probabilities of winning the gamble were unknown). Risky and ambiguous gambles alternated. In total, subjects had to make 48 decisions (24 risky and 24 ambiguous), in which card distribution (respectively the total number of cards) and outcome varied. We used the same probability distribution as Hsu et al. (for exact card distribution, see appendix). Subjects received full feedback on their performance after each choice in a summary table showing them what they chose, which card colour was drawn, and if they won the gamble[5].

The aim of the game was to observe player's behaviour under both types of uncertainty. Subjects were allowed as much time as they needed to make their choices. Responses were made by selecting the corresponding option on the screen. Subjects had the possibility to decide between three options (cf. Figure 1): the sure payoff that paid a certain positive amount of money, or a bet on either side of a binary choice gamble that carried some uncertainty of paying either a positive sum or zero.

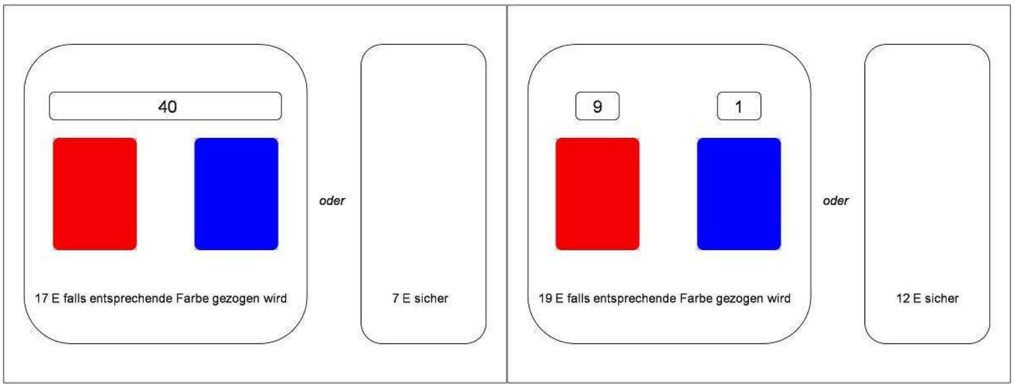
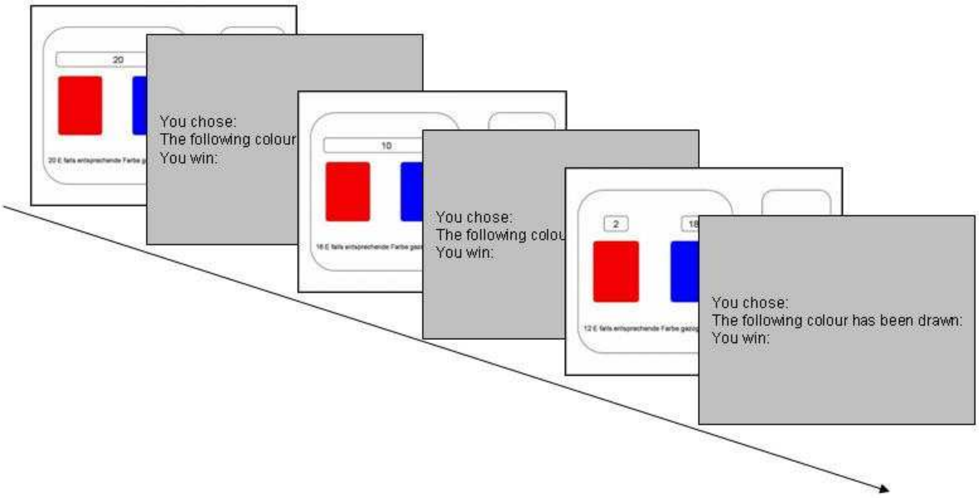



Figure 1: Screens presented to the subjects. Left screen: choice between an ambiguous gamble and a sure amount of money. Right screen: choice between a risky gamble and a sure amount of money.

[5] We used two different graphical user interfaces (GUI) to present the game to the participants. In a first step, the game was programmed in ZTree (Fischbacher, 1999) and used with the student population (n = 35). In a subsequent pretest with older adults, we observed massive difficulties using the game (due to factors like button size and menu alignment). For that reason we changed the GUI to C# instead of ZTree and we adapted slightly the appearance of the game to ensure that it was as easy as possible to manipulate, even for subjects not familiar with the use of a computer interface. An additional student group (n = 16) played the C#-game to ensure the comparability of the student group with the older participants. As there was no significant difference in behaviour between students playing the ZTree-game and playing the C#-game (2-sided t-test for independent groups; risk: $t(49) = -.47$, $p = .64$; ambiguity: $t(49) = -.19$, $p = .85$), we pooled both groups for data analysis.




Timeline of the game.

## *Statistical methods*

Propensity to take risky gambles was measured by the number of times subjects chose a gamble instead of a sure amount of money in risk trials, and was considered as a metric variable ranging from 0 (no gamble chosen at all) to 24 (always chosen the gamble instead of the sure payoff). Propensity to take ambiguous gambles was measured, mutatis mutandis, the same way in ambiguous trials. A search for outliers revealed no results. Measures were centred and reduced to ease comparability.

To test for age effects in risk behaviour (hypothesis 1), we used a one-tailed t-test, because we expected behaviour to tend in the direction of more risky gambles in young adults. Hypothesis 2, i.e., the existence of age effects in the propensity to take ambiguous gambles, was not directed, and we used a two-tailed t-test.

## *Analysis and results*

T-tests for independent groups showed that there is no significant difference in the propensity to take risky gambles between the two age groups (one-tailed t-test: $t_{(73)} = 0.181$, $p = .429$; cf. Table 2). Young and older adults played the same number of risky gambles in the game (average number of risky gambles taken by older participants: 15.96, SD = 5.70; by young participants: 15.71, SD = 5.61). In contrast, there is a significant difference in the propensity to take ambiguous gambles between older and young people (two-tailed t-test: $t_{(73)} = 2.194$, $p = .031$). Older adults are more prone to play ambiguous gambles than young adults are (average number of ambiguous gambles taken by older participants: 17.58, SD = 5.48; by young participants: 14.20, SD = 6.55).

Comparing directly risky to ambiguous gambles in t-tests for paired groups (one-sided), it turns out that older adults are not significantly more ambiguity averse than risk averse ($t_{(23)}$ = 1.302, p = .103), while young adults are ($t_{(50)}$ = 3.482, p = .044).

Table 2: Age effects

| *Gamble* | *Age-group* | *Mean* | *SD* | *Z-Mean* | *t-test* | *t-value (73)* | *p* |
|---|---|---|---|---|---|---|---|
| Risk | Young | 15.71 | 5.61 | -0.015 | one-tailed | 0.181 | 0.429 |
| | Older | 15.96 | 5.70 | 0.031 | | | |
| Ambiguity | Young | 14.20 | 6.55 | -0.171 | two-tailed | 2.194 | 0.031 |
| | Older | 17.58 | 5.48 | 0.363 | | | |

In summary, the experiment shows that, in a task measuring the propensity to gamble under financial uncertainty, older and young adults do not differ significantly in the propensity to gamble under risk. In the propensity to gamble under ambiguity, however, older adults gamble significantly more than young adults do. Also, older adults do not distinguish between risky and ambiguous games, whereas young adults do.

## Discussion

The aim of our study was to take another step towards a better understanding of older adults' decision making in situations of financial uncertainty, and more concretely to investigate age-differences in the propensity to gamble in uncertain situations. We hypothesized age differences in the propensity to gamble in risky conditions, and in the propensity to gamble in ambiguous conditions.

The study only partially confirms our hypotheses, as older adults seem to be equally willing to take risks as young adults in the current task. We confirm the second hypothesis; ambiguity behaviour effectively differs with age. Furthermore, we observe a difference in the propensity to gamble under risk and under ambiguity in young adults, but not in older adults.

Following our first hypothesis, older adults should have a lower propensity to gamble than young adults in the risky condition in decisions from description. This is however not the case. Even though we had, based on the literature, expected to find differences in the propensity to gamble, the result is not entirely surprising. We were aware that age related differences vary considerably as a function of task characteristics (Mata, Josef, Samanez-Larkin, & Hertwig, 2011). In the RAT, learning requirements are relatively low, as probabilities are unequivocally represented in the form of proportions of cards, and as subjects are always allowed to choose a sure option instead of betting on the risky option. Hence, cognitive demands on the task are relatively low, and we are confident that the cognitive load of the task can be handled equally well by young and older adults.

In the study, we also were able to show that older adults gamble more than young adults in ambiguous conditions (keeping in mind that full feedback on performance is provided). Furthermore we have shown that the higher ambiguity aversion compared to risk aversion commonly found in young adults does not appear in older adults; the latter are not significantly more ambiguity than risk averse. These results seemed prima facie counterintuitive to us; nevertheless there are some results of the gerontological literature that can explain this finding.

The first factor that could explain our result is the positivity effect (Mather & Carstensen, 2005). Following this effect older adults are more optimistic than young adults (Borges & Dutton, 1976; Lennings, 2000). Older adults focus more on regulating emotion than young adults do. This has an impact on their overall emotional experience. Some authors suggest that in the ageing process, an increased focus on emotion regulation influences attention and memory (Mather, 2004; Mather & Carstensen, 2003). Older adults are likely to show a memory distortion that prefers chosen options over rejected options (Mather & Johnson, 2000). This implies that older adults sometimes are more likely to repeatedly choose the same options because their memories are biased in favour of positive outcomes of their past choices. The tendency to focus on positive emotions leads to changes in decision making strategies. It is well known that emotions have effects on economic decision making (Lerner, Small, & Loewenstein, 2004), and in particular positive affect can influence decision making (Isen, 2001). In our case, this positivity effect can influence the propensity to gamble in ambiguous conditions in two different ways. First, as it is possible that older adults' memories of gains are more prominent than those of losses, decisions based on the memory of gains in ambiguity gambles can lead to a higher propensity to gamble. The other way the positivity effect can influence ambiguous decisions is by the overall emotional state of the individual; mood influences loss aversion (Camerer, 2005), which is strongly related to ambiguity aversion. Thus, a generally increased positive mood could lead to reduced ambiguity aversion.

An alternative explanation for the age difference in the propensity to gamble under ambiguity is given by Mata and colleagues. In their study, they found a difference in strategies used by young and older adults to make a decision: older adults looked up less information and took more time to process it – while overall decision making of older and young adults was comparable (Mata, Schooler,

& Rieskamp, 2007). If we apply this to the fact that ambiguity is a condition with less information available than risk, we can hypothesize that ambiguous gambles are more suitable to older adults.

Another factor that can play a role in our findings is experience. Older adults had a lifetime to decide and develop strategies for decisions under ambiguity. They can retrieve information from a memory that young adults are just beginning to develop. One survey of bank managers for example revealed that older managers' business decisions were more aggressive than the decisions of younger managers (Brouthers, Brouthers, & Werner, 2000), and different studies found that uncertain investments increased until a certain age (Jianakoplos & Bernasek, 1998; Riley Jr & Chow, 1992; Schooley & Worden, 1999). Thence, while this is speculative, the greater experience of older participants can potentially account for the higher propensity to gamble of older adults in ambiguous situations. This explanation, however, requires further empirical testing.

Like every experiment, the present has its limitations as well. As the number of studies in the field of ageing and decision making is still very small, our experiment aimed at describing differences between young and older adults. Therefore, we selected the older subjects in a way that eased comparability with young subjects. All our older participants were healthy, highly educated and practised a cognitively active lifestyle. Overall, older adults are very heterogeneous in their cognitive abilities, and activity might preserve cognitive ability with ageing. We are aware that our results might apply only to a specific, cognitively active group of older adults, and do not claim that it is valid for the entire population of older people. As both age groups of our experiment belonged to the higher range of education in the distribution, we probably diminished some of the effects claimed in other studies to be attributable to age. For a more detailed analysis of the effects of age, education and other factors influencing the willingness to take risks, we however refer the reader to other authors (e.g. Dohmen, Falk, Huffman, & Sunde, 2011), as this was not the aim of our study. Nevertheless, future experiments should focus on age differences in more heterogeneous subject groups on both sides of the age range (Henrich, et al., 2010).

In this experiment, we wilfully did not try to rule out cohort effects. All western populations are rapidly growing older, so that there is an immediate need to describe older adults' behaviour. Certainly it also is of great importance to understand how these behavioural differences develop over the life-course, but our first aim was to describe the differences between young and older adults, paving the way for future work where we will try to minimize the impact of cohort effects and to find explanations of these age differences.

## Conclusion

In conclusion, we observed that older adults' decision-making behaviour effectively differs from that of younger adults. In risky conditions, older adults behave like young adults if no learning is required, but in ambiguous conditions, age differences appear. We have shown that there are different possible explanations for our results, and further work will be needed to understand the causes of our findings.

On a more practical level, our work contributes to growing evidence that older adults' decision making differs from that of younger adults. In our societies, older adults represent a growing part of the population, and a part of the population that will work until a higher age, thus also making financial decisions at a higher age. Understanding how decision making is affected by age becomes crucial for numerous situations of everyday life, and further research is needed to understand how older adults make their decisions, to help employers, policy makers, financial institutions, but also older adults themselves, to cope with the effects of the demographic change.

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# Decision making and age: Factors influencing decision making under uncertainty

Alec N. Sproten

**Abstract:**

*In an aging society, the extent that aging affects financial decision making becomes increasingly important to understand. In the present study, we explore the effects of aging on decisions in two important domains of uncertainty: risk and ambiguity. To assess these two domains, we compared younger to older adults on various aspects of decision making under conditions of uncertainty. The results revealed no age differences in the propensity to gamble under risk with a priori probabilities. We found, however, age differences for the propensity to gamble in risky conditions with statistical probabilities. Additionally, we found that older adults are more prone than young adults to gamble under ambiguity. We also showed that the presence of feedback has a positive effect on the propensity to gamble in uncertain conditions. We compared the results from our experiments with survey data, demonstrating that education is positively related to risk taking, despite the negative relation with risk taking and age. We conclude that differences in uncertainty-processing exist between young and older adults, and we explore possible explanations of these differences.*

Keywords: Age differences, experiment, risk and uncertainty, feedback

J14, C91

# Introduction:

## *The aging population*

"The aging workforce" has recently become a hot topic in both the popular media and in scientific research. A large extent of children born after the year 2000 in Germany and in other western countries could live to 100 years of age and older (Vaupel, 2010). As a consequence, the elderly will likely retire at an older age than is the case today. Therefore, important decisions need to be made at a higher age, and it becomes increasingly important to understand older adults' decision making. However, most of the research on individual decision making relies on student populations (Henrich, Heine, & Norenzayan, 2010), and results cannot entirely be generalized to other parts of the population.

The few experimental studies that have looked at age effects on economic decision making compared age groups without testing specific hypotheses based on psychological knowledge about life span changes. In these studies, few differences have been found (Charness & Villeval, 2007; Kovalchik, Camerer, Grether, Plott, & Allman, 2005), although older adults are commonly believed to face declines in decision-making abilities (Peters, Finucane, MacGregor, & Slovic, 2000). Research in cognitive psychology has shown the existence of age differences in decision making. However, some studies find that older people are more risk averse than younger people, whereas others have not confirmed this result (L.L. Carstensen & Hartel, 2006; Mata, Josef, Samanez-Larkin, & Hertwig, 2011). Older adults have also been found to follow different goals than younger individuals in decision making and are more motivated to keep a positive affective state (Laura L. Carstensen, Isaacowitz, & Charles, 1999; Mather, 2006).

The remainder of this paper will be structured as follows: we briefly introduce the topics of decision making under financial uncertainty and decision making in older adults. In the experimental section, we will describe our studies and analyse the results. Finally, we will discuss the findings in the light of the current interest in age differences.

## *Uncertainty*

In economics, uncertain conditions usually are understood as conditions in which the outcome of a given condition is bound to some (known or unknown) probabilities, thus the outcome is not certain. As early as in the beginning of the 20$^{th}$ century, uncertain conditions were classified in different subcategories, defined by their "probability situations" (Knight, 1921): *estimates*, *statistical* probabilities[a], and *a priori* probabilities[b]. In current research on the topic, the term ambiguity instead of estimates and the term risk instead of statistical and a priori probabilities are more commonly used. Ambiguity (i.e., estimates) is defined as uncertain conditions in which probabilities cannot be computed empirically because of conflicting or absent information. Statistical probabilities are used to learn the risk of a choice empirically by referring to prior choices with similar outcomes. A priori probabilities define the level of risk by assignment of explicit (or easily computable) probabilities. An abundance of evidence can be found in the literature showing that people are less willing to bet on ambiguous outcomes than on risky ones (Camerer & Weber, 1992), and it appears that older adults are more risk avoidant than young adults when confronted with statistical probabilities but not when confronted with a priori probabilities (Mata, et al., 2011). Various cognitive processes are likely to be involved in the latter effect. For example, when confronted with statistical probabilities, the ability to learn from prior experiences is crucial. Moreover, with statistical probability choices, subjects tend to attribute more impact to rare events than these events deserve, and vice-versa in decisions with a priori probabilities (Hau, Pleskac, Kiefer, & Hertwig, 2008; Hertwig & Erev, 2009).

Our study aims at investigating age effects in decision making under the two dimensions of ambiguity and risk uncertainty. The few existing studies that have assessed decision making in older adults are inconclusive, showing that decision making abilities decline[c] with age or finding no support for this result.

To our knowledge, only one study assessed decision making in both risky and ambiguous conditions in healthy older adults (Zamarian, Sinz, Bonatti, Gamboz, & Delazer, 2008). The authors found that normal aging does not affect decision making under risk. The results, however, did show that aging affects decision making under ambiguity. Older adults demonstrated poorer performance than young adults on the ambiguity task. Although this study clearly revealed differences between uncertain choices on two tasks, the measure used to assess ambiguity, the Iowa gambling task, has been under scrutiny for lacking a concise definition of decision making. That is, the instrument could be assessing other factors than ambiguity, such as risk with statistical probabilities or “hot” and “cold” decision making (Buelow & Suhr, 2009).

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[a] Statistical probabilities are also sometimes called decisions from experience.

[b] A priori probabilities are also sometimes called decisions from description.

[c] A “decline” in decision making abilities, also sometimes called “less advantageous” or “poor” decision making, is often not well-defined in the literature. It generally means making decisions with a worse overall outcome than the outcome of a control group (i.e. young adults) on the same task (e.g. Fein et al., 2007).

Results are more comprehensive in studies that have assessed risk behaviour, albeit sometimes contradictory. For example, numerous research groups have shown that risk taking decreases with age (Chaubey, 1974; Deakin, Aitken, Robbins, & Sahakian, 2004; Dohmen et al., 2005; Hallahan, Faff, & McKenzie, 2004), whereas numerous other studies have shown that older participants make risk decisions equivalent to those of young adults (Ashman, Dror, Houlette, & Levy, 2003; Dror, Katona, & Mungur, 2000; Henninger, Madden, & Huettel, 2010; Zamarian, et al., 2008). This lack of consistency in the literature suggests that the observed effects are the result of differences in methodology and sampling, among other factors such as heterogeneity in psychophysiological ageing. One important methodological factor lies in the difference between decisions from experience and decisions from description (Mata, et al., 2011), an important factor influencing decisions given that both rely on distinct cognitive mechanisms. The presence or absence of feedback during the task is also an important methodological concern. Feedback influences emotions and decision making (Baumeister, Vohs, DeWall, & Zhang, 2007), and it reinforces behaviours more strongly in young than in older adults (Bellucci & Hoyer, 1975; Tripp & Alsop, 1999). Feedback also reduces subjective uncertainty (Hogg & Mullin, 1999; Kramer, 1994). Participants actively select tasks that maximize the reduction of uncertainty (Trope, 1979) given that one of the informational tendencies of humans is the need to attain clarity (Sorrentino, Smithson, Hodson, Roney, & Marie Walker, 2003).

The goal of this study is to advance the field towards a better understanding of the relationship between aging and decision making under financial uncertainty. We report results from an experiment in which we explored behavioural differences in uncertain decisions between young and older adults. We explored age differences in a task that compared a priori risky choices with ambiguous choices, without feedback. We compared risky decisions with a priori probabilities to risky decisions with statistical probabilities in the same subject group. We also compared the results of the risk vs. ambiguity task to participants' behaviour on the same task in an earlier experiment (Sproten et al., this volume) in which participants received full feedback on performance.

We then assessed the robustness of our results by linking them to panel data.

### *Hypotheses*

In an earlier experiment (Sproten et al., this volume), we showed that in a task measuring the propensity to gamble under financial uncertainty older and young adults did not differ significantly in the propensity to gamble under risk with a priori probabilities. However, when the propensity to gamble was under ambiguity, older adults gambled significantly more than young adults. Given that subjects received direct feedback on their performance, we were interested in knowing whether the results still hold in the absence of feedback. We also were interested in knowing whether age differences in risk behaviour would occur when participants encounter statistical probabilities in a risk setting instead of a priori probabilities, and if we could validate our results by comparing them to a larger sample of the population. In the current experiment, participants played the same version of the uncertainty task as in our former experiment with the exception of removing feedback, an additional risk task based on statistical probabilities, and they completed a risk questionnaire which we could link to data from a representative sample of the German population.

## Methods

### *Participants:*

A total of 54 adults participated in the experiment (see Table 1). All of the young adults where students at the University of Heidelberg and were on average 22.67 years-old. The older adults were healthy with an average age of 66.61 years (minimum 58 years, maximum 83 years). The majority of the older adults held a college or university degree and were retired. Older participants were recruited by means of an article appearing in a local newspaper, explaining the need for participants with some basic computer knowledge.

Table 1: Participants

| | Young | Older |
|---|---|---|
| Number | 36 | 18 |
| Male/Female | 17/19 | 9/9 |
| Mean Age (SD) | 22.67 (2.24) | 66.61 (5.82) |
| Years of education* (SD) | 12.86 (0.58) | 11.67 (2.73) |

*until graduation from school

### *Procedures:*

The experiment took place at the AWI-Lab at Heidelberg University. Participants were seated in computer-equipped cubicles devoid of visual access to other participants. All participants received the same instructions, which were also read aloud by the experimenter. Participants first were asked to complete a form which generated their individual code. The experiment started with the balloon analogue risk task (BART) or the risk and ambiguity task (RAT). The order of the tasks was randomly chosen to minimize an order-effect. After the first task, subjects completed a general demographic questionnaire on age, sex, health status, marital status, educational level, and career. In the following step, subjects played another game that consisted of the Holt and Laury lottery task and another unrelated task on social preferences. Subsequently, the experiment ended with the BART or RAT (whichever was not administered at the beginning of the experiment).

Participants received a show-up fee of 3 €. In addition, they were paid an amount of money depending on their performance on the tasks.

### *The tasks:*

(1) The RAT:

The risk and ambiguity task (RAT) is a card game adapted from Hsu and colleagues that measures risk behaviour with a priori probabilities and ambiguity behaviour (Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005). The instrument was developed to be used in fMRI experiments and to be made suitable for standard computer-lab use (thus using a mouse and a keyboard). In this task, subjects make continuous choices between a gamble and a sure amount of money. In half of the trials, participants are faced with a priori risky decisions (i.e. the probabilities of winning are known), and in half of the trials they are faced with ambiguous decisions (i.e. the probabilities of winning the gamble are unknown). Risky and ambiguous gambles alternate. In total, subjects have to make 48 decisions (24 risky and 24 ambiguous), in which card distribution (respectively the total number of cards) and outcome vary (see appendix). We used the same probability distribution as in Hsu et al. (2005). Subjects received no feedback on their performance on the trials.

The aim of the game is to observe player's behaviour under both types of uncertainty. Subjects are allowed as much time as they need to make their choices. Responses are made by selecting the corresponding option on the screen. Subjects have the possibility to decide between three options (cf. Figure 1): the sure payoff that pays a certain positive amount of money or a bet on either side of a binary choice gamble that carries some uncertainty of paying either a positive sum or zero.

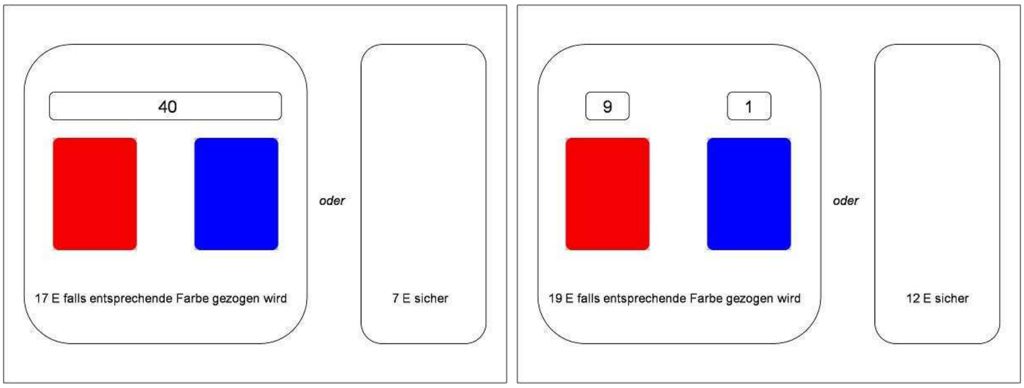



Figure 1: Screens presented to the subjects. Left screen: choice between an ambiguous gamble and a sure amount of money. Right screen: choice between a risky gamble and a sure amount of money.

(2) The balloon analogue risk task (BART):

In the BART (Lejuez et al., 2002), subjects see a series of 20 virtual balloons, one after another, and can earn money by pumping up the balloon. The money is stored on a temporary account until subjects decide to collect the money (transfer it to a permanent account) and to proceed to the next balloon, or until the balloon pops and the money is lost. Participants do not receive detailed information on the probabilities that a balloon pops. Participants know that at some point, every balloon pops, and that the explosion could happen at any moment. It could pop at the first pump or when the balloon fills the entire screen. When a balloon is filled beyond its individual exploding point, it pops on the screen. Whenever a balloon pops, the money of the temporary account is lost followed by the next empty balloon that appears on the screen. At every moment during a trial, the participant can interrupt the pumping and press a "collect money" button. The pressing of this button transfers the money from the temporary account to a permanent account, where it cannot be lost.

After every money transfer or explosion, the trial ends followed by a new balloon that appears on the screen until the participant has seen a total of 20 balloons. The chance that a balloon pops is randomly generated, with a starting probability of 1/64 (0.0156). If the balloon does not pop at the first pump, the probability that it pops at the second pump is 1/63, 1/62 at the third pump, and so on until the 64$^{th}$ pump, where the probability will be 1/1.

Every pump increases the money on the temporary account that can be lost by popping, and diminishes the relative additional earnings by pumping. After the first pump, e.g., participants risk only 5 cents on the temporary account by an additional pump but can increase their potential earnings by 100% by executing this pump. In contrast, after the 30$^{th}$ pump, subjects risk the 1.5 ECU on the temporary account for an additional increase in earnings of only 3.3%.

Note that optimal behaviour on this task is to pump 32 times, based on the payoff structure and probability of popping set by the computerized task.


(3) The risk lottery

The risk elicitation task (Holt & Laury, 2002) is a simple measure for risk aversion using a multiple price list design (cf. table 2). Participants are asked to choose between two lotteries A and B. In the first choice, lottery A offers a 10% chance of receiving 2€ and a 90% chance of receiving 1.60€ (an expected value of 1.64€). Similarly, lottery B offers a 10% chance of winning 3.65€ and a 90% chance of winning 0.10€ (expected value: 0.48€). The two lotteries have in this case a relatively large difference in expected value. As one proceeds down the matrix, playing the game for ten rounds, the expected value of both lotteries increases, and the expected value of lottery B becomes greater than the expected value of lottery A. A risk neutral subject should switch from choosing A to B when the expected value for both lotteries is about the same.

Table 2: Choices in the risk elicitation task

| Option A | Option B | Expected payoff difference |
|---|---|---|
| 1/10 of 2.00€, 9/10 of 1.60€ | 1/10 of 3.85€, 9/10 of 0.10€ | 1.17€ |
| 2/10 of 2.00€, 8/10 of 1.60€ | 2/10 of 3.85€, 8/10 of 0.10€ | 0.83€ |
| 3/10 of 2.00€, 7/10 of 1.60€ | 3/10 of 3.85€, 7/10 of 0.10€ | 0.50€ |
| 4/10 of 2.00€, 6/10 of 1.60€ | 4/10 of 3.85€, 6/10 of 0.10€ | 0.16€ |
| 5/10 of 2.00€, 5/10 of 1.60€ | 5/10 of 3.85€, 5/10 of 0.10€ | -0.18€ |
| 6/10 of 2.00€, 4/10 of 1.60€ | 6/10 of 3.85€, 4/10 of 0.10€ | -0.51€ |
| 7/10 of 2.00€, 3/10 of 1.60€ | 7/10 of 3.85€, 3/10 of 0.10€ | -0.85€ |
| 8/10 of 2.00€, 2/10 of 1.60€ | 8/10 of 3.85€, 2/10 of 0.10€ | -1.18€ |
| 9/10 of 2.00€, 1/10 of 1.60€ | 9/10 of 3.85€, 1/10 of 0.10€ | -1.52€ |
| 10/10 of 2.00€, 0/10 of 1.60€ | 10/10 of 3.85€, 0/10 of 0.10€ | -1.85€ |

(4) Self-assessment of risk preferences

To measure self-assessment of risk preferences, subjects responded to the following item (same question as in the SOEP questionnaire): "On a scale from 0 to 10, how would you assess your willingness to take risks?" A value of 0 corresponded to not willing to take risks at all, and a value of 10 for very willing to take risks.

### *Statistical methods*

In the RAT, the propensity to take risky gambles was measured by the number of times subjects chose a gamble instead of a sure amount of money in risk trials, and was considered as a metric variable ranging from 0 (no gamble) to 24 (always chose the gamble instead of the sure payoff). Propensity to take ambiguous gambles was measured, mutatis mutandis, the same way in ambiguous trials. A search for outliers revealed no results. To test for age effects in risk behaviour, we used a one-tailed t-test, because we expected behaviour to tend to be in the direction of more risky gambles in young adults. For the second hypothesis, i.e., the existence of age effects in the propensity to take ambiguous gambles, we performed a two-tailed t-test, because the possibility of scores in both tails.

In the BART, we used the mean number of pumps on the balloons, excluding those trials where the balloon popped at the first pump as an adjusted mean. To investigate experience and age effects, we conducted a repeated-measure ANOVA[d] with age as the between-subject factor and number of pumps on each trial as the within-subject factors.

In the risk elicitation task, the switching point from option A to B is commonly used to assess risk preferences. We used the amount of times subjects preferred option A to option B, because a large proportion of older adults switched more than once.

To test for age differences in risk preference, we performed one-tailed t-tests, because we expected behaviour to tend to be in the direction of more risky choices in young adults.

[d] We are aware that analysis of variance methods are an uncommon analysis in economics. However, both ANOVAs and regression models are GLMs, with ANOVAs being regression models that allow only for categorical predictors. Even though the underlying hypotheses may somewhat differ, both ANOVAs and regressions yield the same results. Yet, in the context of repeated measures, analysis of variance results are more straightforward to interpret, wherefore we chose this method.

Means were converted to z-scores to facilitate comparisons between the tasks[e].

To test our last hypothesis that age differences in risky decisions will appear more strongly in decisions based on statistical probabilities rather than in decisions based on a priori probabilities, we computed the Hedges' *g* effect size statistic (Hedges & Olkin, 1985), a modification of Cohen's *d* statistic that accounts for small sample sizes. In accordance with Cohen's (1988) thumb rule, the size of an effect is classified as small if its value is around 0.20, as medium if *g* is around 0.50, and as large if the effect size is exceeds 0.80[f].

## *Analysis and results*

- Behavioural differences between age groups

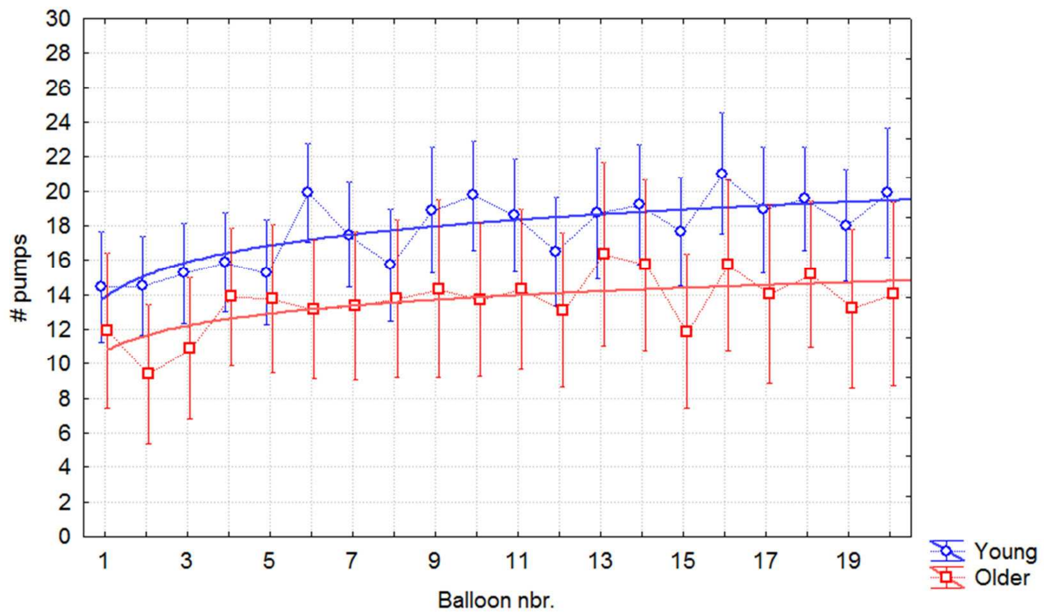
The t-tests for independent groups on RAT scores revealed no significant differences in the propensity to take risky gambles between the two age groups ($t_{(52)} = 0.321$, $p = .375$, one-tailed; cf. Table 3). Young and older adults played the same quantity of risky gambles in the game (average number of risky gambles taken by older participants: 12.8, SD = 1.5; by young participants: 13.3, SD = 1.7). In contrast, a significant difference was found in the propensity to take ambiguous gambles between older and young people ($t_{(52)} = 2.273$, $p = .027$, two-tailed). Older adults are more prone to play ambiguous gambles than young adults (average number of ambiguous gambles taken by older participants: 12.7, SD = 6.3; by young participants: 8.8, SD = 5.9). Older adults are not more averse to ambiguity than risk ($t_{(17)} = 0.027$, $p = .978$, one-tailed), whereas young adults are more averse to ambiguity ($t_{(35)} = 4.102$, $p < .001$, one-tailed).

[e] By centering and reducing, or standardizing, a distribution, we understand a linear transformation of the numerical values of that distribution. That way, the mean of the distribution takes a value of 0, with a standard deviation of 1. This standard deviation is the unit of measurement of the z-scores. The centering and reducing technique frequently is used to ease the comparison of observations from different normal distributions. Note that as the z-values are a linear transformation of the original values, the sole change that is made to the normal distribution are the units of measurement.
z-scores are calculated with the following formula: $z = (X - \mu)/\sigma$, where X is a score from the distribution, μ is the mean of the population, and σ is the standard deviation of the population.

[f] "The easy availability of Cohen's arbitrary guidelines should not be an excuse for us to fail to seek out and/or determine our own domain-specific standards based on empirical data and reasoned arguments" (Volker, 2006). We are aware that Cohen's distinction between effect sizes is an arbitrary rule; nevertheless we consider the distinction between a small, medium, and large effect as well suited for our results, and decided therefore to apply Cohen's rule.

Significant difference were found between young and older adults on risk behaviour measured by the BART ($t_{(52)}$ = 2.424, p = .009, one-tailed). Unlike with the RAT, young adults are more risk-seeking compared to older adults (adjusted average of pumps by young subjects: 21.9, SD = 8.8; by older subjects: 15.8, SD = 8.3).

For the ANOVA analysis, the Mauchly test for sphericity revealed a violation of the sphericity-assumption (Mauchly's W = .001; df = 189; approximate $\chi^2$ = 305.296; p < .001). Therefore, Greenhouse-Geisser-corrected results for the repeated-measures analysis will be reported[g]. We observed from the analysis on intra-subject factors, a significant increase in participants' readiness to take risks ($F_{(11.555;\ 600.876)}$ = 2.277; p = .009; $\eta^2$ = .042) and no interaction between the readiness to take risks and age ($F_{(11.555;\ 600.876)}$ = 0.451; p = .938; $\eta^2$ = .009). For the between-subject factors, behaviour varied significantly as a function of age ($F_{(1;\ 52)}$ = 5.591; p = .022; $\eta^2$ = .097). To present our results, we applied a logarithmic fitting function to the behavioural measures of each age group (Graph 1).




Graph 1: Average behaviour of young and older adults on the BART. Whisker plots represent 95% confidence intervals. Dotted lines are observed behaviour, constant lines correspond to logarithmic fitting functions (young = 13.823 + 4.33 × $\log_{10}(x)$; older = 10.7215 + 3.1117 × $\log_{10}(x)$).

[g] The corrected results do not reveal any fundamental differences compared to conventional, uncorrected results.

Table 3: Age effects

| *Task* | *Age-group* | *Mean* | *SD* | *Z-Mean* | *t-test* | *t-value(52)* | *p* |
|---|---|---|---|---|---|---|---|
| RAT Risk | Young | 13.3 | 1.7 | 0.032 | One-tailed | 0.321 | 0.375 |
| | Older | 12.8 | 1.5 | -0.063 | | | |
| RAT Amb. | Young | 8.8 | 5.9 | -0.213 | Two-tailed | 2.273 | 0.027 |
| | Older | 12.7 | 6.3 | 0.425 | | | |
| BART | Young | 21.9 | 8.8 | 0.225 | One-tailed | 2.424 | 0.009 |
| | Older | 15.8 | 8.3 | -0.451 | | | |
| Holt & Laury | Young | 6.2 | 1.9 | 0.197 | One-tailed | 2.094 | 0.021 |
| | Older | 5.1 | 1.9 | -0.394 | | | |
| Self-assessment | Young | 5.3 | 1.7 | -0.040 | One-tailed | 0.407 | 0.343 |
| | Older | 5.5 | 1.5 | 0.080 | | | |

The Holt and Laury risk lottery scores indicated that older adults appear to have switched faster than young adults from the less risky option to the riskier option ($t_{(52)}$ = 2.094, p = .021). Hence on this specific task, unlike in the RAT or BART, older adults seemed to be less averse to risk than young adults.

Despite significant differences in risk behaviour between young and older adults, no difference were found in the self-assessment of one's own risk attitudes ($t_{(52)}$ = 0.407, p = 0.343).

- The effect of feedback on the RAT:

T-tests for independent groups revealed significant effects of the presence or absence of feedback on behaviour (cf. table 4). In both age groups, feedback increased the propensity to gamble under risk (young adults: $t_{(85)}$ = 2.041, p = .022; older adults: $t_{(40)}$ = 1.796, p = .040) and under ambiguity (young adults: $t_{(85)}$ = 3.967, p < .001; older adults: $t_{(40)}$ = 2.668, p = .006).

Table 4: Effect of feedback on the RAT

| *Age-group* | *Task* | *Feedback* | Mean | SD | *Z-Mean* | *df* | *t-value* | *p* |
|---|---|---|---|---|---|---|---|---|
| Young | Risk | Yes | 15.7 | 5.6 | 0.240 | 85 | 2.041 | 0.022 |
| | | No | 13.3 | 5.3 | -0.196 | | | |
| | Ambiguity | Yes | 14.2 | 6.6 | 0.317 | 85 | 3.967 | < 0.001 |
| | | No | 8.8 | 5.9 | -0.498 | | | |
| Older | Risk | Yes | 16 | 5.7 | 0.233 | 40 | 1.796 | 0.040 |
| | | No | 12.8 | 5.7 | -0.331 | | | |
| | Ambiguity | Yes | 17.6 | 5.5 | 0.652 | 40 | 2.668 | 0.006 |
| | | No | 12.7 | 6.3 | -0.056 | | | |

- The effect size of risk tasks:

The effect sizes were computed for mean differences on RAT and BART scores between young and older adults. In the RAT condition with feedback (cf. table 5), the effect size of mean differences on the propensity to gamble under risk with feedback was negligible, *g* = -0.05, 95% CI (-0.55 to 0.44). The effect size is small to medium for the mean differences on RAT scores without feedback, *g* = 0.30, 95% CI (-0.28 to 0.88). Despite the small to moderate effect size, the 95% confidence interval includes a zero value (thus the mean differences were statistically nonsignificant). The effect size of mean differences on BART scores was medium to large, *g* = 0.70, 95% CI (0.10 to 1.29). Of the three effect sizes reported, only the effect of age on decision making as measured by the BART was significant at a 95% confidence level.

Table 5: Effect sizes

| *Task* | *Hedge's g* | *95% Confidence* |
|---|---|---|
| RAT Risk w. feedback | -0.05 | -0,55 to 0,44 |
| RAT Risk w/o. feedback | 0.30 | -0,28 to 0,88 |
| BART | 0.70 | 0,10 to 1,29 |

*Validation*

To validate our results, we compared our results to (non-incentivized) measures on risk preferences observed in a representative sample of the German population. The German Socio-Economic Panel (GSOEP; Wagner, Frick, & Schupp, 2007) contains different questions related to risk attitudes. The first measure assesses "willingness to take risks, in general" (called henceforth general risk preference). For the second measure of risk preferences, respondents indicate willingness to invest in a hypothetical lottery with explicit stakes and probabilities. Six additional questions use the same scale as the general risk question and ask about willingness to take risks in different contexts: car driving, financial investments, sports and leisure, career, health, and trust in others.

Table 6 shows the first step of a regression results on age differences in risk preferences, where age and gender were regressed on the eight risk dimensions. Given that the experimental sample consisted of relatively highly educated participants, we introduced years of education and general risk preference as a baseline into the regression model.

Examination of the results reveals that in all of the step-one-regressions, age and gender had significant effects on the willingness to take risks (all $p < .001$). Both age and being female are negatively related to the willingness to take risks. After introducing educational level and general risk preferences, the effect of age still held for all measures. Gender differences also remained significant in all but one risk dimension. In this sample, gender had no bearing on the willingness to take risks in trusting others. Education appears to also have had a positive effect on all risk measures. The higher the level of education, the more likely participants were to take risks.

To further control for the effects of education on the relationship between self-reported risk preference and age, we provide additional evidence by drawing two random samples of young and older adults (each N = 100) with a minimum of 13 years of education. Young adults were younger than 30 years (mean: 26.33, SD: 1.407), older adults were between 58 and 88 years of age (mean: 67.83, SD: 6.845). It appears that, as in our experimental group, young and older adults do not differ significantly on the self-assessment of one's own general risk attitudes ($t_{(198)}$ = 1.312, p = .191). On a scale from 0 to 10, young adults reported an average of 4.86 (SD: 2.015) for the willingness to take risks, older adults reported a mean value of 4.47 (SD: 2.186).

Table 6: Regression results of SOEP risk domains

| | General | | Car driving | | Investments | | Sports/Leisure | | Career | | Health | | Trust | | Lottery | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model: | I | II | I | II | I | II | I | II | I | II | I | II | I | II | I | II |
| Age | -.172* | -.170* | -.286* | -.243* | -.144* | -.096* | -.346* | -.304* | -.338* | -.249* | -.203* | -.163* | -.093* | -.052* | -.159* | -.136* |
| | (.001) | (.001) | (.001) | (.001) | (.001) | (.001) | (.001) | (.001) | (.002) | (.001) | (.001) | (.001) | (.001) | (.001) | (.001) | (.001) |
| Female | -.212* | -.208* | -.204* | -.146* | -.190* | -.127* | -.165* | -.107* | -.143* | -.079* | -.149* | -.098* | -.055* | .001 | -.107* | -.075* |
| | (.038) | (.038) | (.043) | (.042) | (.036) | (.036) | (.041) | (.041) | (.047) | (.045) | (.041) | (.040) | (.041) | (.041) | (.016) | (.016) |
| Education | | .059* | | .052* | | .102* | | .084* | | .121* | | .050* | | .131* | | .083* |
| | | (.005) | | (.006) | | (.005) | | (.006) | | (.006) | | (.006) | | (.006) | | (.002) |
| General | | | | .256* | | .268* | | .249* | | .271* | | .228* | | .223* | | .126* |
| | | | | (.009) | | (.008) | | (.009) | | (.010) | | (.009) | | (.009) | | (.004) |
| Constant | 6.968* | 6.474* | 6.967* | 4.476* | 4.174* | 1.620* | 7.235* | 4.527* | 7.266* | 3.897* | 5.369* | 3.251* | 4.291* | 1.526* | 4.771* | 5.421* |
| | (.089) | (.113) | (.101) | (.138) | (.084) | (.115) | (.096) | (.132) | (.109) | (.146) | (.094) | (.131) | (.095) | (.132) | (.037) | (.053) |
| $R^2$ | .074 | .077 | .119 | .184 | .056 | .136 | .146 | .213 | .133 | .219 | .063 | .115 | .012 | .078 | .037 | .059 |

Standardized correlation coefficients β.Standard errors reported in parentheses. *p < .001

## Discussion

The aim of this study was to gain a better understanding of older adults' decision making in situations of financial uncertainty and more broadly to investigate age differences in the propensity to gamble in uncertain situations. We hypothesized that there would be age differences in the propensity to gamble in risky conditions and in the propensity to gamble in ambiguous conditions. In addition, we hypothesized that feedback would increase the propensity to gamble under both types of uncertainty. We also expected to find a stronger effect of statistical probabilities than of a priori probabilities on age differences on decision making under risk.

All hypotheses were supported. Older adults appear to be equally willing to take risks as young adults when considering a priori probabilities. When making decisions based on statistical probabilities, older adults have a tendency to gamble less than young adults under risk. Ambiguity behaviour effectively also differs with age, and feedback increases the propensity to gamble. Statistical probabilities have a significant age effect with respect to decision making under risk while a priori probabilities do not.

Several factors might play a role in the age differences found in statistical but not in a priori probabilities. The most salient factors certainly are the different learning requirements of the tasks. Learning requirements are relatively low for the RAT, given that probabilities are represented as proportions of cards, none of the trials can inform about a subsequent one, and subjects are always allowed to choose a sure option instead of betting on the risky option. In contrast, performance on the BART relies on the participant's ability to learn the probabilities of outcomes from experience. When learning from experience is required to approach ideal behaviour, older adults appear to be more risk averse than young adults, and in a limited set of trials young adults perform better than older adults. One argument for the observed age difference could be that learning rates of young adults are generally steeper than those of older adults (Merriam, Caffarella, & Baumgartner, 2007), and thus young adults approach ideal behaviour faster than older adults. The data from this sample did not support this reasoning. A nonsignificant interaction effect between age group and the propensity to gamble over time indicated that the rate of learning did not differ between young and older adults. Instead, we observed that in both age groups the propensity to gamble increases over the trials with a similar pace. We also observed that both age groups were risk averse. Risk-taking behaviour, on average, stays below the risk neutral behaviour of 32 pumps per balloon over 20 trials. The difference between young and older adults rather lies in the starting values. Older adults begin the game with a lower average number of pumps than their younger counterparts, and then subsequently increase the number of pumps at the same pace as young adults. These findings are consistent with the results of Starns & Ratcliff (2010), who found that older adults are more cautious than young adults (i.e., the reward rate optimal boundary in the diffusion model differs between young and older adults).

Surprisingly, older adults seemed to switch later than young adults from the riskier to the less risky option on the Holt and Laury risk elicitation task, thus to be more risk seeking than young adults on this task. However, given that a large proportion of the older participants were inconsistent in their choice behaviour by switching more than once, we decided not to impute that older adults are more risk seeking on this task. In fact, we administrated our standard lab-use task to both adult groups, without adapting it for older adults' needs. The way this task is presented may have had confounding effects for older adults; choices are presented in a table with three columns. The first and second columns contain text only and represent options A and B, and in the third column, participants need to enter their choice through radio buttons. The other tasks were fundamentally different as the tasks used as little text as possible and participants simply needed to click directly on their choice on the screen. In the Holt and Laury task, participants needed to enter their choices through radio buttons after reading the text, which might have caused some difficulties to older adults.

Our findings in decision-making behaviour under conditions of ambiguity showed that older adults gamble more than young adults in ambiguous conditions, with or without feedback. In addition, the results revealed that higher ambiguity aversion compared to risk aversion commonly found in young adults was not observed in older adults who are no more averse to conditions of ambiguity than risk. These results seemed prima facie counterintuitive to us. Nevertheless, studies that have assessed cognitive processes and strategies might provide explanations for the observed behaviour.

Research has revealed a positivity effect that occurs with aging. Older adults appear to focus more on positive and less on negative information compared to young adults (Borges & Dutton, 1976; Lennings, 2000; Mather & Carstensen, 2005). Older adults focus more on regulating emotion than young adults, which has an impact on their overall emotional experience. Some authors suggest that in the aging process, an increased focus on emotion regulation influences attention and memory (Mather, 2004; Mather & Carstensen, 2003). Older adults are likely to show a memory distortion that prefers chosen options over rejected options (Mather & Johnson, 2000). This suggests that older adults sometimes are more likely to repeatedly choose the same options because their memories are biased in favour of positive outcomes of their previous choices. The tendency to focus on positive emotions leads to changes in decision-making strategies. Emotions have been shown to have effects on economic decision making (Lerner, Small, & Loewenstein, 2004), and in particular, positive affect can influence decision making (Isen, 2001). In the current study, this positivity effect could have influenced the propensity to gamble in ambiguous conditions in two different ways. First, the positive valence of older adults' memories for decision-based gains as opposed to losses could have led to a higher propensity to gamble under conditions of ambiguity. The observed behaviour could also have been due to the overall emotional state of the individual. Mood influences loss aversion (Camerer, 2005), which is strongly related to ambiguity aversion. Thus, a generally increased positive mood could lead to reduced ambiguity aversion.

An alternative explanation for the age difference in the propensity to gamble under ambiguity was provided by Mata et al. (2007). In their study, they found a difference in strategies used by young and older adults to make a decision. Older adults looked up less information and took more time to process it even though overall decision making of older and young adults was comparable. If these results are augmented by the fact that ambiguity is a condition with less information available than risk, we can hypothesize that ambiguous gambles are more suitable to older adults.

Another factor that could have influenced the results is experience. Older adults have had a lifetime to decide and develop strategies for decisions under ambiguity. Hence, their schemas or memory traces are more developed than those of young adults. One survey of bank managers, for example, revealed that older managers' business decisions were more aggressive than the decisions of younger managers (Brouthers, Brouthers, & Werner, 2000), and different studies found that uncertain investments increased until a particular age (Jianakoplos & Bernasek, 1998; Riley Jr & Chow, 1992; Schooley & Worden, 1999). Although speculative, the greater experience of older participants can provide fruitful hypotheses on the propensity to gamble of older adults in ambiguous situations.

Feedback was a salient effect on the propensity to gamble. Young and older adults alike gamble significantly more in the presence of feedback than without it. The main reason for this effect lies in the fact that decisions under uncertainty strongly rely on subjective probabilities. Feedback is an important factor in reducing subjective uncertainty (Hogg & Mullin, 1999), which in our experiment led participants to gamble more than in the absence of feedback. Also, participants have been shown to actively select tasks that reduce uncertainty (Trope, 1979). In the presence of feedback, subjects hence gamble more often to reduce the degree of uncertainty felt in the task. Naturally, in our experiment feedback could not have been used to learn about the probabilities of winning. All trials had to be considered separately because each trial is an independent event. In the risk trials, probabilities of winning the game were explicitly shown. In the ambiguous trials, probabilities were randomly drawn and the probabilities of winning in one trial did not indicate the probabilities of winning in the next trial. Accordingly, feedback can only reduce the subjective level of uncertainty felt by the subjects but objectively does not contribute to a better knowledge about the probabilities of winning.

As with all experiments, the current study also has its limitations. Given that the number of studies in the field of aging and decision making is still very small, our experiments aimed at describing differences between young and older adults. Therefore, we selected the older subjects in a way that eased comparability with young subjects. All our older participants were healthy, highly educated and practised a cognitively active lifestyle. Overall, older adults are very heterogeneous in their cognitive abilities, and activity might preserve cognitive ability with aging. We are aware that our results might apply only to a specific, cognitively active group of older adults, and do not claim that it is valid for the entire population of older people. To account at least to some amount for this issue, we analysed data from a representative sample of the German population. We have shown that whereas age has a negative impact on the willingness to take risks in the population, the level of education of subjects has a positive impact. As both age groups of our experiment belonged to the higher range of education in the distribution, we probably diminished some of the effects claimed in other studies to be attributable to age.  For a more detailed analysis of the effects of age, education and other factors influencing the willingness to take risks, we however refer the reader to other authors (Dohmen, Falk, Huffman, & Sunde, 2011), as this was not the aim of our study. Nevertheless, future experiments should focus on age differences in more heterogeneous subject groups on both sides of the age range (Henrich, et al., 2010).

In this experiment, we wilfully did not try to rule out cohort effects. All western populations are rapidly growing older, so that there is an immediate need to describe older adults' behaviour. Certainly it also is of great importance to understand how these behavioural differences develop over the life-course, but our first aim was to describe the differences between young and older adults, paving the way for future work where we will try to minimize the impact of cohort effects and to find explanations of these age differences.

## Conclusion

In conclusion, we observed that older adults' decision-making behaviour effectively differs from that of younger adults. In risky conditions, older adults behave like young adults if a priori probabilities apply, but in risky conditions were statistical probabilities are part of the decision and in ambiguous conditions, age differences appear. We have shown that there are different possible explanations for our results, and further work will be needed to understand the causes of our findings.

On a more practical level, our work contributes to growing evidence that older adults' decision making differs from that of younger adults. In our societies, older adults represent a growing part of the population, and a part of the population that will work until a higher age, thus also making financial decisions at a higher age. Understanding how decision making is affected by age becomes crucial for numerous situations of everyday life, and further research is needed to understand how older adults make their decisions, to help employers, policy makers, financial institutions, but also older adults themselves, to cope with the effects of the demographic change.

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# Age differences in uncertainty processing: a fMRI experiment

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## Abstract

*In an aging society, understanding the mechanisms underlying age differences in decision making becomes increasingly important. In the present study, a group of young adults (< 30 years, N = 25) and a group of older adults (> 58 years, N = 21) performed a task investigating decision making under uncertainty while brain activity was measured using fMRI. Besides age differences in behavior, age differences in brain activity in a large network of brain regions appeared. An interaction effect between age group and uncertainty condition was observed in clusters of the anterior insula, the amygdala, and the prefrontal cortices. Region of interest analysis confirmed an interaction effect in these regions, and revealed a main-effect of age in the right orbitofrontal cortex. Further, an age x uncertainty interaction effect appeared in the connectivity between the left anterior insula and the ventromedial prefrontal cortex. We try to relate the differences in behavior to the effects observed in the brain. We conclude that widespread processes, such as valuation, risk processing, and cognitive and emotion processing may be involved in the observed age differences in behavior.*

## Introduction

Older adults in our society are faced with many quandaries in their everyday lives. For example, they have to make difficult health care or financial decisions (e.g., whether to undergo a surgery, when to retire). Very often, older adults cannot avoid to be confronted with decisions regarding these issues, and the decisions have to be made based on absent or relatively little information (Chou, Lee, & Ho, 2007). When people grow older, they seem to need more time to reach decisions (Henninger, Madden, & Huettel, 2010), they become more vulnerable to misleading information and emotion processing changes (E. Peters, Hess, Västfjäll, & Auman, 2007), and a tendency towards an increase in conservative choices has been reported (Deakin, Aitken, Robbins, & Sahakian, 2004; Leland & Paulus, 2005). It is by now generally accepted that the age related change in brain morphology (R. Peters, 2006) and function (Cabeza, 2002; Cabeza, Anderson, Locantore, & McIntosh, 2002; Tucker-Drob, 2011) is related to changes in cognitive strategies and processes. Previous studies on age-related changes in neurocognitive processing have found that older adults, compared to younger adults, generally show a more bilateral pattern of prefrontal cortex (PFC) activity in cognitive tasks as diverse as episodic encoding (Logan, Sanders, Snyder, Morris, & Buckner, 2002; Stebbins et al., 2002), inhibitory control (Nielson, Langenecker, & Garavan, 2002), cued and verbal recall (Bäckman et al., 1997), working memory (Reuter-Lorenz et al., 2000), word and face recognition (Grady, Bernstein, Beig, & Siegenthaler, 2002; Madden et al., 1999), perception (Grady, McIntosh, Horwitz, & Rapoport, 2000), and semantic retrieval (Cabeza et al., 1997). Age differences have also been found in brain regions associated with emotion processing (for a review, see Mather (2012)), namely in the insula and in the amygdala. Fearful emotions are encoded differently in young and older adults, with young adults more strongly relying on the amygdala, whereas older adults show stronger activations in the insula (Fischer, Nyberg, & Bäckman, 2010); an age-related decline in insular volume also has been associated with age differences in the initial emotional sensation (Good et al., 2001). Age-related decreases in amygdala activation also have been associated with improved spontaneous emotion regulation (Leclerc & Kensinger, 2011; Murty et al., 2008; St. Jacques, Bessette-Symons, & Cabeza, 2009), decreased arousal response to negatively valenced stimuli (Cacioppo, Berntson, Bechara, Tranel, & Hawkley, 2011), and shifts in emotion processing strategies (Leclerc & Kensinger, 2011; Mather et al., 2004).

A growing body of research also suggests that our reaction to uncertainty changes with age (Mather, 2006). In economics, uncertain conditions usually are understood as conditions in which the outcome of a given decision is bound to some (known or unknown) probabilities, thus the outcome is not certain. Uncertain conditions can be classified into different subcategories, defined by their probability situations (Lo & Mueller, 2010). In an economic context, uncertainty either results from the presence of risk or from the presence of ambiguity. Risk refers to conditions in which there are multiple possible outcomes that could occur with explicit or easily computable probabilities (Bernoulli, 1738). Uncertainty can also refer to ambiguous conditions, in which probabilities cannot be computed empirically due to conflicting or absent information (Camerer & Weber, 1992; Ellsberg, 1961). Experimental evidence suggests that people often prefer options with known probabilities (risk) to options with unknown probabilities (ambiguity), even when expected utility theory predicts indifference or even the contrary preference (Heath & Tversky, 1991; Lauriola & Levin, 2001).

The distinct neural mechanisms underlying risk and ambiguity are currently a topic of extensive research (e.g., (Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005; Huettel, Stowe, Gordon, Warner, & Platt, 2006; Schultz et al., 2008)) and available data suggest that decision making under uncertainty involves a series of cognitive and affective processes that aim at balancing the potential gains and losses of actions (Arce, Miller, Feinstein, Stein, & Paulus, 2006). Ernst and Paulus (2005) identify a general brain network underlying reward-based decision making that comprises orbitofrontal cortex (OFC), anterior cingulate cortex (ACC), dorsolateral prefrontal cortex (DLPFC), parietal cortices, the caudate nucleus, and the thalamus. These brain regions, among others (e.g. insula, amygdala), have been repeatedly found in the literature to be involved in decision making under uncertainty (for a meta-analysis, see Krain et al., 2006; for a review, see Platt and Huettel, 2008). Hsu et al. (2005) observed that OFC, amygdala, and dorsomedial PFC (DMPFC) are relatively more activated under ambiguity than under risk, and link this system to the neural reaction to emotional information (amygdala), to the cognitive modulation of amygdalar activity (DMPFC), and to the integration of emotional and cognitive input (OFC). Greater activation under risk as compared to ambiguity was seen in the dorsal striatum (caudate nucleus), whose activation is interpreted as reflecting a greater reward anticipation response under risk than under ambiguity.

There is to date little evidence regarding the specific nature of age effects on the neural bases of decision making under uncertainty. Ageing-related changes in structure and function of various brain areas (Cabeza, Nyberg, & Park, 2005; R. Peters, 2006; Raz et al., 1997) can result in changes in cognitive task processing, including tasks of uncertainty processing, in older adults (Grady, 2000). Various patterns of age-related shifts in brain activation have been described. A shift from lateralized to more bilateral prefrontal activity has been summarized in the hemispheric asymmetry reduction in older adults model (HAROLD; Cabeza, 2002). The HAROLD model is a model of compensatory activation (Daselaar & Cabeza, 2005), based on the idea that, with high task demands, collaboration between the right and left hemisphere is more advantageous than within-hemispheric processing. Another age-related shift pattern is described in the posterior-anterior shift in aging (PASA) model (Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008). In the PASA model, decreases in activation in posterior brain regions are compensated for by increases in activation of frontal regions. According to Lee and colleagues, such an increase in the recruitment of other brain regions appears to be a general response to situations of neural effort in decision making (Lee, Leung, Fox, Gao, & Chan, 2007).

By applying the HAROLD model (Cabeza, 2002) and the PASA model (Davis, et al., 2008) to the domain of decision making under uncertainty, we hypothesized that decision making in older adults, compared to young adults, should involve an increased reliance on orbitofrontal cortex in older adults compared to young adults, and an overall more bilateral pattern of activation in older adults. As decision making under uncertainty also involves emotion processing (Loewenstein, Weber, Hsee, & Welch, 2001), and emotion processing and its underlying mechanisms in the brain change with age (Mather, 2012), we also expect to find age differences in activation of brain regions generally accepted to be involved in emotion processing, such as amygdala and insula. To test these predictions, we employed a modified version of Hsu and colleagues' (2005) risk and ambiguity task (RAT) while BOLD signals were measured using functional magnetic resonance imaging (fMRI). Finally, as age-related differences in functional connectivity for emotion processing have been reported (St.

Jacques, Dolcos, & Cabeza, 2009, 2010), we also explored age differences in functional connectivity between activated brain regions.

## Methods

### *Participants*

A total of 46 healthy volunteers participated in the current study. Young participants were on average 24.36 years of age (SD: 2.42 years; min 20, max 29, N = 25), older adults had an average age of 66.29 years (SD: 5.82 years; min 59, max 83, N = 21). All younger participants were students of the University of Heidelberg. In the older adults, eight went to a *Gymnasium*, 6 went to a *Realschule* and 6 to a *Hauptschule*[13]. After participants read an information sheet explaining the course of the experiment, written informed consent was obtained according to a procedure approved by the ethics committee of the University of Heidelberg.

### *Experimental Procedures*

Subjects played an adapted version of the risk and ambiguity task (RAT) used by Hsu et al. (2005), that differed from the original version by using an event-related single trial design rather than a blocked design and by including a certain condition as control. In the RAT, subjects had to make a sequence of 72 choices between a gamble and a sure amount of money. In one third of the trials, participants were faced with risky decisions (i.e., the probabilities of winning were known), in one third of the trials, they were faced with ambiguous decisions (i.e., the probabilities of winning the gamble were unknown), and in one third, they had to choose between two certain amounts of money (the control condition). Risky, ambiguous, and certain gambles alternated in a pseudo-randomized order, with at maximum two gambles of the same kind in a row. Card distribution (i.e., the total

[13] The German schooling system is mainly subdivided in 3 secondary school types: *Gymnasium*, *Realschule* and *Hauptschule*. Only degrees from a *Gymnasium* correspond to A-levels. Degrees from the other two types of schools do not allow pupil to access university studies directly, and degrees obtained in a *Hauptschule* are usually valorized less than degrees from a *Realschule*. One subject did not send back the questionnaires; therefore the schooling statistics do not sum up to 21 subjects.

number of cards) and outcome varied across trials (supplementary table 1). We used the same probability distribution as Hsu et al. (2005).

In each trial, subjects had to decide between three options: the sure payoff that paid a certain positive amount of money or a bet on either side of the binary choice gamble that carried variable degrees of uncertainty (depending on condition) of paying either a positive sum or zero. Responses were made by pressing the button corresponding to the location of the options (left-middle-right; balanced across trials) on the screen (Figure 1).

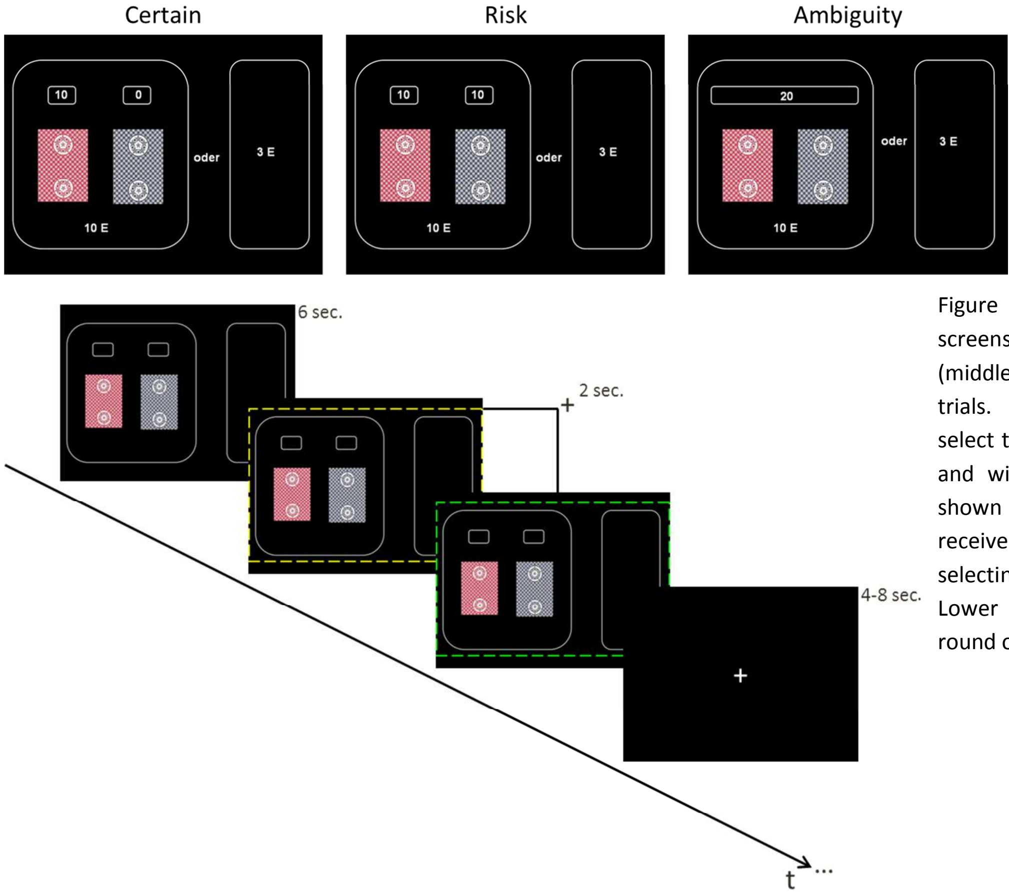



Figure 1: upper part: sample screens of certain (left), risky (middle) and ambiguous (right) trials. Participants could either select to bet on one of the colors and win the amount of money shown under the card decks, or receive a certain amount by selecting not to bet. Lower part: sequence of one round of the game.

The task started with a screen showing for 6 seconds a certain, risky, or ambiguous gamble. Then, a yellow frame appeared around the screen, signalling that subjects needed to enter their decision pressing the corresponding button. When the answer was registered, the colour of the frame changed to green. The total duration of yellow and green frame together was 2 seconds, which constituted the maximum response time. The response period was followed by a variable inter trial interval of 4-8 sec, and no feedback was given regarding task performance. At the end of the experiment, two of the gambles were chosen at random for pay-out and plaid with real cards.

### *fMRI Data Acquisition*

Images were acquired with a TrioTim 3T Siemens whole body MR system using a head volume coil. A high resolution T1-weighted anatomical scan (TR = 2.3; TE = 2.98; 160 slices; slice thickness 1.1 mm; 1*1 mm in-plane resolution) was acquired, followed by the functional scans using gradient-echo echo-planar imaging (EPI; TR = 2.7, TE = 27, 40 axial slices oriented at a +20° angle to the AC-PC plane, slice thickness 2.3 mm, 0 mm gap, 2.3*2.3 mm in-plane resolution, FOV = 220*220mm). A total of 374 volumes were recorded; the first four volumes were discarded to allow steady state magnetization.

### *fMRI data analysis*

Data analysis was mainly performed with SPM8 (http://www.fil.ion.ucl.ac.uk/spm). Additional SPM-toolboxes used in this analysis include: MarsBar (Brett, Anton, Valabregue, & Poline, 2002). Preprocessing image quality control was double checked with FSL (http://www.fmrib.ox.ac.uk/fsl/). Threshold levels were corrected for multiple comparisons using AlphaSim of the AFNI package (Ward, 2000). After excluding the first four volumes, images were motion corrected using a six-parameter rigid body transformation and resliced. No participant showed excessive head motion. Functional images were normalized into a standard stereotaxic space (Montreal Neurological Institute) with voxels of size 1.5*1.5*1.5mm$^3$ using the DARTEL method for intersubject comparison. To increase the signal-to-noise-ratio, the fMRI images were spatially smoothed by an isotropic Gaussian filter with 8 mm FWHM.

Subject-specific analyses involved estimating a general linear model with predictors for the onset of each condition (certain, risk, ambiguity). Movement parameters were added as covariates of no interest and low frequency noise was temporally high-pass filtered (cutoff: 128s). Random-effect group analyses were computed by means of a 3 (uncertainty condition: certain vs. risk vs. ambiguity) x 2 (group: young adults vs. older adults) full factorial design. We investigated in a first step the main effects of age and of uncertainty, followed by the interaction effect of uncertainty condition and group to avoid confounding differences in hemodynamic modulation between age groups (Gazzaley & D'Esposito, 2005; G. R. Samanez-Larkin & D'Esposito, 2008). The interaction effect was subsequently transformed into a mask using xjview (http://www.alivelearn.net/xjview8), within which the further analyses were performed (mask extent and parameters can be found in Table 1 and Figure 3). To protect against false-positive activations, we used a double-threshold approach, combining a voxel-based threshold with a minimum cluster size (Forman et al., 1995). The nonarbitrary voxel cluster size corresponding to a corrected p-value of $p < .05$ was determined by using the program AlphaSim (Ward, 2000; afni.nimh.nih.gov/afni/doc/manual/AlphaSim), resulting in a cluster-size of 90 at a p-value of .0001 (uncorrected) for the entire brain, and in a cluster size of 101 with a p-value of .005 within the mask representing the uncertainty x age group interaction.

## Results

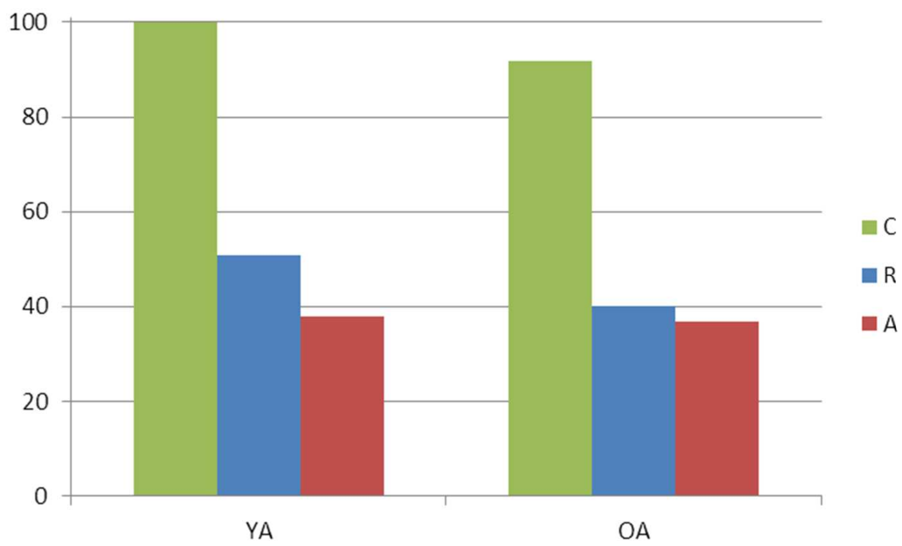



Figure 2: Age differences in decision making under certainty, risk and ambiguity. YA = young adults; OA = older adults. Green bars represent the percentage of gambles taken under certainty, blue bars represent the percentage of gambles taken under risk, red bars represent the percentage of gambles taken under ambiguity.

Behavioural performance was measured as the percentage of trials in which subjects chose the gamble in the risky or ambiguous trials. Due to technical reasons, data was only partially collected in two of the older adults; we therefore exclude them from the behavioural analysis. When comparing behaviour of young and older adults under certainty, risk, and ambiguity using a mixed-model ANOVA, a significant effect of the uncertainty condition ($F_{(2;84)} = 93.800$, $p < .001$) and of age group appeared ($F_{(1;42)} = 4.378$, $p = .042$); no significant uncertainty x age interaction effect could be reported ($p > .05$). When resolving the interaction to examine age effects separately for each uncertainty condition, we observed that young and older adults gambled equally on the ambiguous trials, but not on the risky and certain trials. Under ambiguity, young adults gambled on average in 38.21% (SE: 5.47) of the trials, compared to 39.20% (SE: 6.90) of the older adults ($t_{(42)} = 0.114$, $p = .910$). Under certainty, young adults chose the higher amount of money in all trials (100%). Older adults chose the higher amount in 91.01% (SE = 2.78) of all trials ($t_{(18)} = 3.231$, $p = .005$, corrected for unequal variances). On the risky trials, young adults gambled on average on 50.67% of the trials (SE: 3.90), compared to only 36.07% in older adults (SE: 5.44; $t_{(42)} = 2.183$, $p = .030$).

## *fMRI results*

### *Whole-brain analyses*

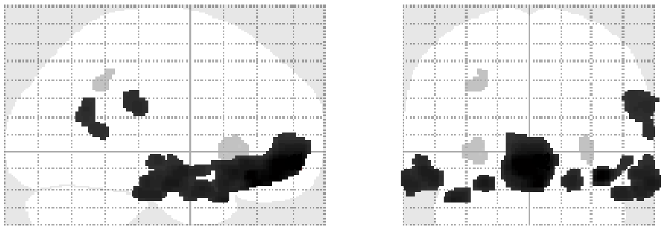
In a first step, we searched for brain regions that show age or condition differences (table 1). Young adults, as compared to older adults, show a stronger activation in the left and right nucleus caudatus, as well as in the calcarine, the postcentral gyrus and the superior parietal lobe. Older adults, in comparison, show stronger activations in the right OFC, in the left middle temporal lobe, superior occipital lobe, and supramarginal gyrus, and in the right middle frontal lobe.

When comparing certain to uncertain conditions, we observe an extensive activation peaking in the right supramarginal gyrus, extending over the entire middle temporal lobe. Further, we observe activations in the ventromedial prefrontal and in the right orbitofrontal cortex, in both the right and left amygdala, in the dorsal part of the posterior cingulate cortex, and in the left angular gyrus. In uncertain conditions, we find stronger activations in the left and right anterior insulae (extending from the left AI to the left DLPFC), in the right OFC and dorsolateral prefrontal cortex, the thalamus (extending to the right putamen and nucleus caudatus), the left putamen and nucleus caudatus, the left hippocampus, and the anterior part of the medial cingulate cortex. Further, we observe activation in the right inferior operculum frontale, in the right precuneus, in the cerebellum, and extensive activation peaking in the right lingual gyrus, but extending to left lingual and other occipital regions.

Table 1: Main effects of age group and uncertainty

| Contrast | Brain region | Hemisphere | MNI Coordinates X | Y | Z | $t_{max}$ | Extent |
|---|---|---|---|---|---|---|---|
| Young>Older | Calcarine | Bi | 3 | -93 | -4 | 7.44 | 3553 |
| | Postcentral | R | 27 | -44 | 48 | 5.79 | 191 |
| | Sup. parietal | L | -26 | -57 | 59 | 5.27 | 295 |
| | Nuc. Caudatus | R | 14 | 20 | 12 | 4.61 | 90 |
| | | L | -15 | 21 | 11 | 4.53 | 141 |
| | Sup. occipital | L | -11 | -87 | 42 | -5.50 | 390 |
| | Middle frontal | R | 40 | 10 | 45 | -5.14 | 130 |
| | Middle temporal | L | -39 | -62 | 17 | -4.81 | 116 |
| | Supramarginal | L | -65 | -47 | 27 | -4.78 | 130 |
| | OFC | R | 38 | 30 | -13 | -4.18 | 90 |
| Certain>Unc. | Supramarginal | R | 60 | -47 | 36 | 7.56 | 10881 |
| | OFC | Bi | 2 | 34 | -13 | 7.21 | 4563 |
| | | R | 33 | 30 | -15 | 5.58 | 95 |
| | Angular | L | -57 | -59 | 27 | 6.96 | 2704 |
| | dorsal PCC | Bi | 12 | -50 | 38 | 6.09 | 2165 |
| | Amygdala | L | -24 | -6 | -18 | 5.61 | 256 |
| | | R | 27 | -3 | -18 | 5.47 | 241 |
| | Middle temporal | L | -62 | -8 | -13 | 4.93 | 308 |
| | Lingual | R | 21 | -66 | -7 | -8.94 | 25278 |
| | anterior Insula | R | 32 | 29 | -1 | -8.74 | 1156 |
| | | L | -29 | 21 | -1 | -7.77 | 6168 |
| | anterior MCC | Bi | -6 | 25 | 42 | -7.97 | 2537 |
| | OFC | R | 21 | 41 | -16 | -7.34 | 166 |
| | DLPFC | R | 46 | 35 | 24 | -6.28 | 1911 |
| | Thalamus | Bi | 8 | -30 | -4 | -6.21 | 2964 |
| | Cerebelum/Vermis | Bi | 0 | -54 | -36 | -5.89 | 201 |
| | Precuneus | R | 12 | -72 | 51 | -5.33 | 856 |
| | Cerebelum | L | -41 | -66 | -49 | -5.16 | 126 |
| | Putamen/Nuc. Caudatus | L | -15 | 13 | 0 | -4.88 | 154 |
| | Hippocampus | L | -23 | -29 | -1 | -4.65 | 125 |
| | Inf. operculum front. | R | 46 | 12 | 30 | -4.40 | 96 |

Brain regions identified at corrected $p < .05$ (unc. $p = .0001$, $k = 90$).
Extent = number of voxels ($1.5*1.5*1.5mm^3$) in the cluster.



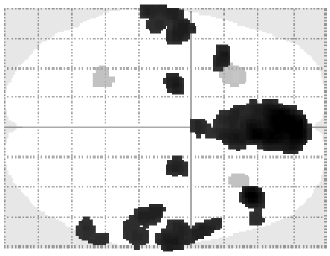


Figure 3: Glass brain of the interaction age-group x uncertainty at unc. p = .0001 k = 90. Black areas represent positive t-values, grey areas represent negative t-values.

In the following step, we searched for brain regions that show an interaction of age group and uncertainty condition. This interaction effect was observed in a system encompassing right lateral orbitofrontal cortex (extending to ventrolateral prefrontal cortex) and ventromedial prefrontal cortex (extending from clusters in the anterior cingulate cortex over the medial orbitofrontal cortex to clusters in the rostromedial prefrontal cortex), the right and left amygdalae, right and left anterior insulae, the right and left temporal lobes, the right angular and supramarginal gyri, and the left inferior parietal cortex. A high-resolution rendered image of activated regions can be found in the supplements (figure S1).

Table 2: Brain Regions displaying an age group * uncertainty interaction.

| | | MNI coordinates | | | | |
|---|---|---|---|---|---|---|
| Brain region | Hemisphere | X | Y | Z | $t_{max}$ | Extent |
| OFC | Bi | -6 | 48 | -7 | 6.83 | 4356 |
| | R | 39 | 33 | -15 | 6.66 | 249 |
| Mid. temporal lobe | R | 65 | -12 | -18 | 5.13 | 805 |
| | L | -56 | -5 | -13 | 5.07 | 752 |
| Inf. temporal lobe | R | 51 | -26 | -24 | 4.88 | 166 |
| Temporal pole | L | -41 | 18 | -28 | 5.12 | 115 |
| Hippocampus/Amygdala | L | -24 | -8 | -18 | 5.11 | 127 |
| | R | 23 | -9 | -16 | 4.82 | 140 |
| Supramarginal | R | 62 | -29 | 24 | 4.34 | 277 |
| Angular Gyrus | R | 57 | -56 | 24 | 4.24 | 212 |
| Anterior Insula | L | -27 | 22 | -1 | -5.48 | 279 |
| | R | 30 | 27 | -1 | -4.77 | 135 |
| Inf. Parietal | L | -26 | -50 | 38 | -4.35 | 101 |

Brain regions identified at corrected $p < .05$ (unc. $p = .0001$, $k = 90$).
Extent = number of voxels ($1.5*1.5*1.5mm^3$) in the cluster.

To resolve the exact nature of the observed interaction effect, we assessed age group effects separately for the tree uncertainty conditions. These analyses were restricted to those areas showing an age group x uncertainty interaction. In the certainty condition, no age effects appeared to contribute to the interaction. For risky trials, the right anterior insula was more strongly activated in young adults, whereas older adults showed stronger activation in the right and medial OFC, in the right angular and supramarginal gyri, bilaterally in the middle temporal lobes, and in the left temporal pole. Under ambiguity, there were no regions that showed stronger activation in young than in older adults. In older adults, however, the medial and right lateral OFC, and the bilateral middle temporal lobes were more strongly activated than in young adults.

Table 3: Post-hoc brain regions

| | | MNI Coord. | | | | |
|---|---|---|---|---|---|---|
| Brain region | Hemisphere | X | Y | Z | $t_{max}$ | Extent |
| Risk: Older > Young | | | | | | |
| Anterior Insula | R | -29 | 21 | 0 | -3.28 | 110 |
| Mid. temporal | R | 65 | -17 | -18 | 5.67 | 759 |
| | L | -62 | -11 | -18 | 4.55 | 510 |
| Angular/Temporal | R | 57 | -56 | 23 | 5.63 | 212 |
| OFC | R | 39 | 32 | -13 | 5.22 | 227 |
| | Bi | 0 | 46 | -15 | 4.70 | 2330 |
| Temporal pole | L | -38 | 19 | -25 | 4.77 | 103 |
| Supramarginal | R | 65 | -27 | 21 | 3.78 | 117 |
| Ambiguity: Older > Young | | | | | | |
| OFC | R | 38 | 32 | -13 | 5.12 | 208 |
| | Bi | 9 | 25 | -16 | 4.18 | 1039 |
| Mid. temporal | R | 62 | -45 | 12 | 4.38 | 188 |
| | R | 54 | -9 | -13 | 3.34 | 316 |
| | L | -54 | -12 | -12 | 3.36 | 154 |

Brain regions identified within the brain mask at corrected $p < .05$ (unc. $p = .005$, $k = 101$)
Extent = number of voxels ($1.5*1.5*1.5mm^3$) in the cluster.

*ROI-analyses*

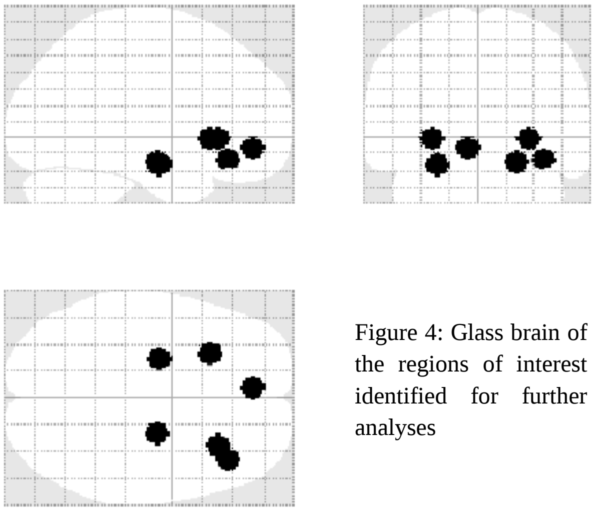


Figure 4: Glass brain of the regions of interest identified for further analyses

To address the potential problems that can arise from group differences in brain structure, it is common practice to use region of interest (ROI) analyses to compare age groups (Samanez-Larkin & D'Esposito, 2008). To examine how the interaction effect in the whole-brain analyses composes, we defined six functional regions of interest with a 6mm radius around the peak voxel in bilateral anterior insulae, bilateral amygdalae, medial OFC, and right OFC. Mixed model ANOVAs showed significant effects of uncertainty in all regions of interest (left AI, $F_{(2;88)} = 27.118$, $p < .001$; right AI, $F_{(2;88)} = 33.562$, $p < .001$; left amygdala, $F_{(2;88)} = 12.139$, $p < .001$; right amygdala, $F_{(2;88)} = 3.379$, $p = .039$; medial OFC, $F_{(2;88)} = 21.730$, $p < .001$; right OFC, $F_{(2;88)} = 5.288$, $p = .007$), as well as significant interactions between uncertainty and age group (left AI, $F_{(2;88)} = 13.011$, $p < .001$; right AI, $F_{(2;88)} = 9.931$, $p < .001$; left amygdala, $F_{(2;88)} = 10.731$, $p < .001$; right amygdala, $F_{(2;88)} = 10.295$, $p < .001$; medial OFC, $F_{(2;88)} = 21.544$, $p < .001$; right OFC, $F_{(2;88)} = 16.726$, $p < .001$). A significant age effect appeared only in the right OFC ($F_{(1;44)} = 17.344$, $p < .001$, Figure 5), and in none of the other ROIs. This suggests that age-related differences in cerebral vasculature are not significant, and that comparison in neural activities between the two age groups could be reasonably interpreted in the current study. Graphical representations of activations in the regions of interest can be found in the supplements (figure S2).

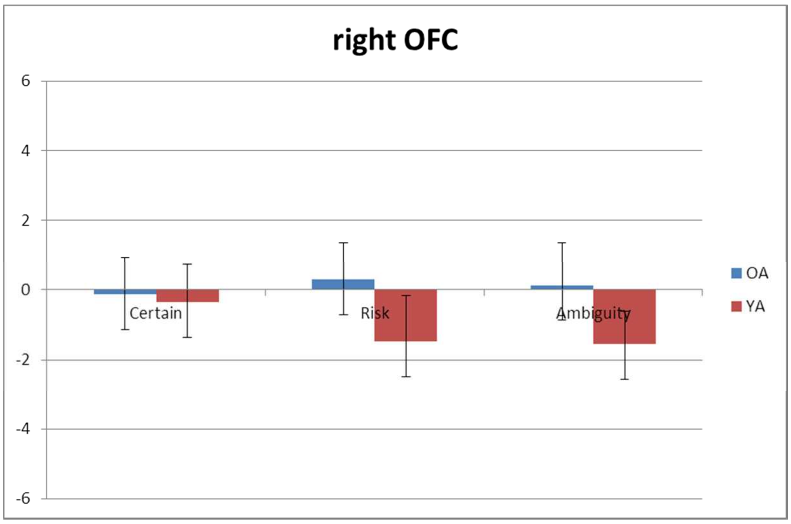



Figure 5: Activation in the right OFC region of interest. Blue bars represent main activity in older adults; red bars represent main activity in young adults. Error bars: standard deviations.

To evaluate temporal changes in the activations of these ROIs, finite impulse response (FIR) analyses were performed. Based on Hsu et al. (2005), we expected to find differences in peri-stimulus time horizons (PSTH) between the uncertainty conditions. FIR analyses show the existence of significant differences for the uncertainty conditions in all ROIs (left AI, $F_{(20;1320)}$ = 889.32; right AI, $F_{(20;1320)}$ = 1152.4; left amygdala, $F_{(20;1320)}$ = 2084.7; right amygdala, $F_{(20;1320)}$ = 2961.7; medial OFC, $F_{(20;1320)}$ = 3178.9; right OFC, $F_{(20;1320)}$ = 969.34; all $p < .0001$; figure S3), and no significant interaction effects between age and condition (all $p > .05$). Significant overall age effects in PSTH modulation appear in the medial and right OFC (medial OFC, $F_{(10;1320)}$ = 2.539, p = .005; right OFC, $F_{(10;1320)}$ = 2.649, p = .003), and in the left and right AI (left AI, $F_{(10;1320)}$ = 2.401, p = .008; right AI, $F_{(10;1320)}$ = 2.864, p = .002). In the amygdalae, no general age differences in activation time courses appear. Figure S4 contains more detailed PSTH curves representing age effects and age x condition interactions.

*PPI-analyses*

We performed psychophysiological interaction (PPI, (Friston et al., 1997)) analyses based on the ROIs. PPI analysis assesses the hypothesis that activity in one brain region can be explained by an interaction between the presence of a cognitive process and activity in another part of the brain. Volumes of interest were defined with the same specifications as the regions of interest. Our analysis revealed a significant interaction between age group and the PPI between uncertainty conditions and left anterior insula activity, expressed within a region at the border of the ventromedial prefrontal cortex (vmPFC) and the anterior cingulate cortex (ACC). In other words, functional connectivity between the left anterior insula and the vmPFC/ACC region during certain vs. uncertain conditions differs between young and older adults. Within the young adults, PPI analysis revealed a significant interaction between risk versus ambiguity conditions and right OFC activation, expressed in the left AI. That is, young adults show greater connectivity with left anterior insula during risky than during ambiguous trials. Furthermore, young adults show a significant interaction between ambiguous versus risk conditions and medial OFC activation, expressed in a more ventral cluster of activation in the medial OFC.

The vmPFC and ACC voxels activated in reaction to the left anterior insula PPI lie partly within the medial-OFC volume of interest. Thence the idea to extract PPI-interaction values of the left AI and medial OFC of each participant. Figure S5 shows a scatterplot with linear fitting functions for each condition. It appears that in young adults, the orbitofrontal cortex responds positively to activation of the left AI in certain trials ($\beta = .106$, $t = -10.243$, $p < .001$), negatively in risky trials ($\beta = -.138$, $t = -13.376$, $p < .001$), and close to zero in ambiguous trials ($\beta = -.016$, $t = -1.533$, $p = .125$). In older adults, orbitofrontal cortex response is positive in all conditions, however with a stronger relationship for risky ($\beta = .351$, $t = 33.034$, $p < .001$) and certain trials ($\beta = .321$, $t = 29.954$, $p < .001$) than for ambiguous trials ($\beta = .146$, $t = 12.990$, $p < .001$).

Table 4: PPI results

| | | Condition | | | L/R | MNI Coord. X | Y | Z | $t_{max}$ | Extent |
|---|---|---|---|---|---|---|---|---|---|---|
| AI | L | Int. Age * Unc. | | vmPFC/ACC | | 2 | 54 | -3 | 3.38 | 169 |
| | | | | ACC | | -8 | 45 | 0 | 3.79 | 128 |
| | | Certain | OA | medial OFC | | -11 | 54 | 9 | 5.44 | 476 |
| | | Risk | YA | medial OFC | | -6 | 58 | 0 | 4.41 | 701 |
| | | | | Supramarginal | R | 66 | -27 | 27 | 3.36 | 185 |
| | | | | Mid. Temporal | L | -62 | -5 | -18 | 3.51 | 218 |
| | | Ambiguity | YA | medial OFC | | 6 | 25 | -10 | 3.28 | 102 |
| | | | | medial OFC | | 5 | 55 | 6 | 3.22 | 226 |
| | | | | Angular | R | 63 | -57 | 17 | 3.42 | 103 |
| | R | Certain | YA | ACC | | 6 | 54 | 5 | 3.31 | 110 |
| | | | | Mid. Temporal | R | 68 | -5 | -18 | 3.27 | 133 |
| | | Risk | YA | OFC/ACC | | -6 | 60 | -3 | 4.12 | 579 |
| | | | OA | OFC | R | 35 | 29 | -16 | 4.78 | 117 |
| | | Ambiguity | YA | Angular | R | 58 | -59 | 20 | 3.72 | 139 |
| | | | | vmPFC/ACC | | 5 | 60 | -4 | 3.56 | 511 |
| | | | | medial OFC | | -6 | 22 | -18 | 3.42 | 117 |
| | | | OA | Amygdala | R | 26 | -6 | -18 | 4.11 | 118 |
| | | | | Amygdala | L | -24 | -6 | -18 | 3.42 | 106 |
| | | | | Supramarginal | R | 60 | -35 | 36 | 3.3 | 242 |
| Amyg. | L | Risk | YA | Supramarginal | R | 68 | -29 | 29 | 3.83 | 175 |
| | | | OA | Mid. Temporal | R | 57 | 3 | -18 | 3.31 | 113 |
| | | Ambiguity | YA | vmPFC/ACC | | 3 | 57 | 2 | 3.31 | 210 |
| | | | | Supramarginal | R | 57 | -29 | 32 | 3.55 | 107 |
| | | | OA | Mid. Temporal | R | 68 | -14 | -15 | 4.32 | 140 |
| | R | Ambiguity | OA | Mid. Temporal | R | 65 | -14 | -18 | 3.70 | 209 |
| OFC | Bi | Amb>Risk | YA | medial OFC | | -8 | 40 | -16 | 3.43 | 114 |
| | | Certain | YA | vmPFC/ACC | | 11 | 48 | -6 | 3.92 | 146 |
| | | Ambiguity | YA | medial OFC | | -8 | 39 | -10 | 3.24 | 197 |
| | | | | Angular/Supramarginal | R | 60 | -35 | 30 | 3.45 | 116 |
| | | | OA | Mid. Temporal | R | 62 | 3 | -24 | 3.34 | 135 |
| | R | Risk>Amb | YA | AI | L | -27 | 27 | 2 | 4.34 | 106 |
| | | Certain | YA | vmPFC/ACC | | -5 | 58 | -9 | 4.37 | 648 |
| | | Risk | YA | AI | L | -27 | 27 | 2 | 4.77 | 128 |
| | | | OA | Mid. Temporal | R | 60 | -12 | -12 | 3.56 | 130 |
| | | Ambiguity | OA | medial OFC | | -6 | 36 | -18 | 3.19 | 105 |
| | | | | Mid. Temporal | R | 65 | -5 | -22 | 3.68 | 342 |
| | | | | | L | -66 | -17 | -16 | 4.59 | 257 |
| | | | | Angular | R | 57 | -59 | 24 | 3.52 | 143 |

Brain regions identified within the brain mask at corrected p < .05 (unc. p = .005, k = 101)
Extent = number of voxels ($1.5*1.5*1.5mm^3$) in the cluster. YA: young adults; OA: older adults

## Discussion

The current study had two aims. The first aim was to investigate the relationship between age, behavior, and brain function in reaction to uncertainty. As in the behavioral results, we also find significant age group and uncertainty effects in brain regions that have been repeatedly reported to be involved in decision making. We try to explain the effects by comparing young and older adults in a post-hoc analysis of brain regions involved in the interaction between uncertainty conditions and age group. To our knowledge, this is the first study to investigate the neural basis of these age effects not only in risky conditions, but also in ambiguous conditions.

The second aim of the study was to investigate how functional connectivity within the uncertainty-processing system changes with age. It appears that clusters of the medial orbitofrontal cortex respond to left anterior insula activation in interaction with age and uncertainty conditions. It is a first evidence that young and older adults not only recruit different brain regions on average in decision making under uncertainty, but also that the connectivity between these regions varies.

The results of the interaction between age group and uncertainty condition provide direct evidence of age related differences in uncertainty processing. To understand how this interaction effect composes, we analyzed in more detail the brain regions activated in the different conditions involved in the interaction.

In line with the HAROLD model (Cabeza, 2002) and the results of Lee et al. (2007), medial and right orbitofrontal cortex activation appears to be stronger in older adults than in young adults in all conditions. The involvement of pre- and orbitofrontal regions in decision making under uncertainty is well documented in young adults (Hsu, et al., 2005; Huettel, et al., 2006; Krain, et al., 2006; Levy, Snell, Nelson, Rustichini, & Glimcher, 2010), but has gotten little explanatory attention in older adults (Hosseini et al., 2010; Lee, et al., 2007). In young adults, the lateral OFC has been shown to represent unsteady outcomes and to prepare for response shifts, whereas the medial OFC represents steady stimulus-outcome associations, integrates emotional and cognitive input, and can be linked to action monitoring and the selection of action sets (Elliott, Dolan, & Frith, 2000; McClure, Laibson, Loewenstein, & Cohen, 2004; Rushworth, Buckley, Behrens, Walton, & Bannerman, 2007; Rushworth, Walton, Kennerley, & Bannerman, 2004; Windmann et al., 2006). In the few studies on aging and decision making under uncertainty, an increase in right and medial OFC activity is a common result, being explained by several models (e.g., the HAROLD model (Cabeza, 2002), the "frontal lobe hypothesis" (West, 1996), and the posterior-anterior shift in aging (PASA) model (Davis, et al., 2008)). These models all have in common the idea that age-related changes in cognitive function are compensated by an increase in recruitment of frontal regions. Our study suggests a compensatory activation of the right OFC, as this region is the only of the regions of interest which shows a significant age effect in overall activation. With respect to hemodynamic modulation in response to different conditions, the right OFC furthermore shows activation curves distinct from the other regions of interest. In the activation PSTHs of most of the regions of interest, we observe that trials of the certain condition evoke opposite responses to uncertain trials. That is, when uncertain trials evoke an overall increase in hrf in the ROI, certain events evoke a decrease, and vice versa. This pattern is somewhat different in the right OFC. Here, we observe a rather parallel pattern of activation for certain and ambiguous trials, and a relatively late peak in hrf under risk (between TR 8 and 9).

Left and right anterior insula activation is stronger in uncertain than in certain conditions. Furthermore, right anterior insula shows stronger activation in young adults compared to older adults under risk, and in risky conditions compared to ambiguous conditions in young adults. Under risk and under ambiguity, right and left insulae appear to react quickly, with a steep increase in activation within the first TR, and a slow subsequent decrease in activation. In the medial OFC, this activation pattern is opposite, with a steep decrease in activation in the first and second TR under risk and under ambiguity, followed by a subsequent slow increase. It has been shown than anterior insula activation correlates with risk prediction and risk prediction error (Preuschoff, Quartz, & Bossaerts, 2008), and with the anticipated value of decisions (Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007). The reaction of the anterior insula to risk has been repeatedly shown in brain imaging studies without clear distinction between risk prediction and risk prediction error (Critchley, Mathias, & Dolan, 2001; Paulus, Rogalsky, Simmons, Feinstein, & Stein, 2003). In our experiment, the activation of anterior insula for risk prediction seems the most likely in young adults, as a prediction error would involve feedback, which was absent in the present study. Samanez-Larkin et al.

(2007) have shown age differences in anterior insula activation for gain and loss anticipation, with older adults showing an anticipatory signal in the anterior insula in gain conditions similar to young adults, but not in loss conditions. We expected therefore not to observe a difference in anterior insula activation between young and older adults in risk conditions, as our task contained only gain conditions. However, the anterior insulae play also a role in risk processing, which is not present in the study of Samanez-Larkin and colleagues. The age difference in insula activation might also relate to the behavioral differences we observed in decision making under risk. Mather (2012) suggests that a decrease in insula activation correlates with a decrease in reaction to the emotional valence of negative stimuli. Hence, a lower reaction to the emotional value of stimuli, combined with the finding that the anterior insula plays a role in risk prediction, might give an explanation of the lower propensity to gamble in risky conditions observed in older adults as compared to young adults.

We also find a stronger activation of the left amygdala under certainty than under uncertain conditions. The amygdala forms part of a network of brain regions that underlie the learning process through which neural stimuli become predictive of the value of outcomes (Cardinal, Parkinson, Hall, & Everitt, 2002; Holland & Gallagher, 2004), and represents appetitive goal values in goal directed choices (Balleine, 2005). Amygdala activation has also been found to be involved in negative prediction error (Yacubian et al., 2006) and in the processing of stimulus relevance for the goals and motivations of the decision maker (Cunningham & Brosch, 2012). Interestingly, left amygdalar PSTH responses show different patterns of activation compared to Hsu et al. (2005). Whereas in their experiment, hemodynamic response function quickly peaks in left and right amygdala after stimulus onset, we observe a slight increase in right amygdalar activation in the first TR, followed by a steep decrease, and an immediate decrease in left amygdalar activation under both risk and ambiguity. In the right OFC, results are similar; whereas Hsu and colleagues observe an increase in hrf following risky and ambiguous stimulus onset, we report an initial decrease in activity in the first TR, followed by an increase. However, as the coordinates and specifications of the regions of interest used by Hsu and colleagues are not reported, it is difficult to determine whether our results differ, or whether it is just a question of differences in ROI specification.

Our second aim in this study was to investigate whether functional connectivity within the decision making network differed between young and older adults. It is well documented that age not only has effects on overall activation of brain regions in cognitive and decision making tasks, but also on connectivity between the involved regions (Grady, 2004; Reuter-Lorenz & Cappell, 2008). To our knowledge, no previous brain imaging study has examined age differences in functional connectivity during decision making under uncertainty. In the current study, we found an interaction between age group, uncertainty condition and response to left AI activity in the medial OFC. More precisely, in young adults, OFC responds positively to the interaction between certain trials and left AI activity, negatively to an interaction with risk, and not significantly to an interaction with ambiguity. In older adults, medial OFC response is positive in all left AI x uncertainty interactions, but with a stronger relationship for risky and certainty trials than for ambiguity trials. Even though we are not aware of any studies investigating age-related differences in functional connectivity between anterior insula and medial orbitofrontal cortex, the PPI results may give an explanation to the observed behavioral effects. First, when comparing overall brain activation in young and older adults under risk, we observe stronger anterior insula activation in young adults, and a stronger OFC activation in older adults. Behaviorally, we observe a difference between the age groups in risk taking, which, together with the connectivity data (opposite effects between young and older adults in the reaction of the medial OFC to activity in the left AI), suggests an involvement of the OFC – AI connection in behavioral age differences. Second, when comparing young and older adults under ambiguity, we do again observe a stronger activation in the OFC in older adults, but we do not find any brain regions that show a significantly stronger activation in young than in older adults. Under ambiguity, however, we do not observe a difference in behavior between young and older adults, together with PPI-data showing a significant positive connection in older adults between anterior insula and medial orbitofrontal cortex, compared to a nonsignificant connection in young adults. This seems to be in line with the aforementioned compensation models, which state that frontal regions (i.e. also the medial OFC) are recruited in support of less efficient recruitments of other brain regions, to compensate for age-related declines. Thus, in summary, we speculate that a moderate additional strength of the link between AI and medial OFC compensates for age-related declines in brain regions involved in decision making under uncertainty, whereas extreme differences in connectivity result in differences in behavior. Further work will however be needed to fully understand age differences in connectivity in decision making networks.

## Conclusion

In an aging society, it becomes increasingly important to understand the processes underlying age-related differences in decision making. Previous brain-imaging research on these differences has mainly focused on risky decision making. The present study extends the existing literature by investigating age differences not only under risk but also under ambiguity, and by investigating age differences in brain connectivity under uncertain conditions. The observed differences point in the direction of age differences in the recruitment of the decision making network. Understanding these differences is one of the central goals in aging research, as it is a crucial step in preserving and enhancing decision making abilities. In this study, we have shown that it is not only important to search for age differences on the standard whole brain level, but that changes in connectivity may have effects on behavior too. We can show that the activation of brain regions underlying widespread processes, such as cognitive and emotion processing, risk processing, and valuation, changes with age. Future work will need to clarify the exact contribution of each of these mechanisms to age differences in decision making.

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# Supplementary material

Supplementary table 1: card decks

| Condition | Nr. | Red | Blue | Total cards | Gain bet | Gain certain |
|---|---|---|---|---|---|---|
| Risk | 1 | 2 | 18 | 20 | 12 | 8 |
| | 2 | 18 | 12 | 30 | 16 | 12 |
| | 3 | 9 | 1 | 10 | 19 | 12 |
| | 4 | 3 | 9 | 12 | 16 | 13 |
| | 5 | 3 | 12 | 15 | 20 | 10 |
| | 6 | 21 | 9 | 30 | 20 | 15 |
| | 7 | 8 | 32 | 40 | 16 | 10 |
| | 8 | 5 | 10 | 15 | 12 | 8 |
| | 9 | 6 | 14 | 20 | 18 | 12 |
| | 10 | 16 | 24 | 40 | 16 | 8 |
| | 11 | 4 | 36 | 40 | 20 | 14 |
| | 12 | 18 | 9 | 27 | 15 | 10 |
| | 13 | 26 | 13 | 39 | 12 | 8 |
| | 14 | 10 | 20 | 30 | 12 | 10 |
| | 15 | 3 | 2 | 5 | 18 | 12 |
| | 16 | 27 | 3 | 30 | 14 | 11 |
| | 17 | 12 | 28 | 40 | 16 | 14 |
| | 18 | 4 | 1 | 5 | 14 | 8 |
| | 19 | 8 | 12 | 20 | 18 | 9 |
| | 20 | 7 | 21 | 28 | 12 | 8 |
| | 21 | 24 | 8 | 32 | 19 | 13 |
| | 22 | 8 | 2 | 10 | 16 | 10 |
| | 23 | 7 | 3 | 10 | 13 | 10 |
| | 24 | 15 | 5 | 20 | 12 | 6 |
| Ambiguity | 1 | | | 20 | 20 | 10 |
| | 2 | | | 10 | 16 | 7 |
| | 3 | | | 40 | 20 | 12 |
| | 4 | | | 30 | 13 | 7 |
| | 5 | | | 40 | 17 | 7 |
| | 6 | | | 30 | 18 | 6 |
| | 7 | | | 20 | 20 | 11 |
| | 8 | | | 30 | 12 | 7 |
| | 9 | | | 15 | 20 | 12 |
| | 10 | | | 30 | 20 | 12 |
| | 11 | | | 12 | 19 | 6 |
| | 12 | | | 15 | 16 | 7 |
| | 13 | | | 40 | 14 | 8 |
| | 14 | | | 28 | 18 | 8 |
| | 15 | | | 40 | 20 | 11 |
| | 16 | | | 10 | 16 | 9 |
| | 17 | | | 32 | 19 | 9 |
| | 18 | | | 39 | 16 | 6 |
| | 19 | | | 10 | 20 | 11 |
| | 20 | | | 27 | 20 | 8 |
| | 21 | | | 5 | 17 | 8 |
| | 22 | | | 20 | 12 | 5 |
| | 23 | | | 5 | 18 | 11 |
| | 24 | | | 20 | 16 | 6 |

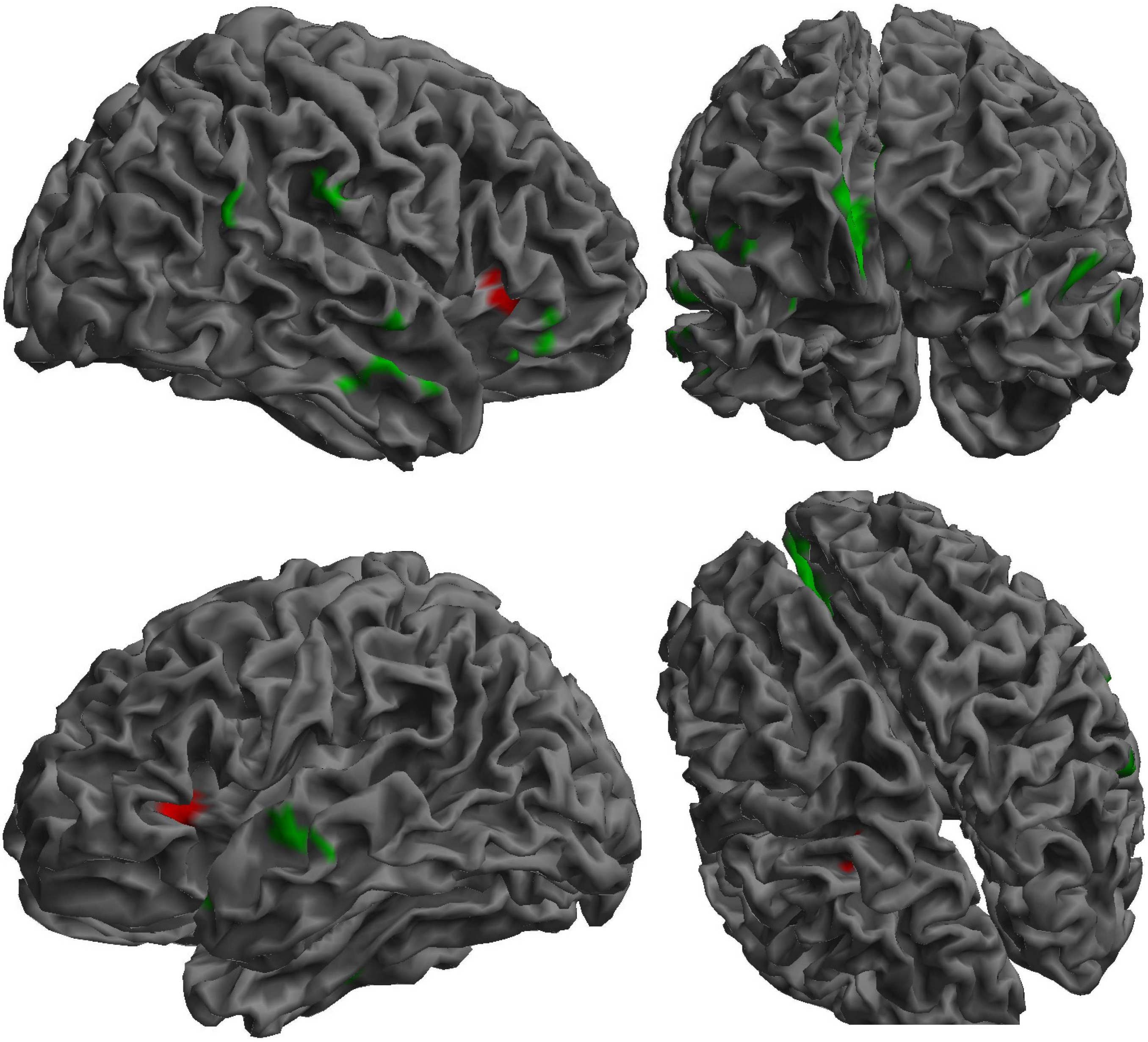
| | | | | | | |
|---|---|---|---|---|---|---|
| Certainty | 1 | 0 | 30 | 30 | 20 | 10 |
| | 2 | 20 | 0 | 20 | 16 | 7 |
| | 3 | 0 | 10 | 10 | 20 | 12 |
| | 4 | 20 | 0 | 20 | 13 | 7 |
| | 5 | 0 | 30 | 30 | 17 | 7 |
| | 6 | 30 | 0 | 30 | 18 | 6 |
| | 7 | 0 | 15 | 15 | 20 | 11 |
| | 8 | 20 | 0 | 20 | 12 | 7 |
| | 9 | 0 | 10 | 10 | 20 | 12 |
| | 10 | 5 | 0 | 5 | 20 | 12 |
| | 11 | 0 | 40 | 40 | 19 | 6 |
| | 12 | 28 | 0 | 28 | 16 | 7 |
| | 13 | 0 | 40 | 40 | 14 | 8 |
| | 14 | 20 | 0 | 20 | 18 | 8 |
| | 15 | 0 | 12 | 12 | 20 | 11 |
| | 16 | 30 | 0 | 30 | 16 | 9 |
| | 17 | 0 | 27 | 27 | 19 | 9 |
| | 18 | 32 | 0 | 32 | 16 | 6 |
| | 19 | 0 | 15 | 15 | 20 | 11 |
| | 20 | 39 | 0 | 39 | 20 | 8 |
| | 21 | 0 | 40 | 40 | 17 | 8 |
| | 22 | 40 | 0 | 40 | 12 | 5 |
| | 23 | 0 | 10 | 10 | 18 | 11 |
| | 24 | 5 | 0 | 5 | 16 | 6 |

Card decks were presented in pseudo-randomized order. Numbers 1-24 do not represent the order in which card decks were presented.

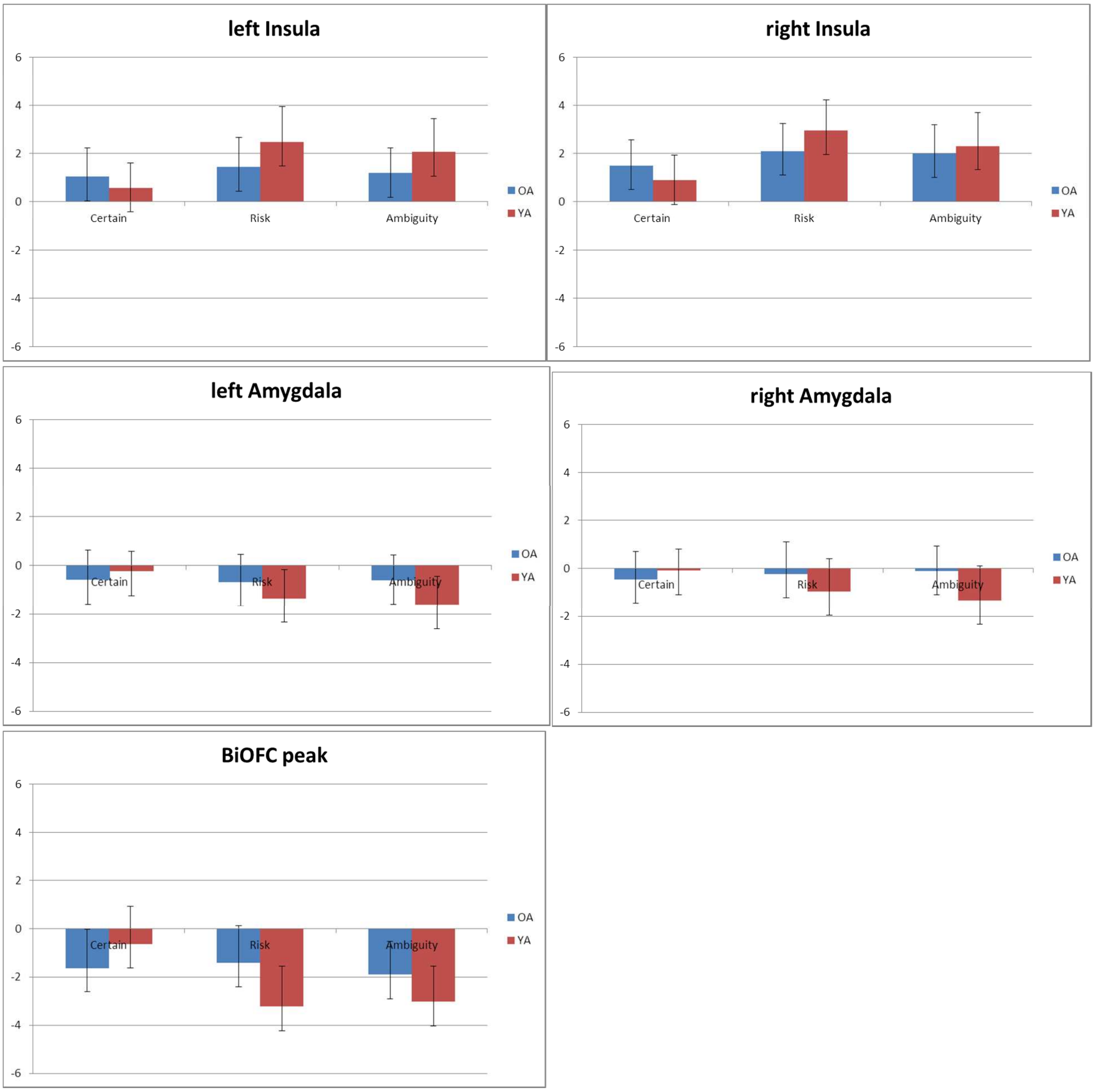
Supplementary table 2: Activations of unmasked brain

| Brain region | Hemisphere | MNI Coord. X | Y | Z | $t_{max}$ | Extent |
|---|---|---|---|---|---|---|
| Risk: Young > Older | | | | | | |
| Calcarine | Bi | 3 | -95 | -3 | 6.76 | 3567 |
| Postcentral | R | 27 | -42 | 45 | 6.38 | 280 |
| Sup. parietal | L | -26 | -57 | 59 | 5.90 | 596 |
| Caudate | R | 12 | 18 | 12 | 4.50 | 113 |
| | L | -15 | 21 | 11 | 4.25 | 101 |
| Inf. temporal | R | 41 | -60 | -7 | 4.43 | 120 |
| Supramarginal | L | -65 | -47 | 27 | -5.76 | 2405 |
| Mid. temporal | R | 65 | -17 | -18 | -5.67 | 3697 |
| | L | -60 | -30 | -3 | -5.51 | 1016 |
| PFC | R | 39 | 32 | -13 | -5.22 | 295 |
| Mid. frontal | R | 42 | 10 | 45 | -5.18 | 166 |
| Sup. occipital | L | -11 | -87 | 42 | -5.00 | 174 |
| MCC/PCC | | -5 | -38 | 36 | -4.85 | 369 |
| Ventral AI | L | -38 | 19 | -24 | -4.77 | 153 |
| OFC | Bi | 0 | 46 | -15 | -4.70 | 258 |
| Ambiguity: Young > Older | | | | | | |
| Lingual | R | 24 | -66 | -4 | 7.30 | 2733 |
| Inf. occipital | L | -26 | -80 | -4 | 6.21 | 348 |
| Postcentral | R | 27 | -44 | 48 | 5.81 | 216 |
| Sup.&Inf. parietal | L | -26 | -48 | 53 | 4.87 | 224 |
| Caudate | L | -15 | 19 | 12 | 4.76 | 228 |
| | R | 14 | 20 | 12 | 4.91 | 104 |
| Sup. occipital | L | -11 | -89 | 41 | -5.56 | 315 |
| PFC | R | 38 | 32 | -13 | -5.12 | 93 |
| Sup. temporal | R | 65 | -21 | 15 | -4.72 | 108 |
| | R | 60 | -42 | 14 | -4.54 | 268 |
| vlPFC | R | 51 | 29 | -3 | -4.65 | 134 |
| Supramarginal | L | -65 | -42 | 24 | -4.49 | 141 |
| Rolandic Operculum | R | 51 | -24 | 17 | -4.48 | 134 |
| Young: Risk > Ambiguity | | | | | | |
| Putamen/Pallidum | L | -24 | 3 | -1 | 5.28 | 1424 |
| Putamen | R | 27 | 2 | 9 | 4.99 | 957 |
| Vermis | | 2 | -59 | -39 | 4.91 | 180 |
| Mid. temporal / Angular | L | -59 | -60 | 24 | -5.67 | 432 |
| Angular | R | 55 | -54 | 35 | -4.42 | 151 |

Brain regions identified at corrected p < .05 (unc. p = .0001, k = 90).
Extent = number of voxels ($1.5*1.5*1.5mm^3$) in the cluster.

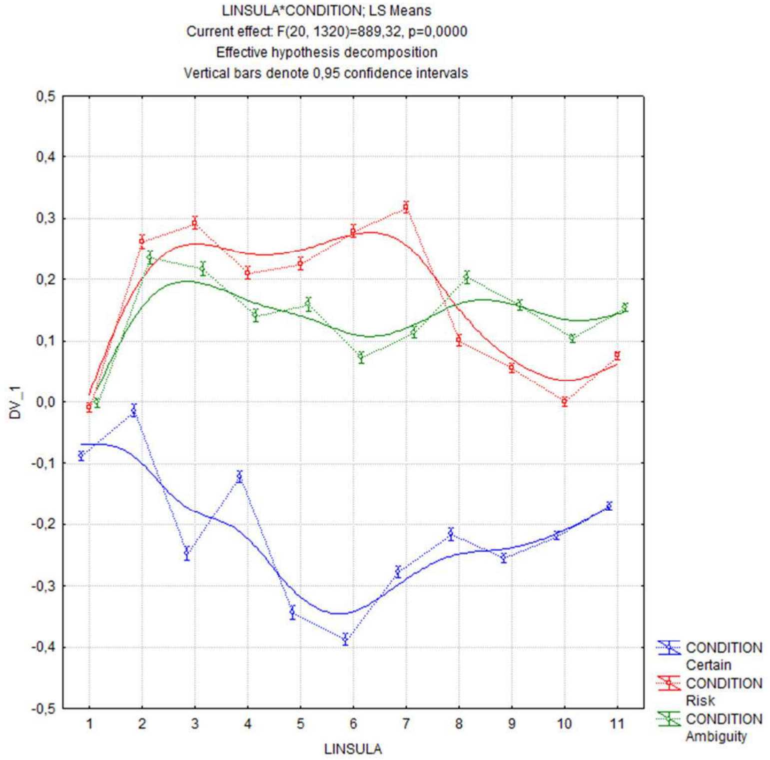


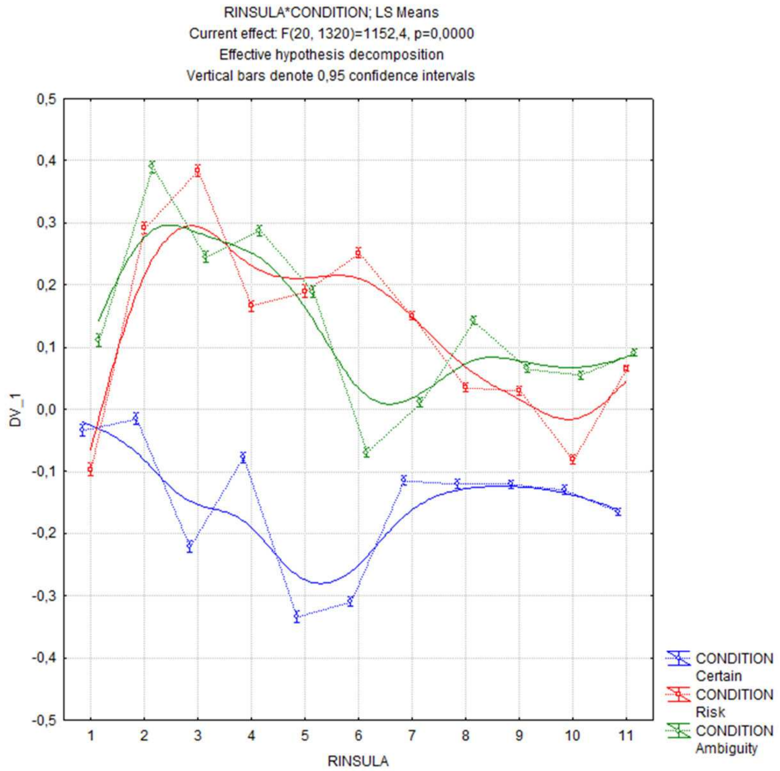
Supplementary figure S1: Brain activation in the interaction effect Age group x Uncertainty condition. Green areas: positive t-values, red areas: negative t-values. Upper left: view of the right hemisphere; upper right: frontal view; down left: view of the left hemisphere; down right: top view of the brain.

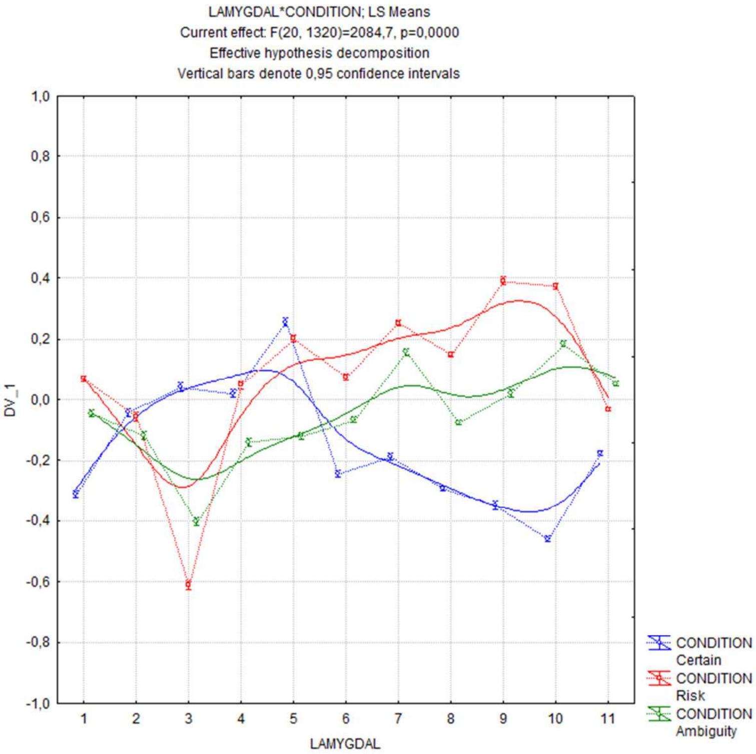


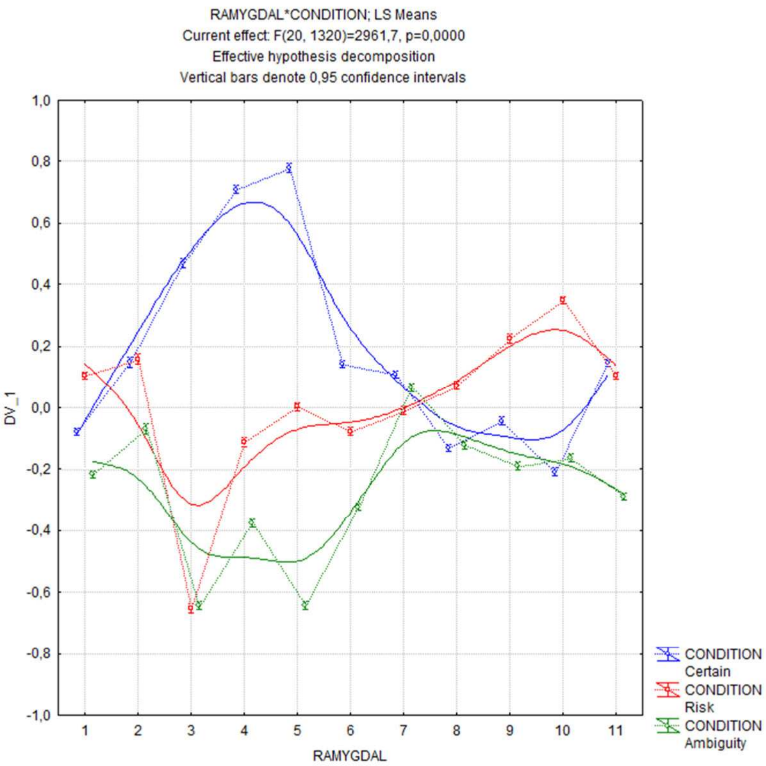

Supplementary figure S2: Activation in the regions of interest. Blue bars represent main activity in older adults; red bars represent main activity in young adults. Error bars: standard deviations.

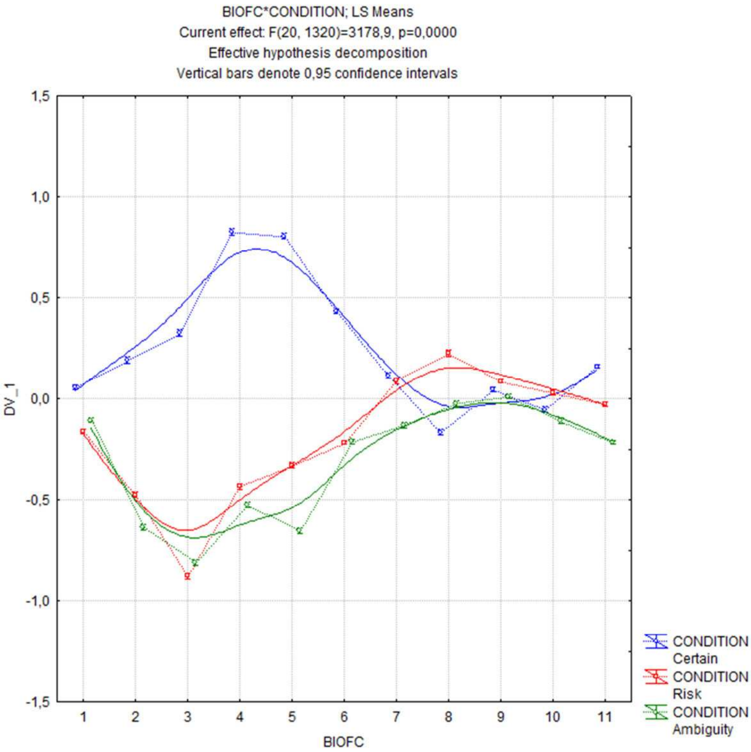
Supplementary figure S3: PSTH activation in regions of interest, young and older adults combined. Blue lines represent activity in certainty conditions, red lines correspond to risk conditions, green lines represent activity under ambiguity. Data points correspond to condition means with 95% confidence intervals. Scale of the x-axis: TRs. Lines begin at stimulus onset. Solid lines correspond to least squares fitting functions with 20% stiffness.

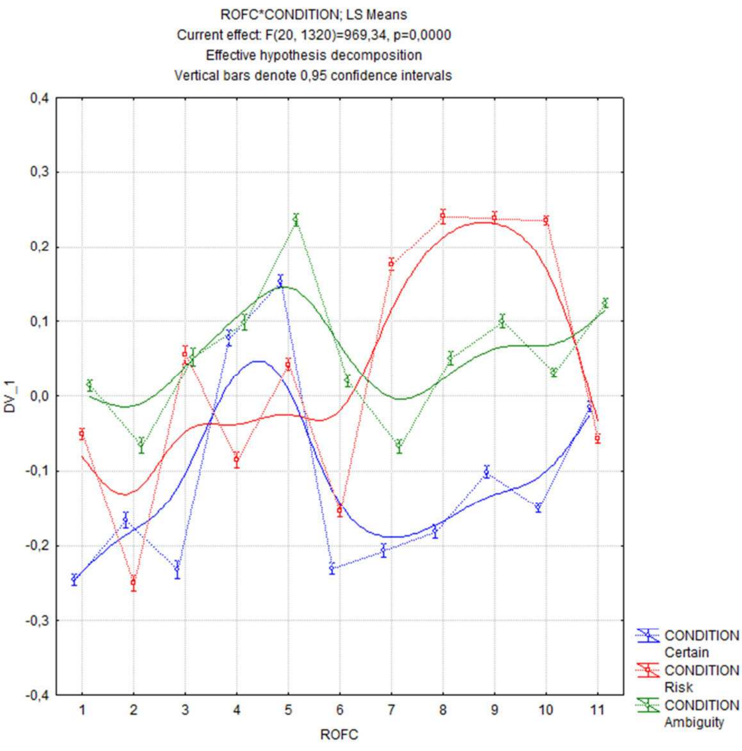


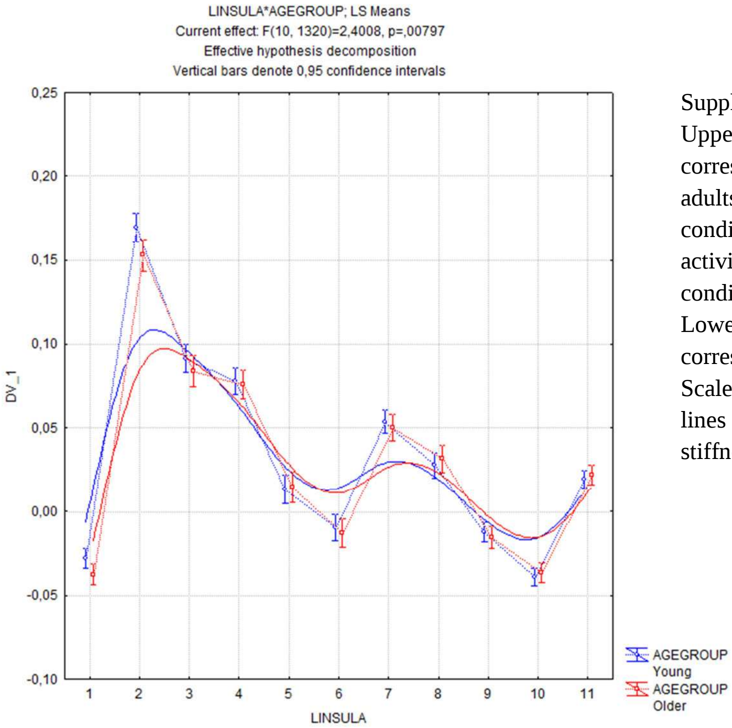




LAMYGDAL*CONDITION; LS Means
Current effect: F(20, 1320)=2084,7, p=0,0000
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
LAMYGDAL
CONDITION Certain
CONDITION Risk
CONDITION Ambiguity

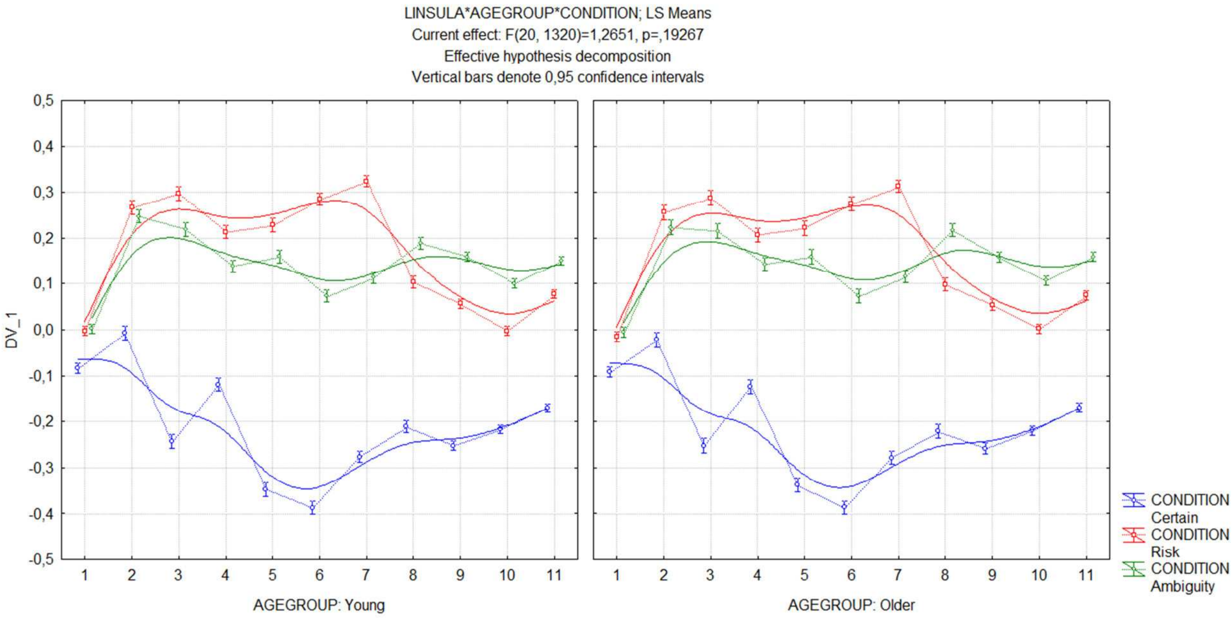

RAMYGDAL*CONDITION; LS Means
Current effect: F(20, 1320)=2961,7, p=0,0000
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
RAMYGDAL
CONDITION Certain
CONDITION Risk
CONDITION Ambiguity

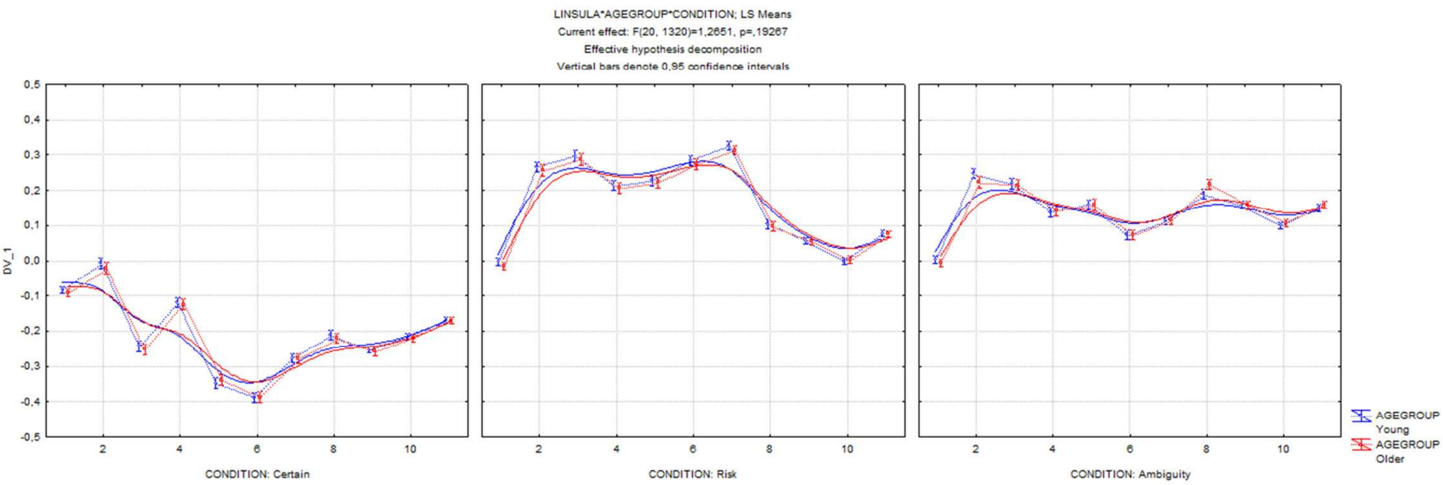

BIOFC*CONDITION; LS Means
Current effect: F(20, 1320)=3178,9, p=0,0000
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
BIOFC
CONDITION Certain
CONDITION Risk
CONDITION Ambiguity

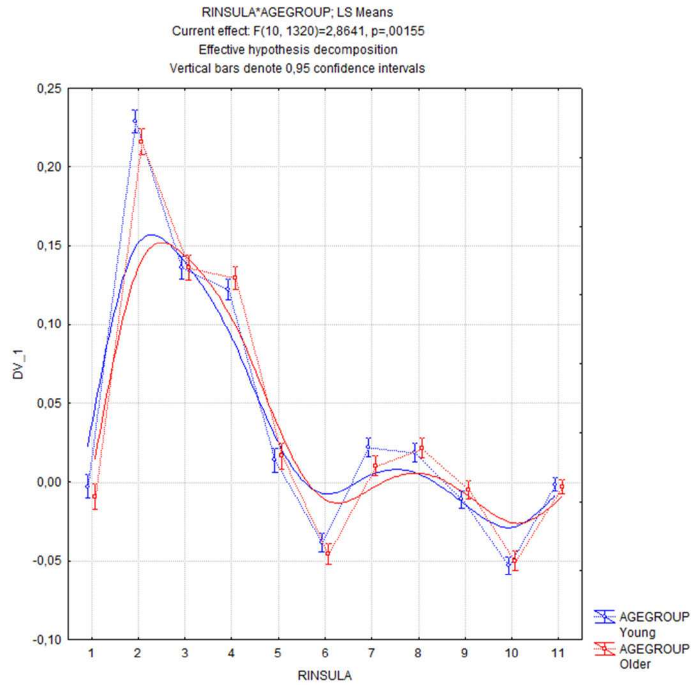

ROFC*CONDITION; LS Means
Current effect: F(20, 1320)=969,34, p=0,0000
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
ROFC
CONDITION Certain
CONDITION Risk
CONDITION Ambiguity

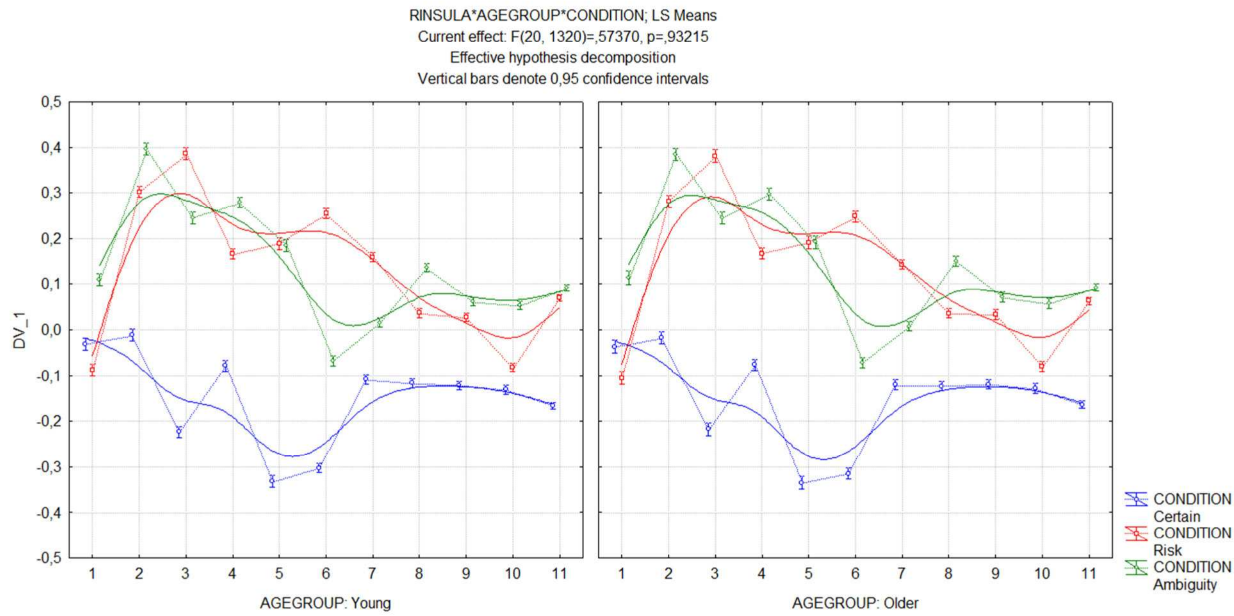


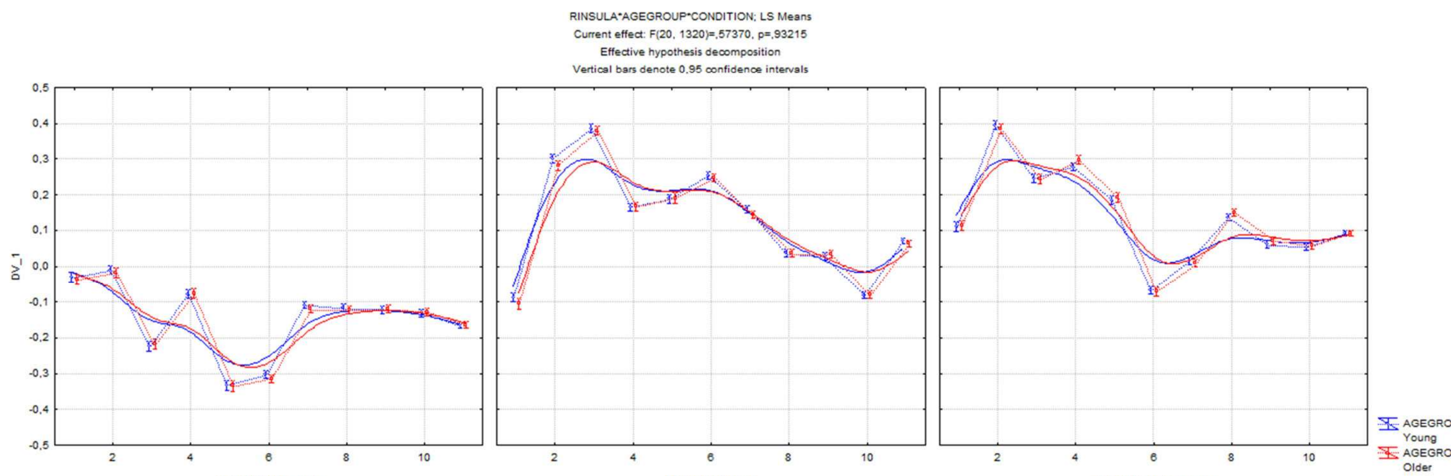

Supplementary figure S4: PSTH activation in regions of interest. Upper graph: age differences, all conditions combined. Red lines correspond to older adults, blue lines correspond to young adults. Middle graph: left activation in young adults, split by conditions; right, activation in older adults. Blue lines represent activity in certainty conditions, red lines correspond to risk conditions, green lines represent activity under ambiguity. Lower graph: age differences, split by condition. Data points correspond to condition means with 95% confidence intervals. Scale of the x-axis: TRs. Lines begin at stimulus onset. Solid lines correspond to least squares fitting functions with 20% stiffness.

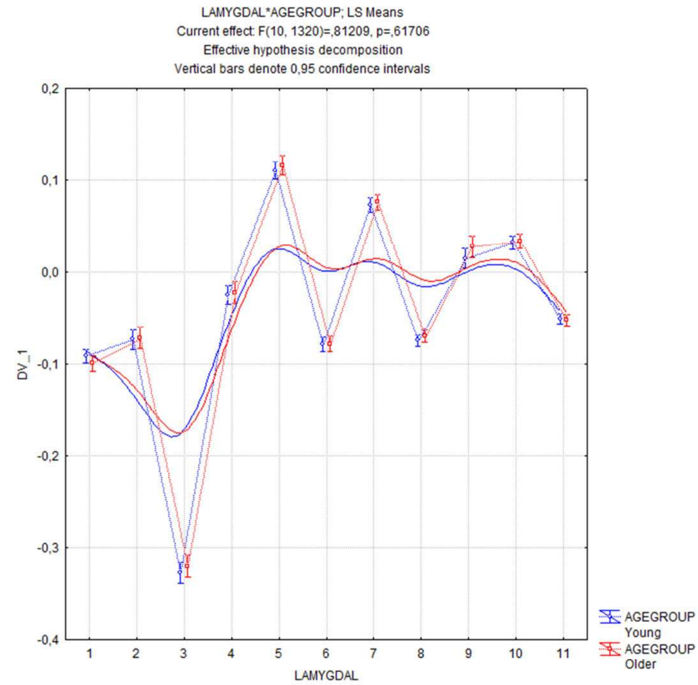


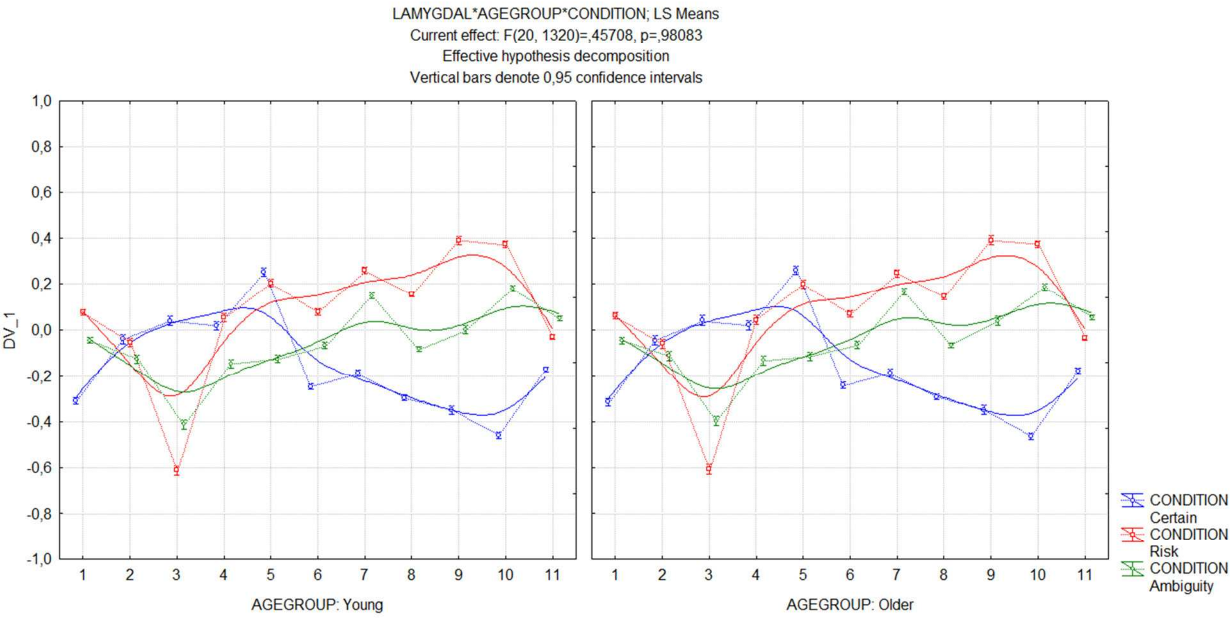



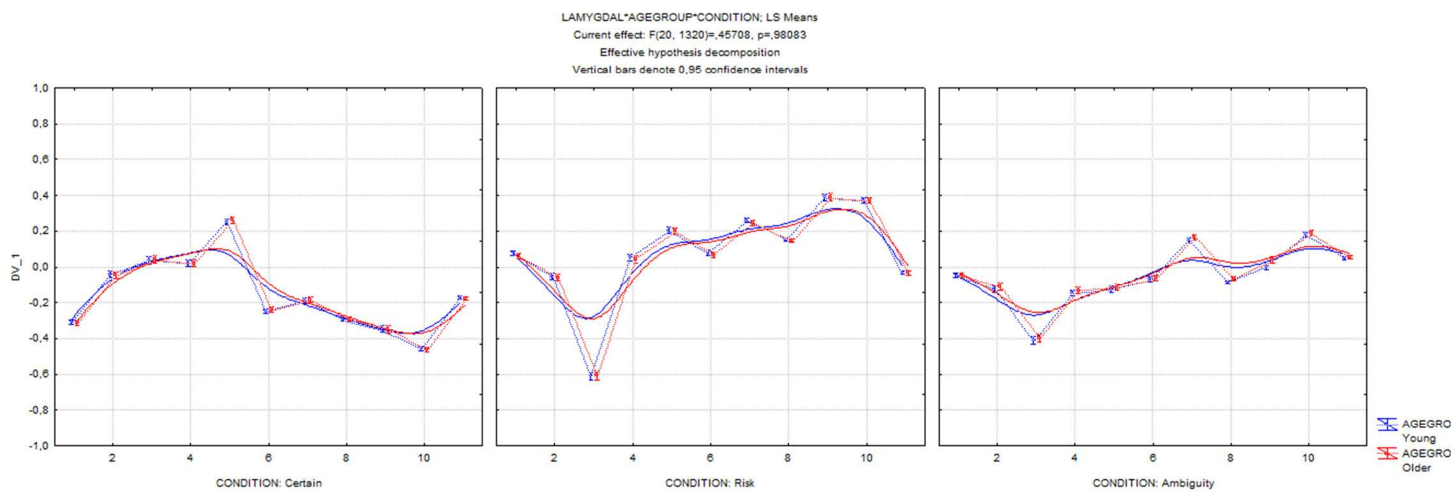

RINSULA*AGEGROUP; LS Means
Current effect: F(10, 1320)=2,8641, p=,00155
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
RINSULA
AGEGROUP Young
AGEGROUP Older

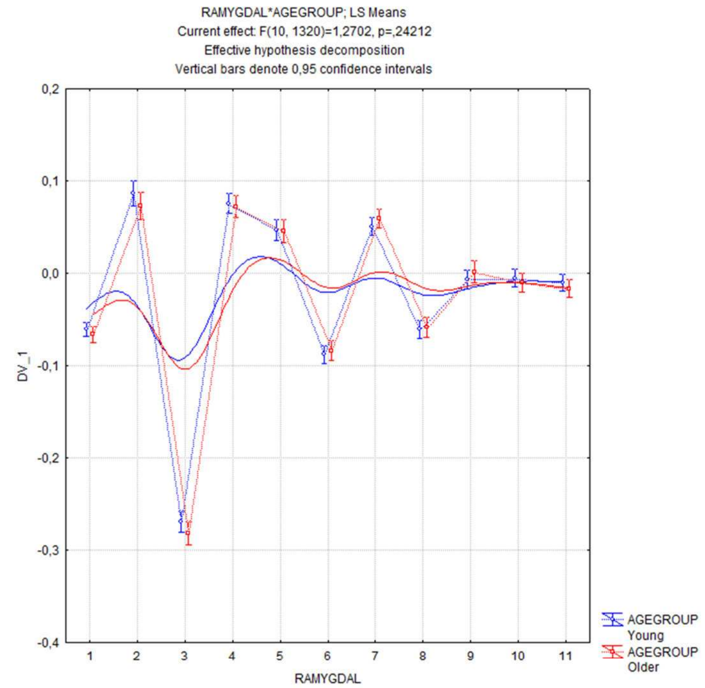

RINSULA*AGEGROUP*CONDITION; LS Means
Current effect: F(20, 1320)=,57370, p=,93215
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
AGEGROUP: Young
AGEGROUP: Older
CONDITION Certain
CONDITION Risk
CONDITION Ambiguity

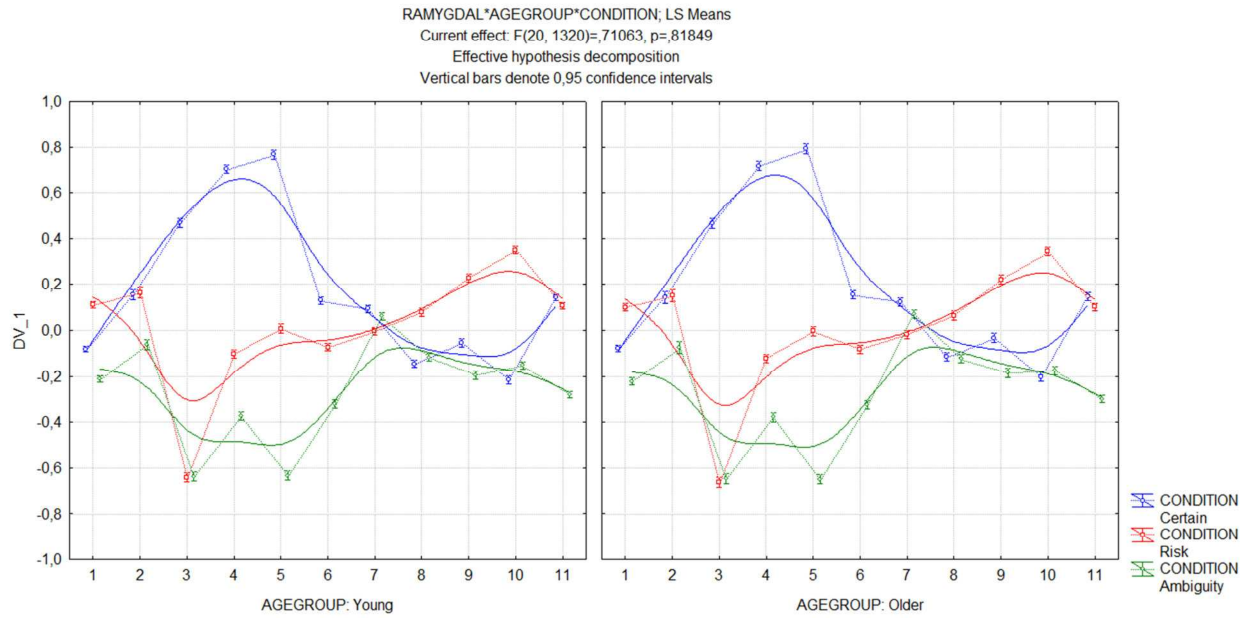

RINSULA*AGEGROUP*CONDITION; LS Means
Current effect: F(20, 1320)=,57370, p=,93215
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
CONDITION: Certain
CONDITION: Risk
CONDITION: Ambiguity
AGEGRO Young
AGEGRO Older

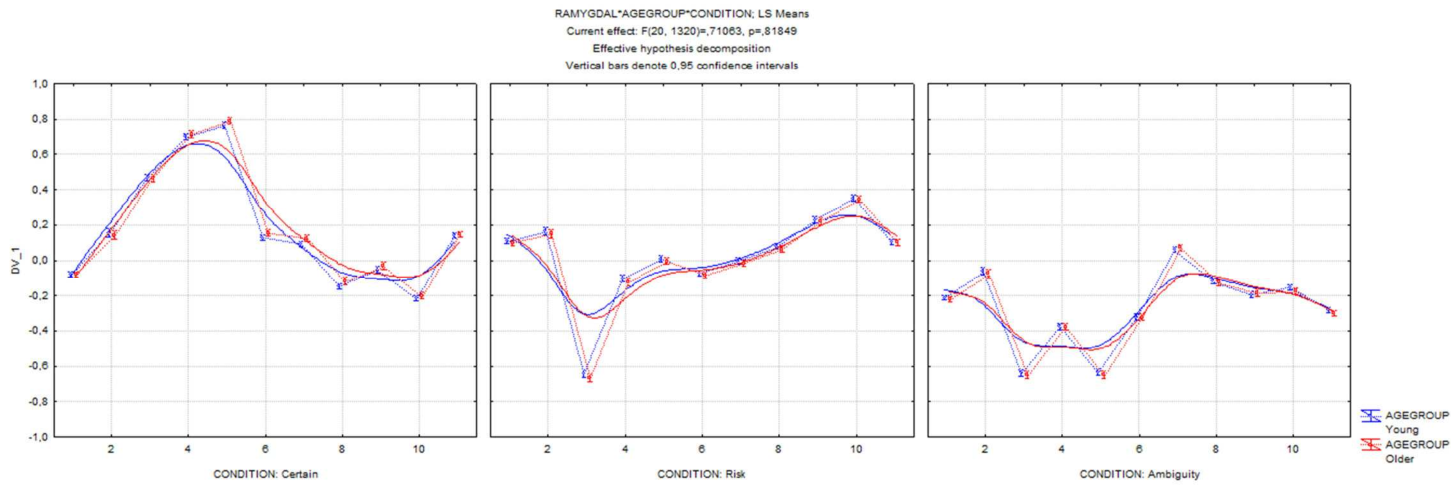

LAMYGDAL*AGEGROUP; LS Means
Current effect: F(10, 1320)=,81209, p=,61706
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
LAMYGDAL
AGEGROUP Young
AGEGROUP Older

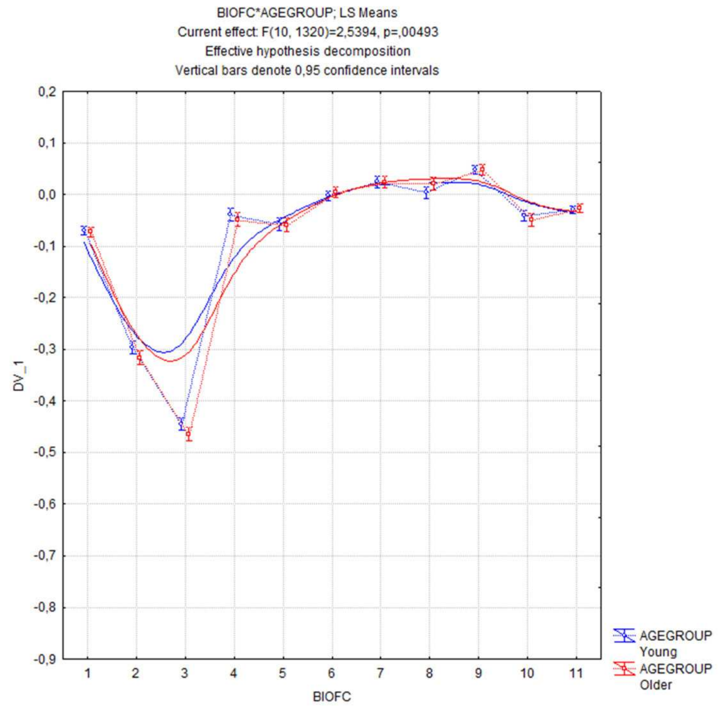

LAMYGDAL*AGEGROUP*CONDITION; LS Means
Current effect: F(20, 1320)=,45708, p=,98083
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
AGEGROUP: Young
AGEGROUP: Older
CONDITION Certain
CONDITION Risk
CONDITION Ambiguity

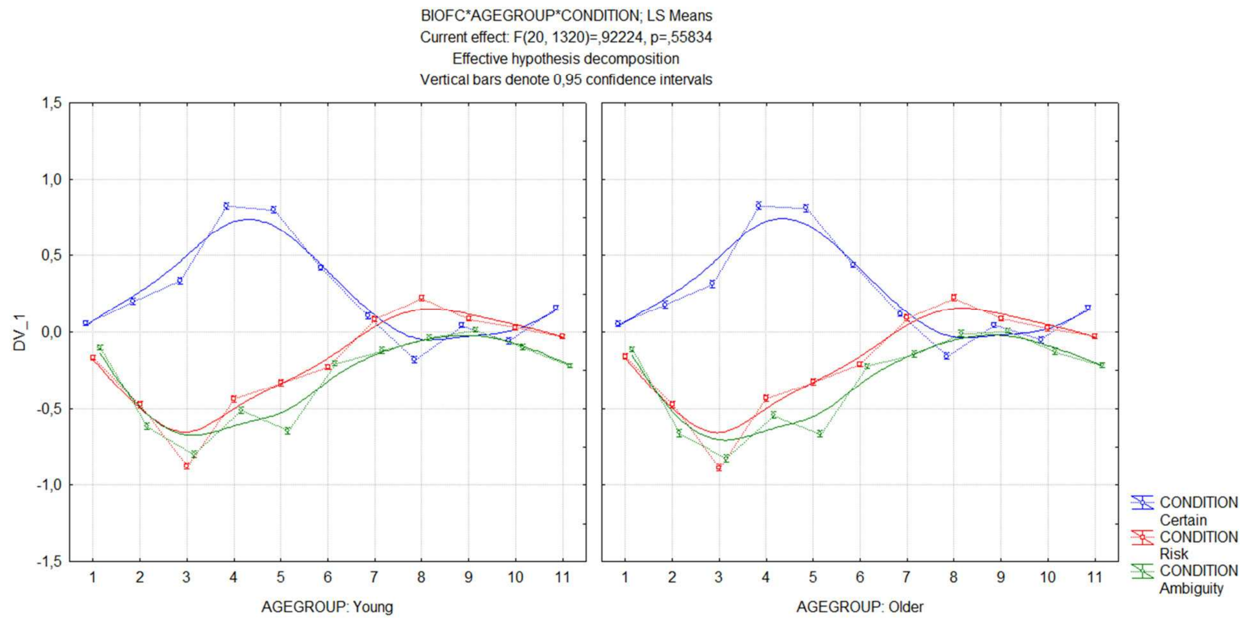

LAMYGDAL*AGEGROUP*CONDITION; LS Means
Current effect: F(20, 1320)=,45708, p=,98083
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
CONDITION: Certain
CONDITION: Risk
CONDITION: Ambiguity

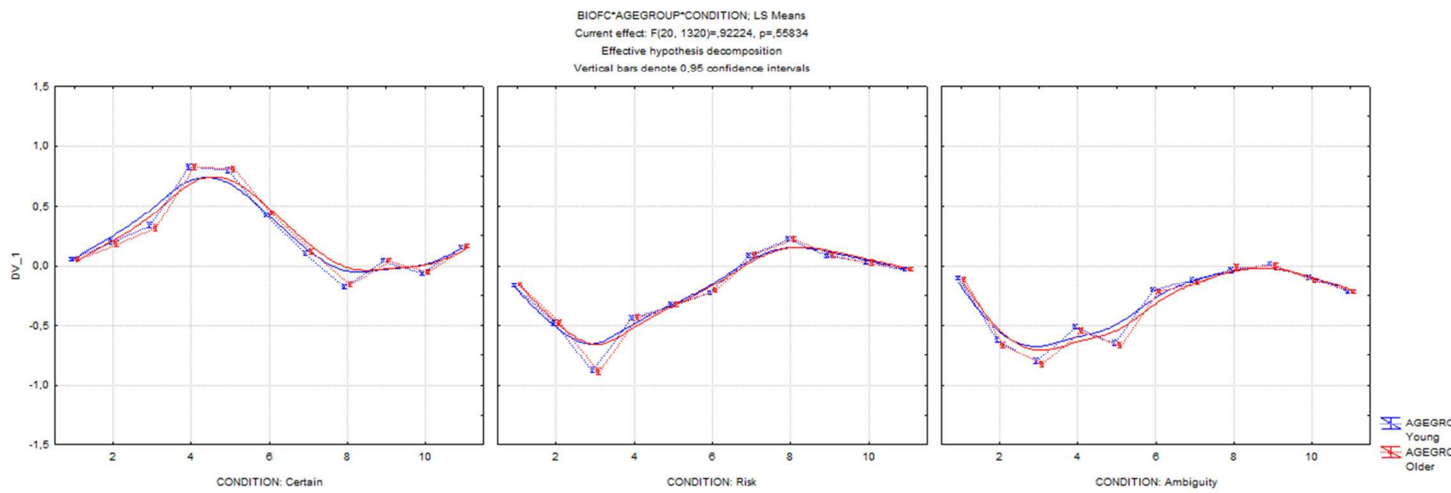

RAMYGDAL*AGEGROUP; LS Means
Current effect: F(10, 1320)=1,2702, p=,24212
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
RAMYGDAL
AGEGROUP Young
AGEGROUP Older

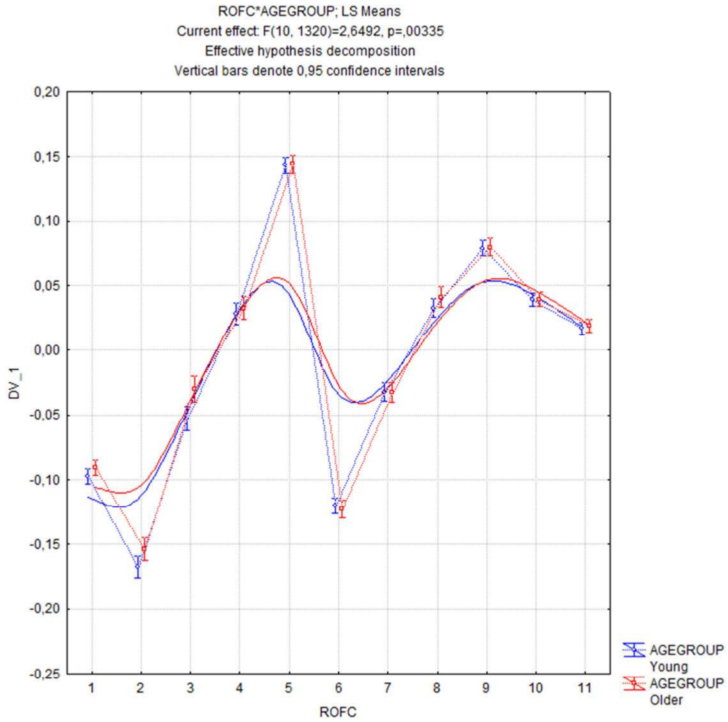

RAMYGDAL*AGEGROUP*CONDITION; LS Means
Current effect: F(20, 1320)=,71063, p=,81849
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
AGEGROUP: Young
AGEGROUP: Older
CONDITION Certain
CONDITION Risk
CONDITION Ambiguity

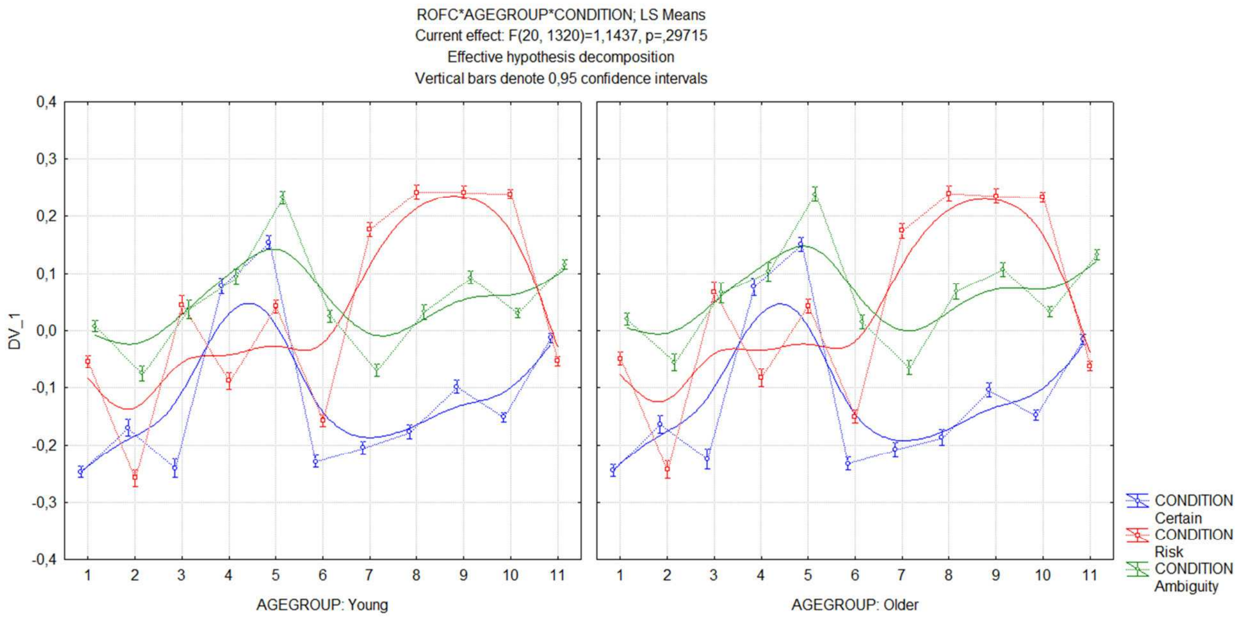

RAMYGDAL*AGEGROUP*CONDITION; LS Means
Current effect: F(20, 1320)=,71063, p=,81849
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
CONDITION: Certain
CONDITION: Risk
CONDITION: Ambiguity
AGEGROUP Young
AGEGROUP Older

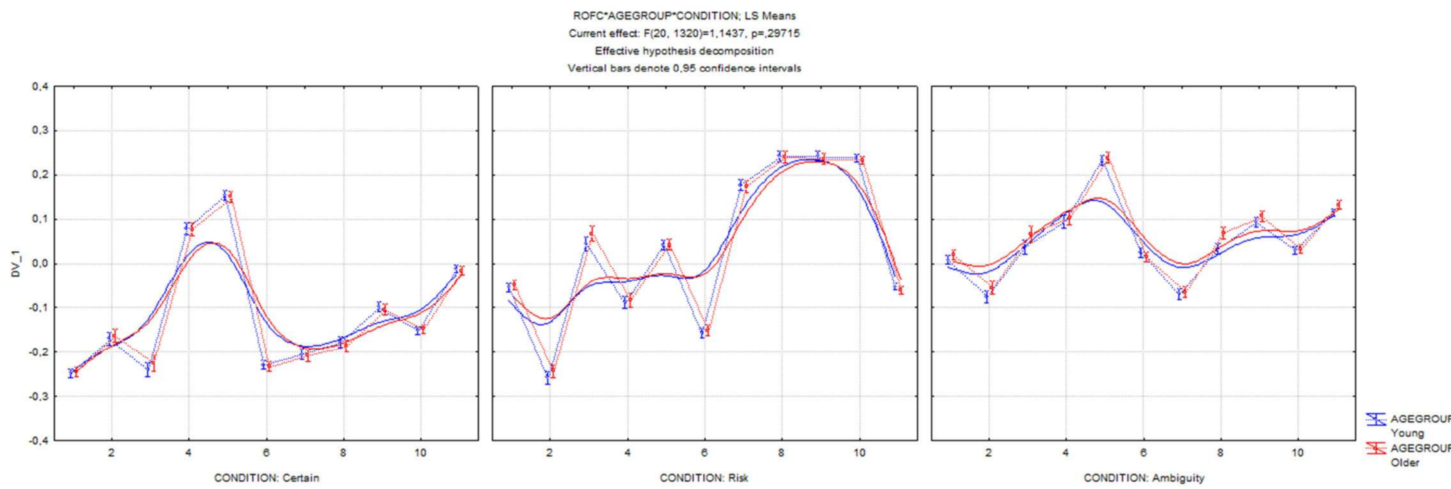

BIOFC*AGEGROUP; LS Means
Current effect: F(10, 1320)=2,5394, p=,00493
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
BIOFC
AGEGROUP Young
AGEGROUP Older


BIOFC*AGEGROUP*CONDITION; LS Means
Current effect: F(20, 1320)=,92224, p=,55834
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
AGEGROUP: Young
AGEGROUP: Older
CONDITION Certain
CONDITION Risk
CONDITION Ambiguity


BIOFC*AGEGROUP*CONDITION; LS Means
Current effect: F(20, 1320)=,92224, p=,55834
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
CONDITION: Certain
CONDITION: Risk
CONDITION: Ambiguity


ROFC*AGEGROUP; LS Means
Current effect: F(10, 1320)=2,6492, p=,00335
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
ROFC
AGEGROUP Young
AGEGROUP Older


ROFC*AGEGROUP*CONDITION; LS Means
Current effect: F(20, 1320)=1,1437, p=,29715
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
AGEGROUP: Young
AGEGROUP: Older
CONDITION Certain
CONDITION Risk
CONDITION Ambiguity

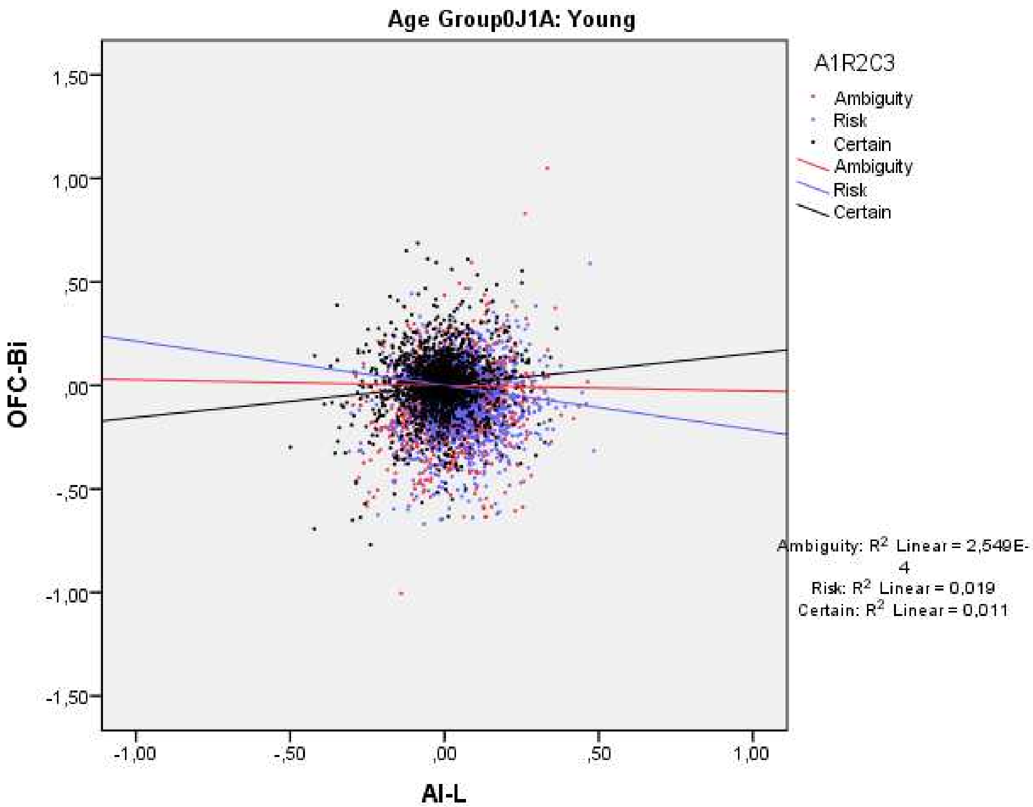

ROFC*AGEGROUP*CONDITION; LS Means
Current effect: F(20, 1320)=1,1437, p=,29715
Effective hypothesis decomposition
Vertical bars denote 0,95 confidence intervals
DV_1
CONDITION: Certain
CONDITION: Risk
CONDITION: Ambiguity
AGEGROUF Young
AGEGROUF Older

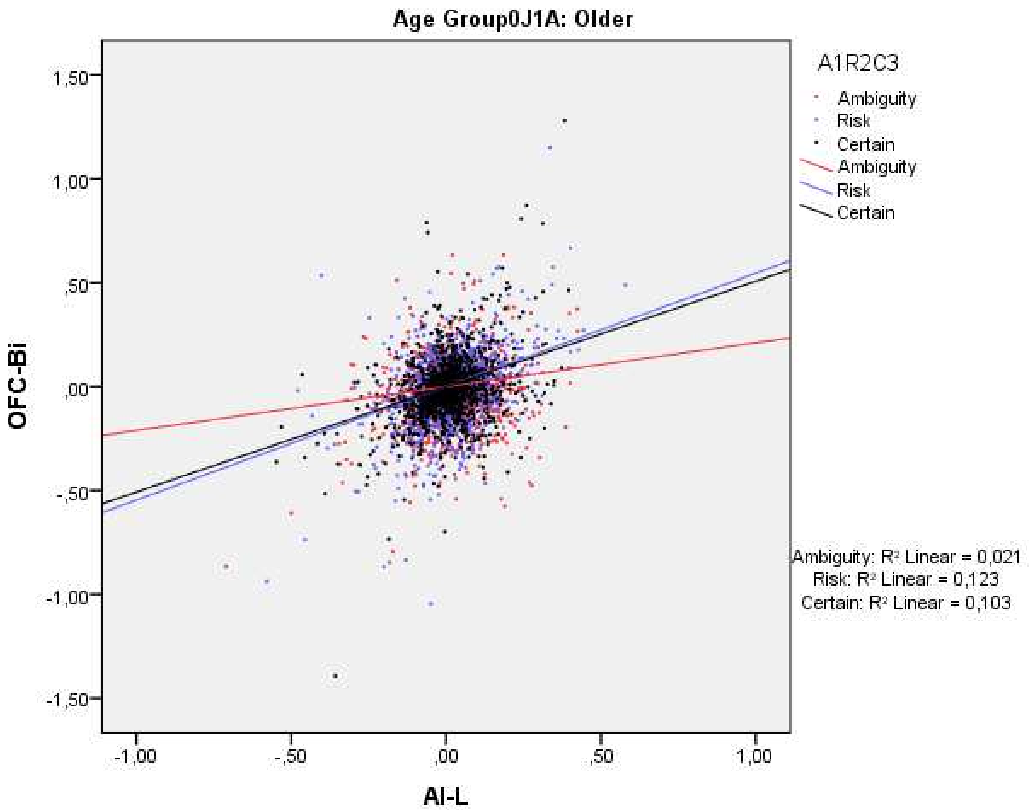
Supplementary Table 3: Beta values of PPI regressions

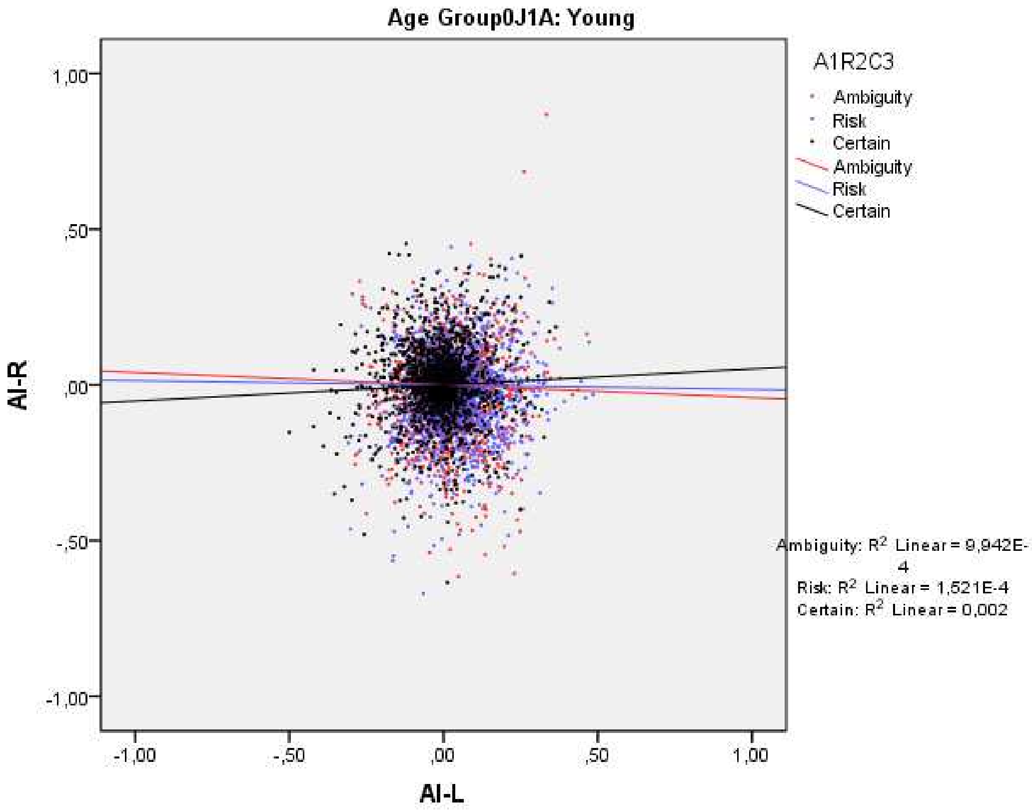
| Region x region | | Condition | β YA | β OA |
|---|---|---|---|---|
| AI-L | AI-R | Ambiguity | ,508*** | ,415*** |
| | | Risk | ,538*** | ,458*** |
| | | Certain | ,451*** | ,437*** |
| | Amyg-L | Ambiguity | -,011 | ,308*** |
| | | Risk | -,047*** | ,244*** |
| | | Certain | -,010 | ,268*** |
| | Amyg-R | Ambiguity | ,005 | ,284*** |
| | | Risk | -,029** | ,240*** |
| | | Certain | ,064*** | ,187*** |
| | OFC-Bi | Ambiguity | -,016 | ,146*** |
| | | Risk | -,138*** | ,351*** |
| | | Certain | ,106*** | ,321*** |
| | OFC-R | Ambiguity | -,032** | ,153*** |
| | | Risk | -,012 | ,254*** |
| | | Certain | ,043*** | ,149*** |
| AI-R | Amyg-L | Ambiguity | ,000 | ,197*** |
| | | Risk | -,038*** | ,192*** |
| | | Certain | ,023* | ,184*** |
| | Amyg-R | Ambiguity | ,092*** | ,255*** |
| | | Risk | ,079*** | ,197*** |
| | | Certain | ,116*** | ,220*** |
| | OFC-Bi | Ambiguity | -,006 | ,213*** |
| | | Risk | -,148*** | ,275*** |
| | | Certain | ,121*** | ,187*** |
| | OFC-R | Ambiguity | -,027* | ,205*** |
| | | Risk | -,058*** | ,239*** |
| | | Certain | ,129*** | ,177*** |
| Amyg-L | Amyg-R | Ambiguity | ,652*** | ,649*** |
| | | Risk | ,575*** | ,684*** |
| | | Certain | ,613*** | ,627*** |
| | OFC-Bi | Ambiguity | ,411*** | ,353*** |
| | | Risk | ,423*** | ,311*** |
| | | Certain | ,248*** | ,334*** |
| | OFC-R | Ambiguity | ,270*** | ,279*** |
| | | Risk | ,245*** | ,290*** |
| | | Certain | ,208*** | ,337*** |
| Amyg-R | OFC-Bi | Ambiguity | ,368*** | ,246*** |
| | | Risk | ,396*** | ,226*** |
| | | Certain | ,316*** | ,302*** |
| | OFC-R | Ambiguity | ,196*** | ,199*** |
| | | Risk | ,208*** | ,182*** |
| | | Certain | ,181*** | ,203*** |
| OFC-Bi | OFC-R | Ambiguity | ,507*** | ,338*** |
| | | Risk | ,436*** | ,258*** |
| | | Certain | ,424*** | ,394*** |

Significance: * < .05, ** < .01, *** < .001
AI-L: left anterior insula; AI-R: right anterior insula; Amyg-L: left amygdala; Amyg-R: right amygdala; OFC-Bi: medial orbitofrontal cortex; OFC-R: right orbitofrontal cortex

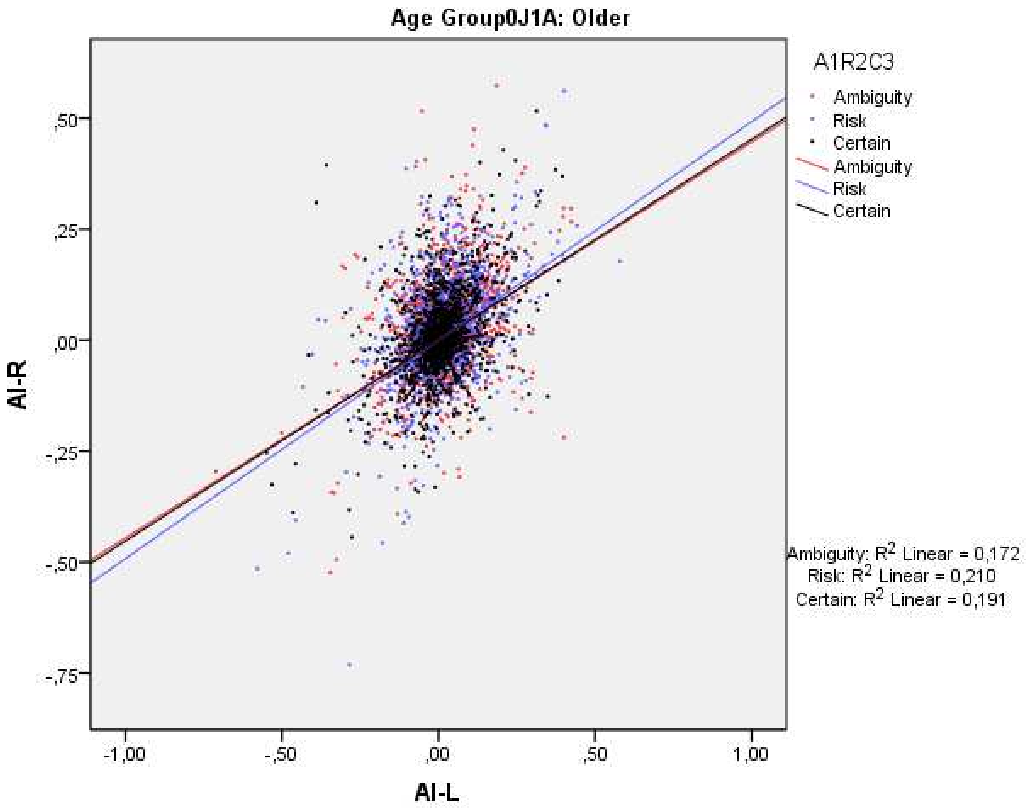
Supplementary figure S5: Scatterplots of psychophysiological interactions. Data points correspond to PPI-values. Each data point represents 1 scan. 370 scans were collected per participant. Red: Ambiguity-PPI; Blue: Risk-PPI; Black: Certainty-PPI. Straight lines correspond to linear fitting functions.



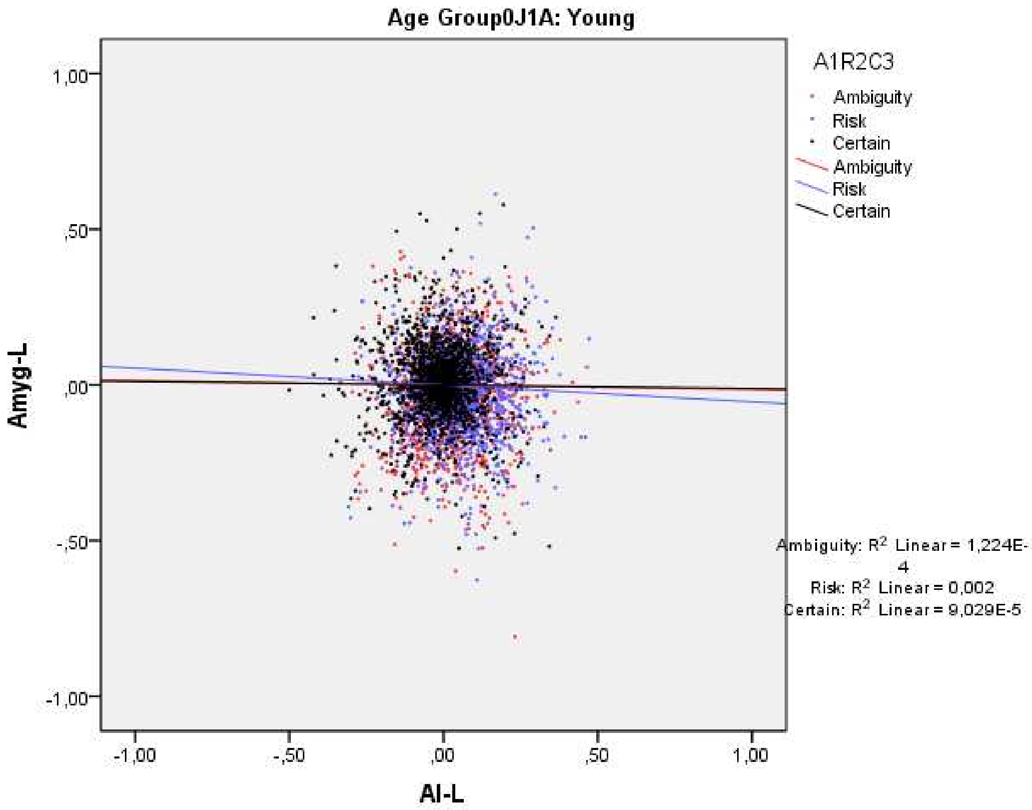



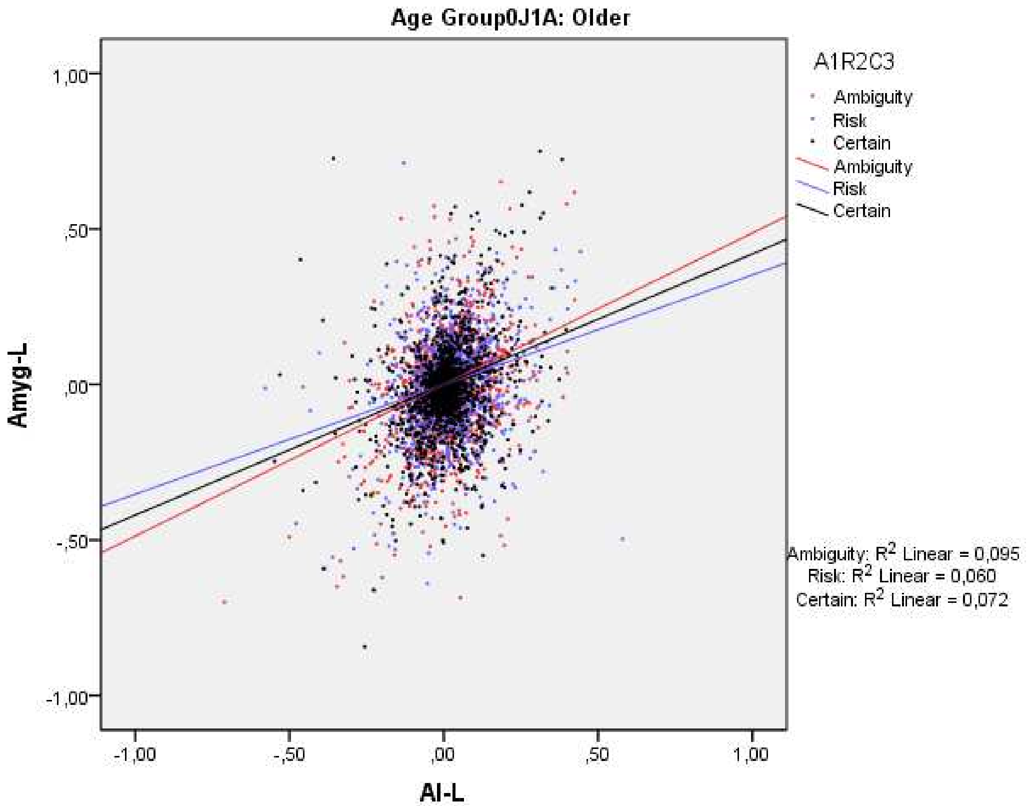


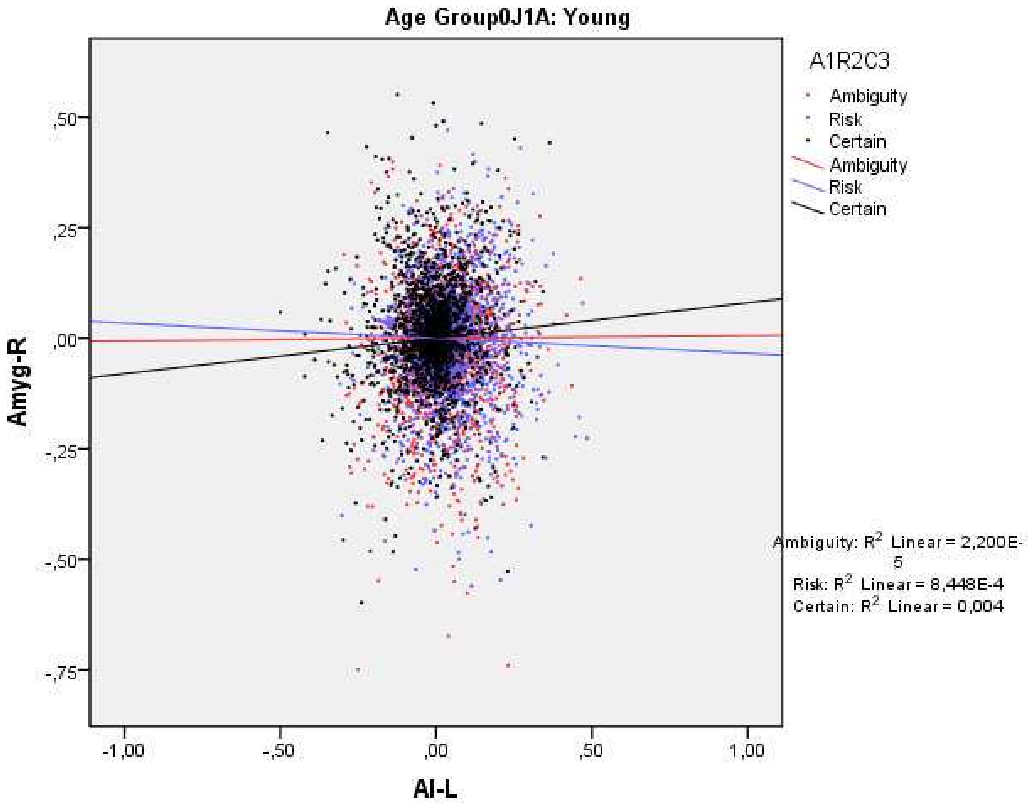
Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 9,942E-4
Risk: R2 Linear = 1,521E-4
Certain: R2 Linear = 0,002
AI-R
AI-L
1,00
,50
,00
-,50
-1,00

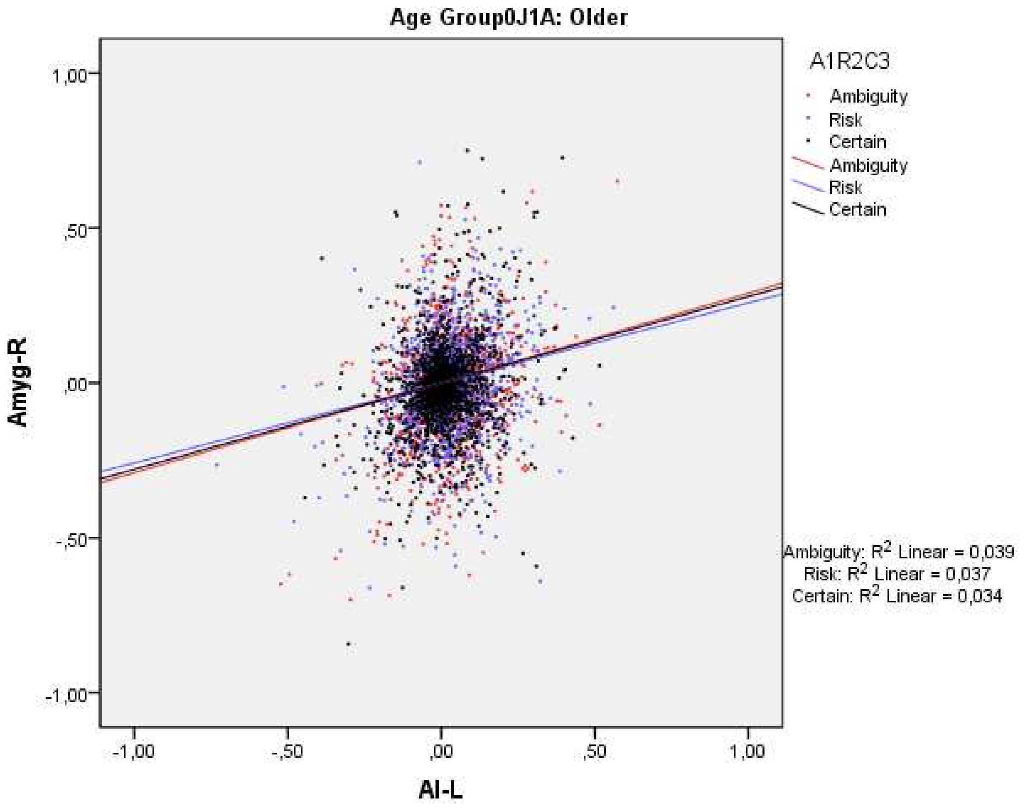



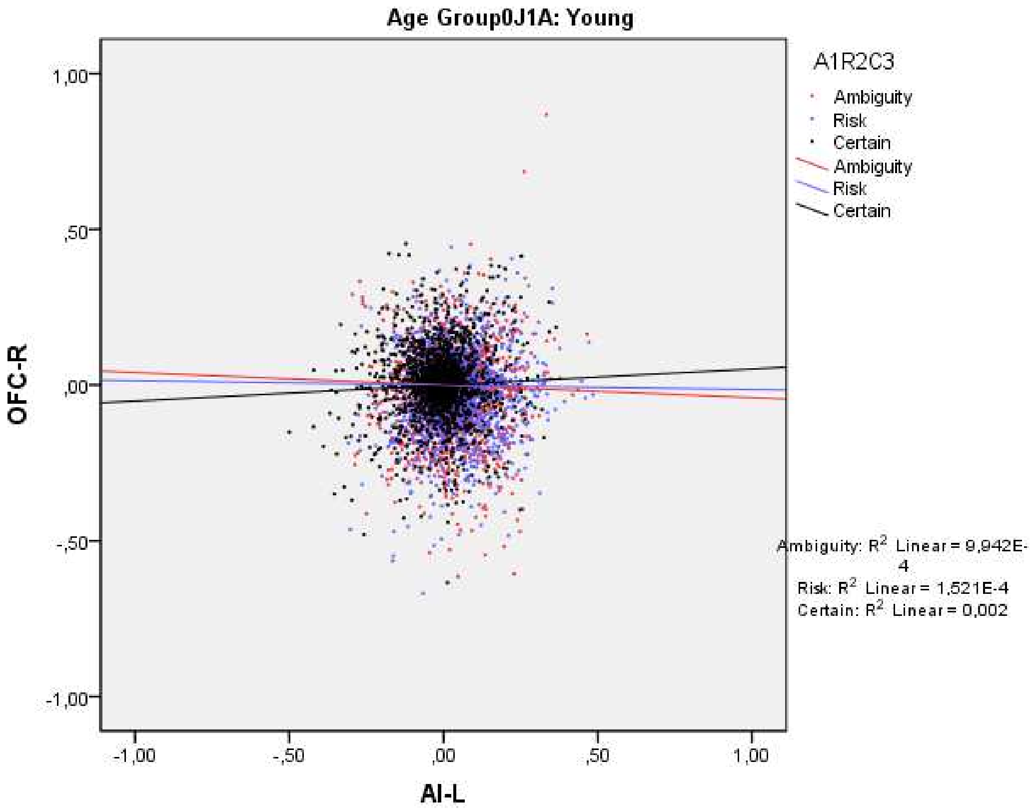
Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 0,172
Risk: R2 Linear = 0,210
Certain: R2 Linear = 0,191
AI-R
AI-L
,50
,25
,00
-,25
-,50
-,75
-1,00
1,00


Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 1,224E-4
Risk: R2 Linear = 0,002
Certain: R2 Linear = 9,029E-5
Amyg-L
AI-L
1,00
,50
,00
-,50
-1,00
-1,00
-,50
,00
,50
1,00

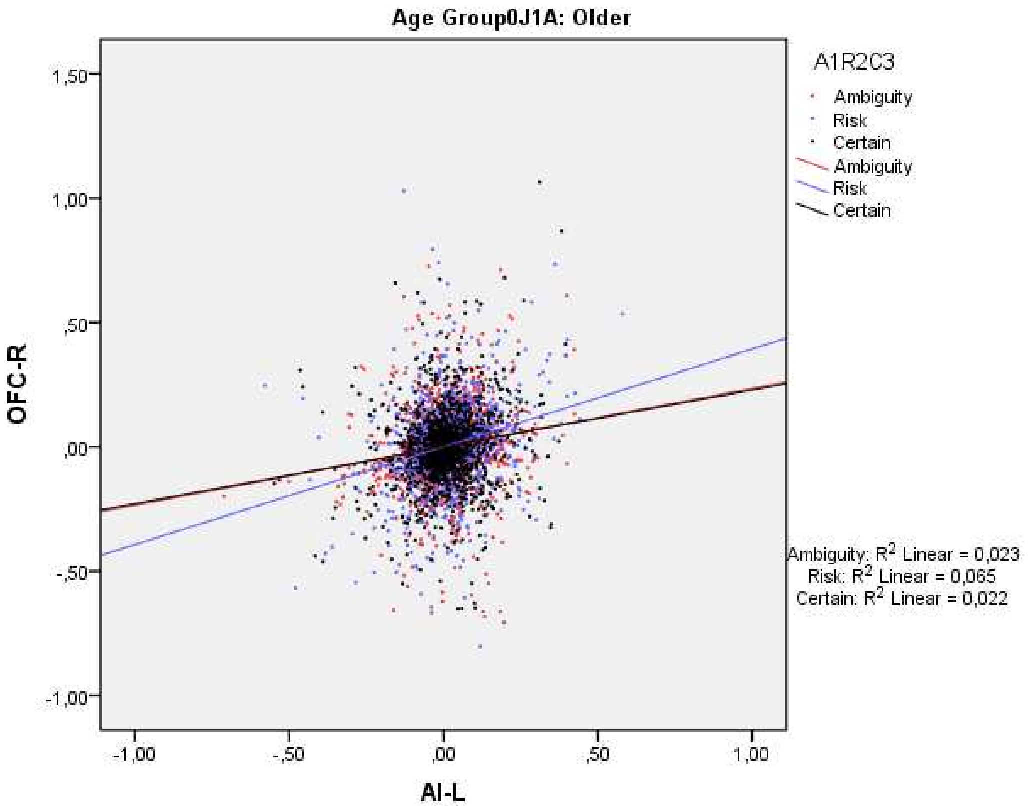

Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 0,095
Risk: R2 Linear = 0,060
Certain: R2 Linear = 0,072
Amyg-L
AI-L
1,00
,50
,00
-,50
-1,00
-1,00
-,50
,00
,50
1,00


Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
,50
,25
,00
-,25
-,50
-,75
Amyg-R
-1,00
-,50
,00
,50
1,00
AI-L
Ambiguity: R2 Linear = 2,200E-5
Risk: R2 Linear = 8,448E-4
Certain: R2 Linear = 0,004

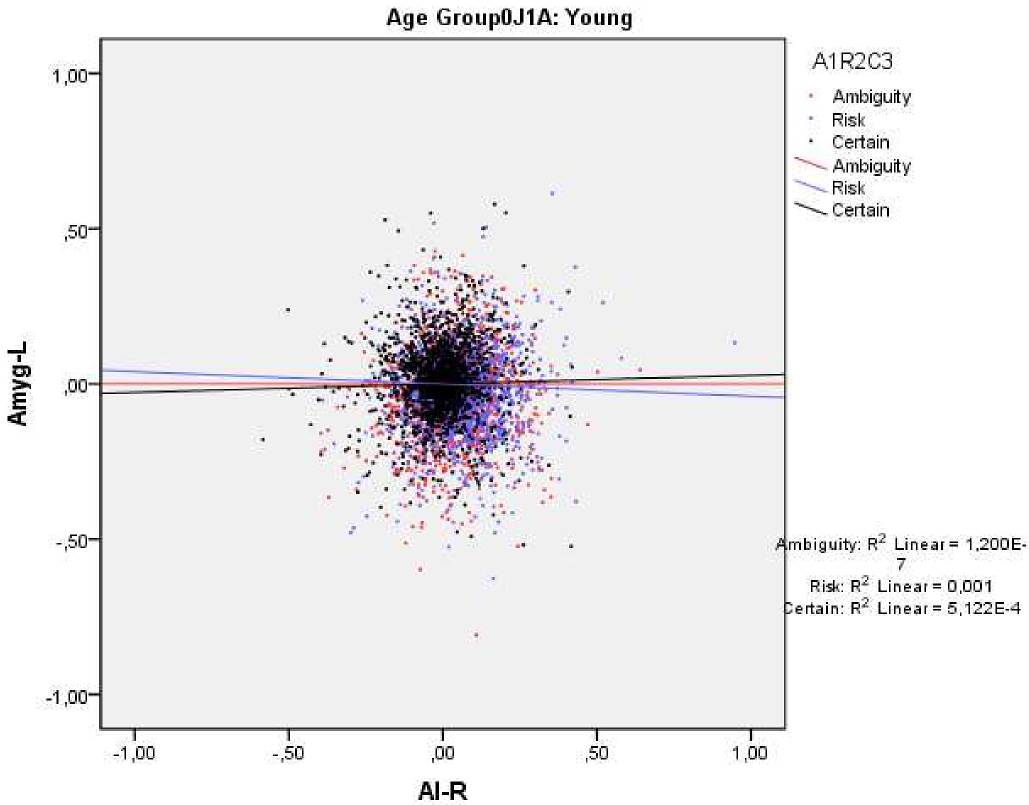

Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
1,00
,50
,00
-,50
-1,00
Amyg-R
-1,00
-,50
,00
,50
1,00
AI-L
Ambiguity: R2 Linear = 0,039
Risk: R2 Linear = 0,037
Certain: R2 Linear = 0,034

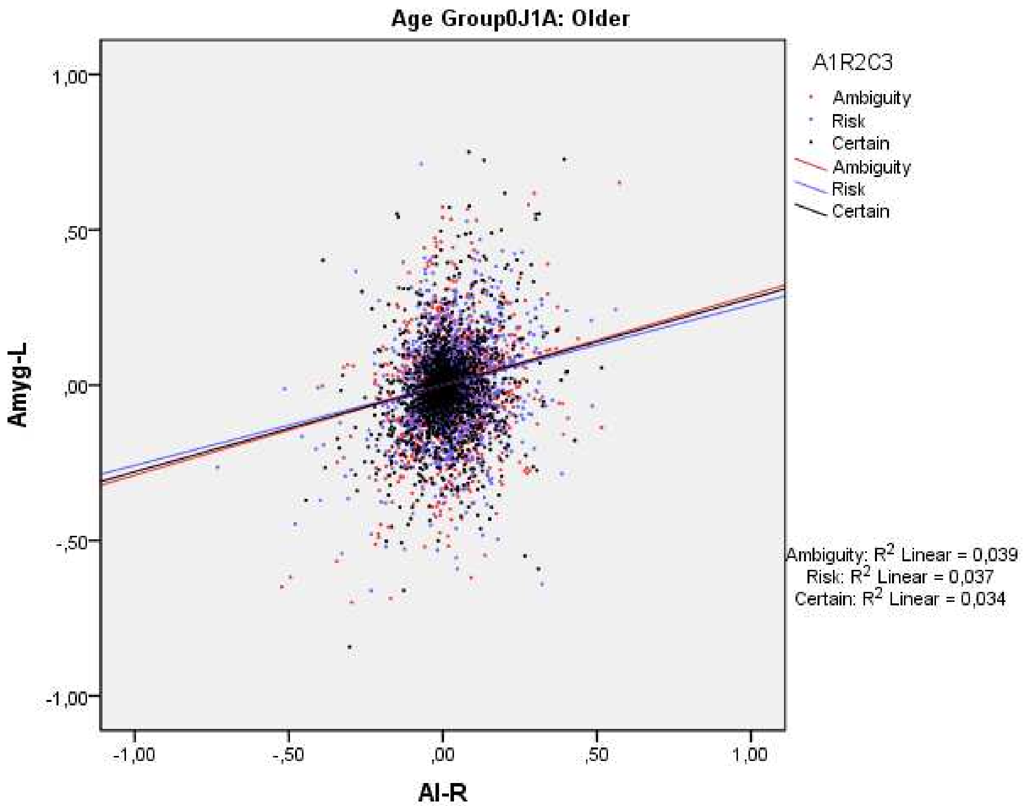


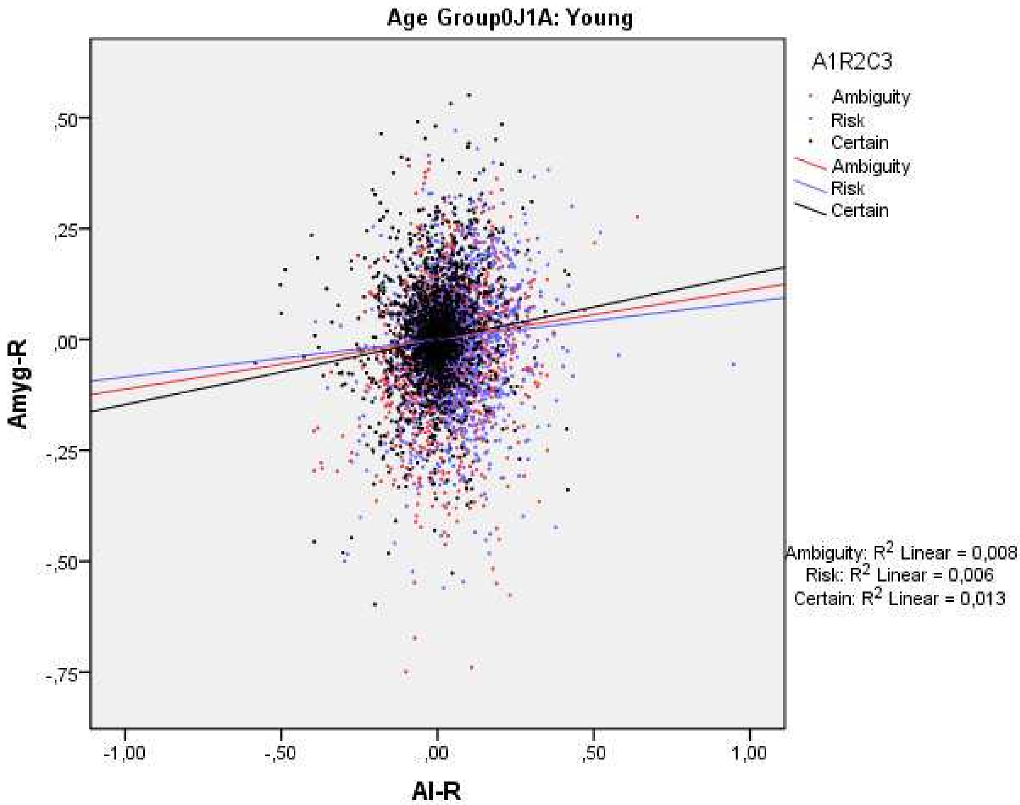
Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
1,00
,50
,00
-,50
-1,00
OFC-R
-1,00
-,50
,00
,50
1,00
AI-L
Ambiguity: $R^2$ Linear = 9,942E-4
Risk: $R^2$ Linear = 1,521E-4
Certain: $R^2$ Linear = 0,002

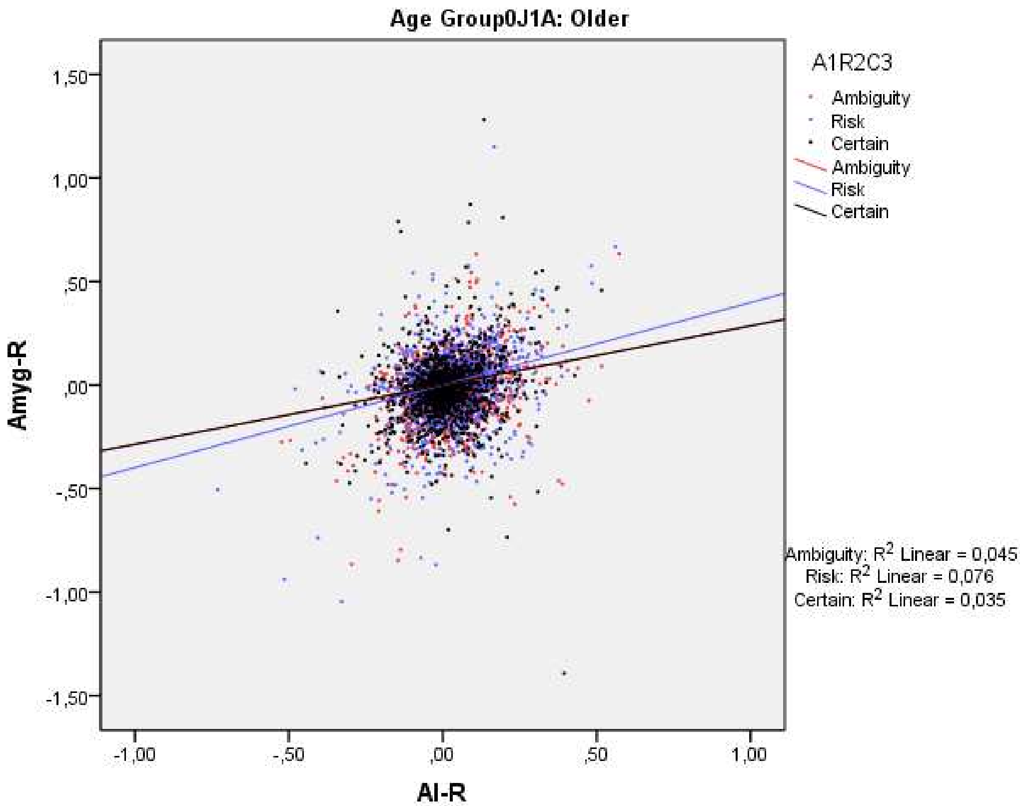
Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
1,50
1,00
,50
,00
-,50
-1,00
OFC-R
-1,00
-,50
,00
,50
1,00
AI-L
Ambiguity: $R^2$ Linear = 0,023
Risk: $R^2$ Linear = 0,065
Certain: $R^2$ Linear = 0,022


Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Amyg-L
AI-R
1,00
,50
,00
-,50
-1,00
-1,00
-,50
,00
,50
1,00
Ambiguity: R2 Linear = 1,200E-7
Risk: R2 Linear = 0,001
Certain: R2 Linear = 5,122E-4

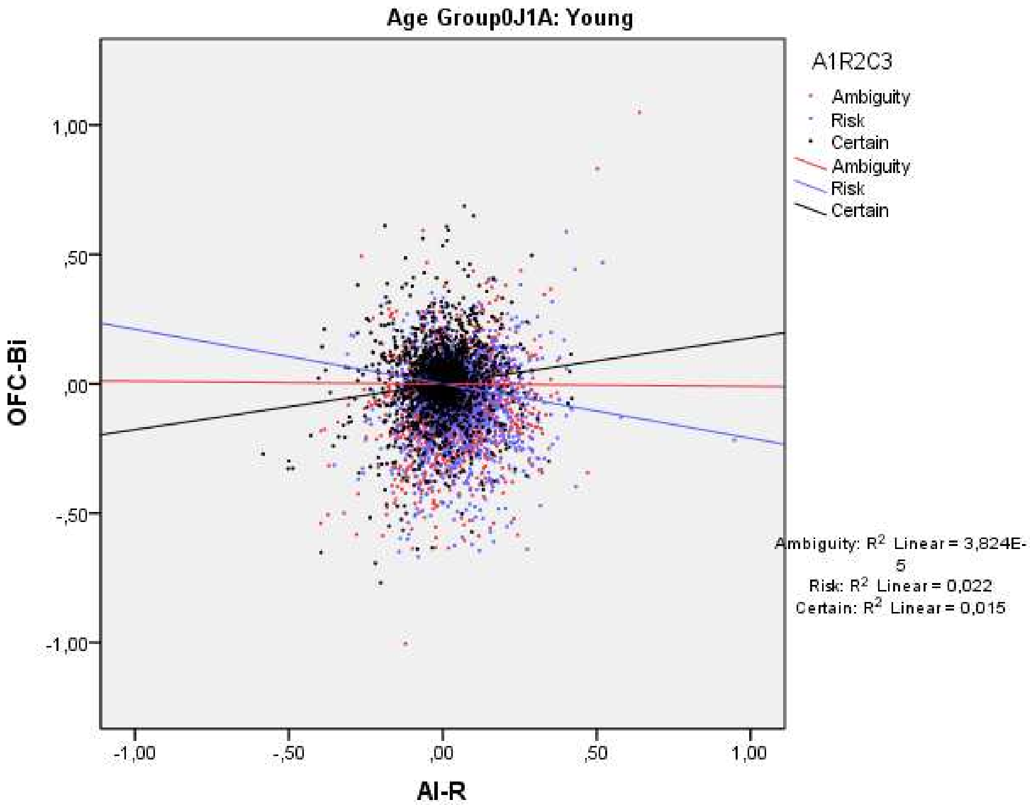

Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Amyg-L
AI-R
1,00
,50
,00
-,50
-1,00
-1,00
-,50
,00
,50
1,00
Ambiguity: R2 Linear = 0,039
Risk: R2 Linear = 0,037
Certain: R2 Linear = 0,034

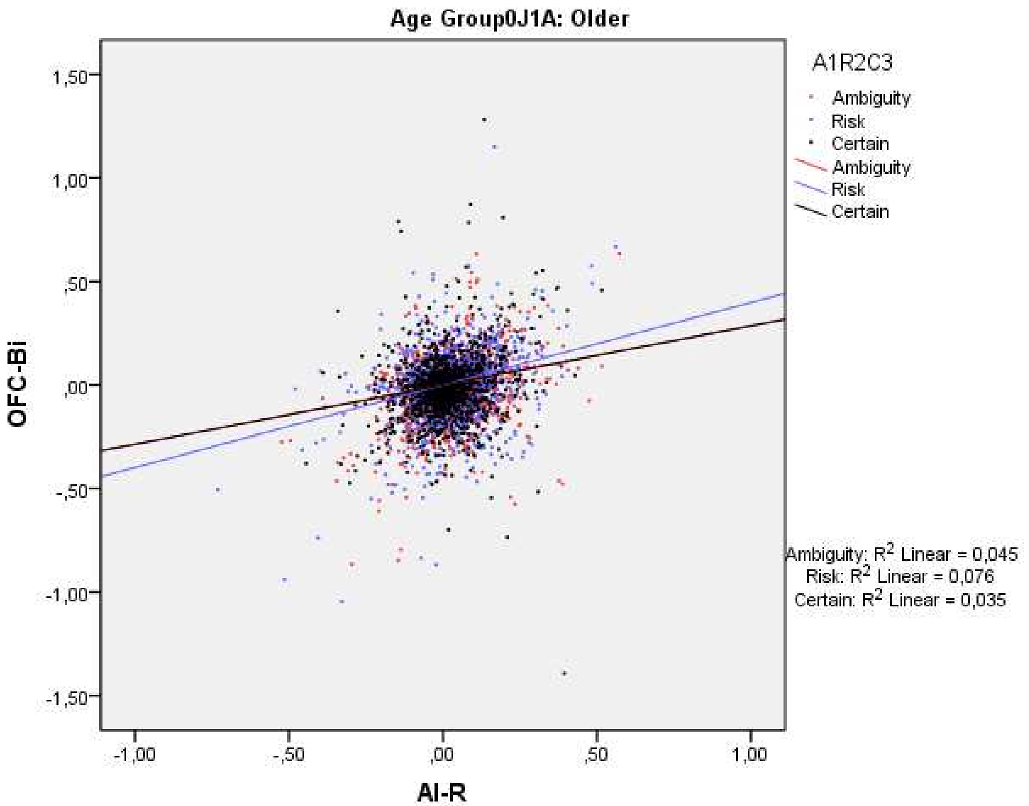


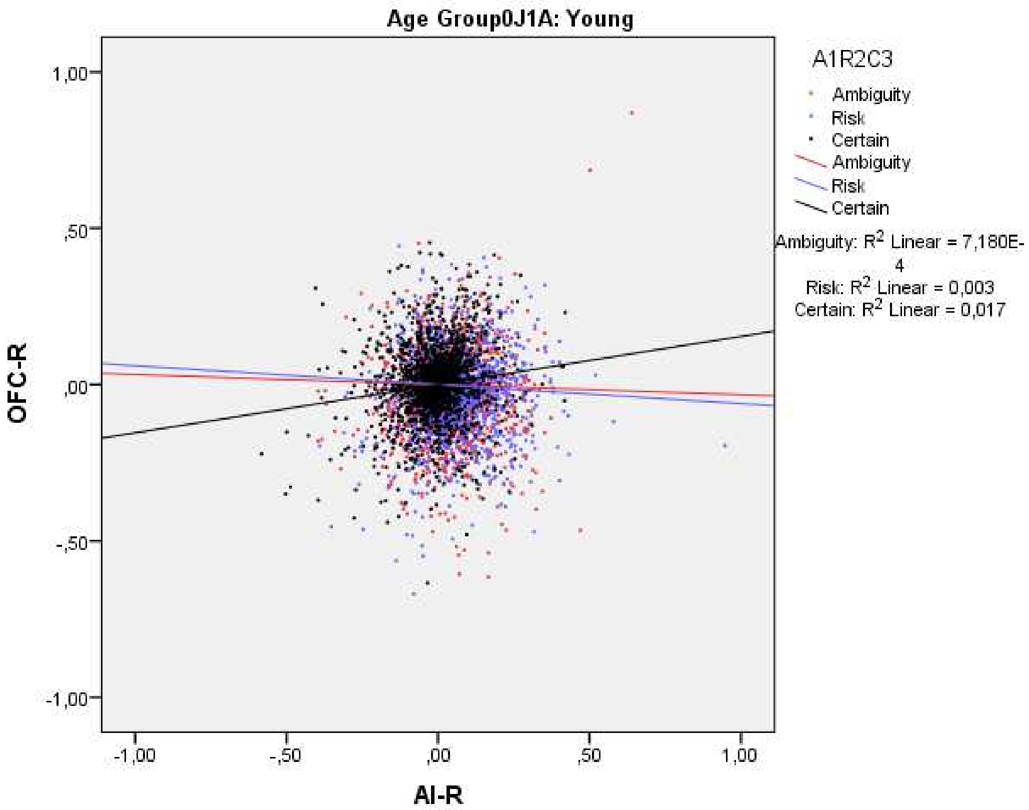
Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: $R^2$ Linear = 0,008
Risk: $R^2$ Linear = 0,006
Certain: $R^2$ Linear = 0,013
Amyg-R
AI-R

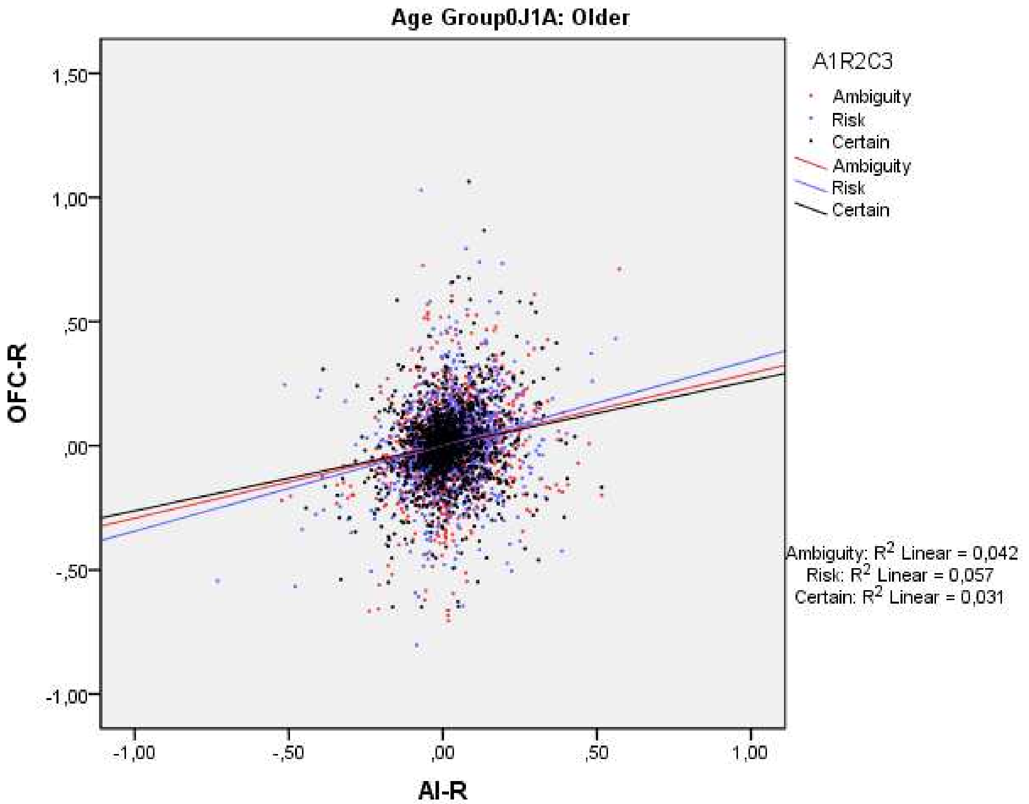
Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: $R^2$ Linear = 0,045
Risk: $R^2$ Linear = 0,076
Certain: $R^2$ Linear = 0,035
Amyg-R
AI-R


Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
1,00
,50
,00
-,50
-1,00
OFC-Bi
-1,00
-,50
,00
,50
1,00
AI-R
Ambiguity: R2 Linear = 3,824E-5
Risk: R2 Linear = 0,022
Certain: R2 Linear = 0,015

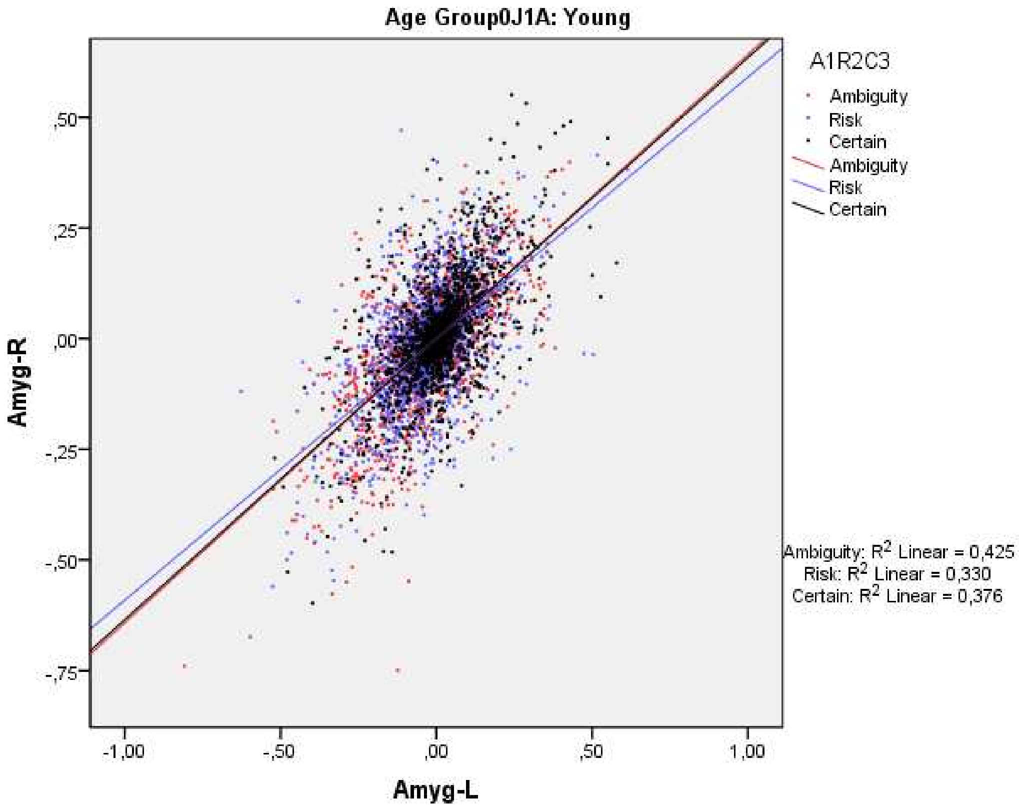

Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
1,50
1,00
,50
,00
-,50
-1,00
-1,50
OFC-Bi
-1,00
-,50
,00
,50
1,00
AI-R
Ambiguity: R2 Linear = 0,045
Risk: R2 Linear = 0,076
Certain: R2 Linear = 0,035

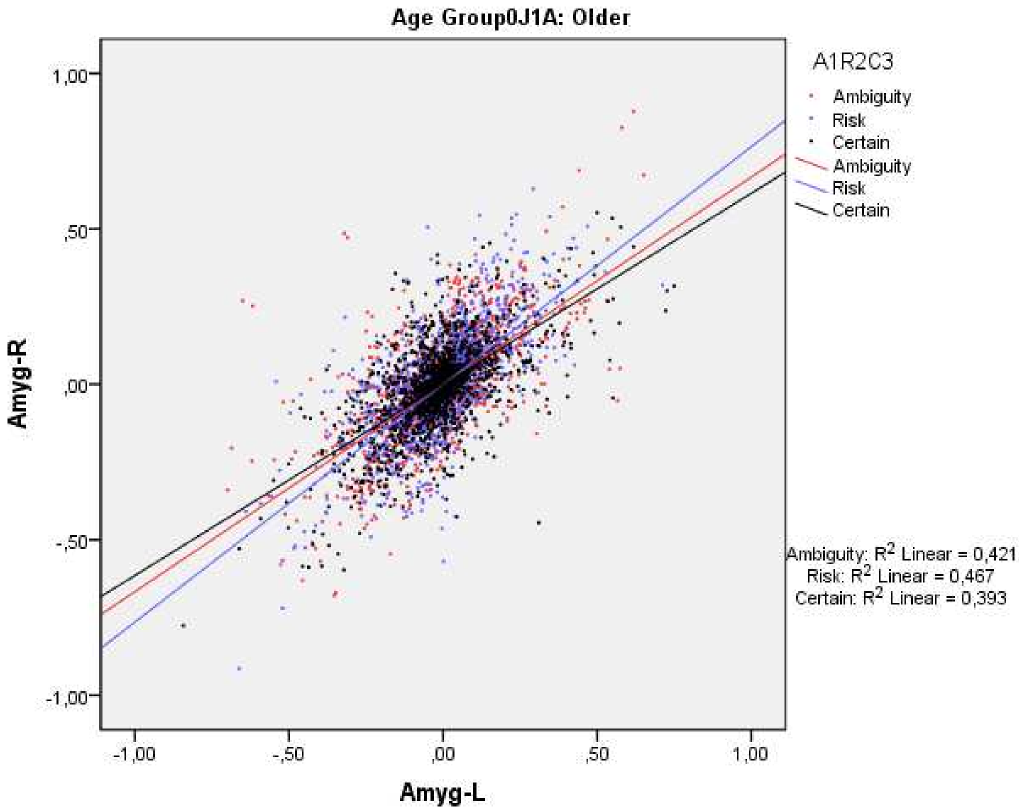


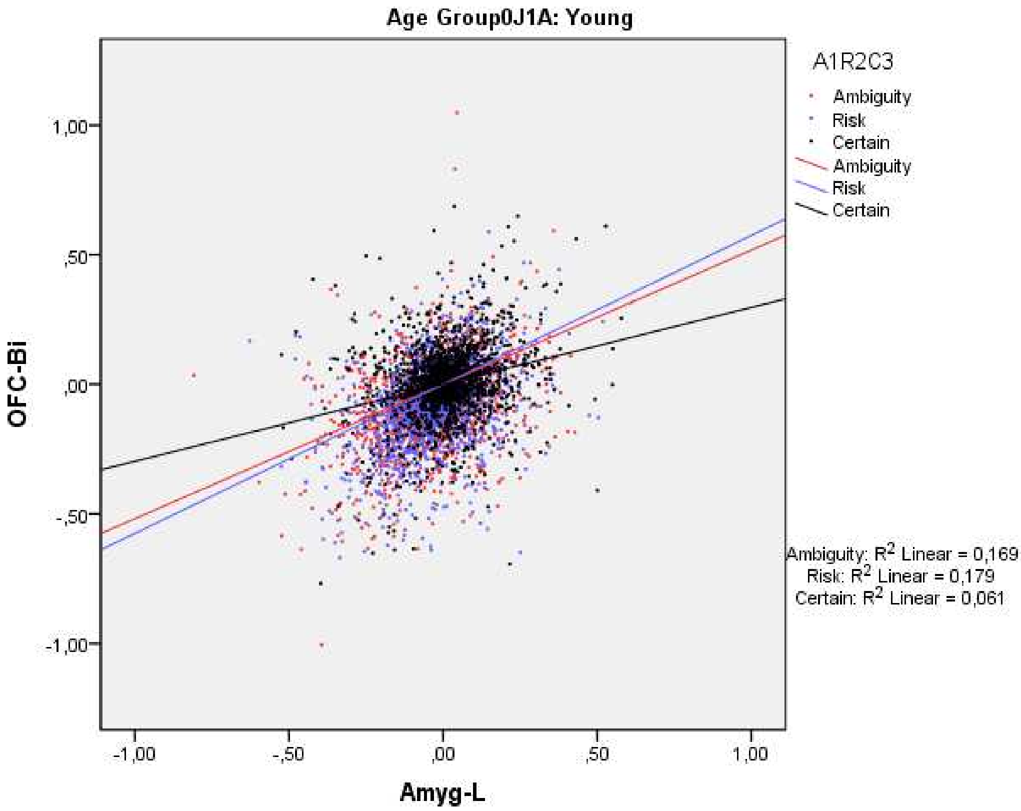
Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 7,180E-4
Risk: R2 Linear = 0,003
Certain: R2 Linear = 0,017
OFC-R
AI-R
1,00
,50
,00
-,50
-1,00

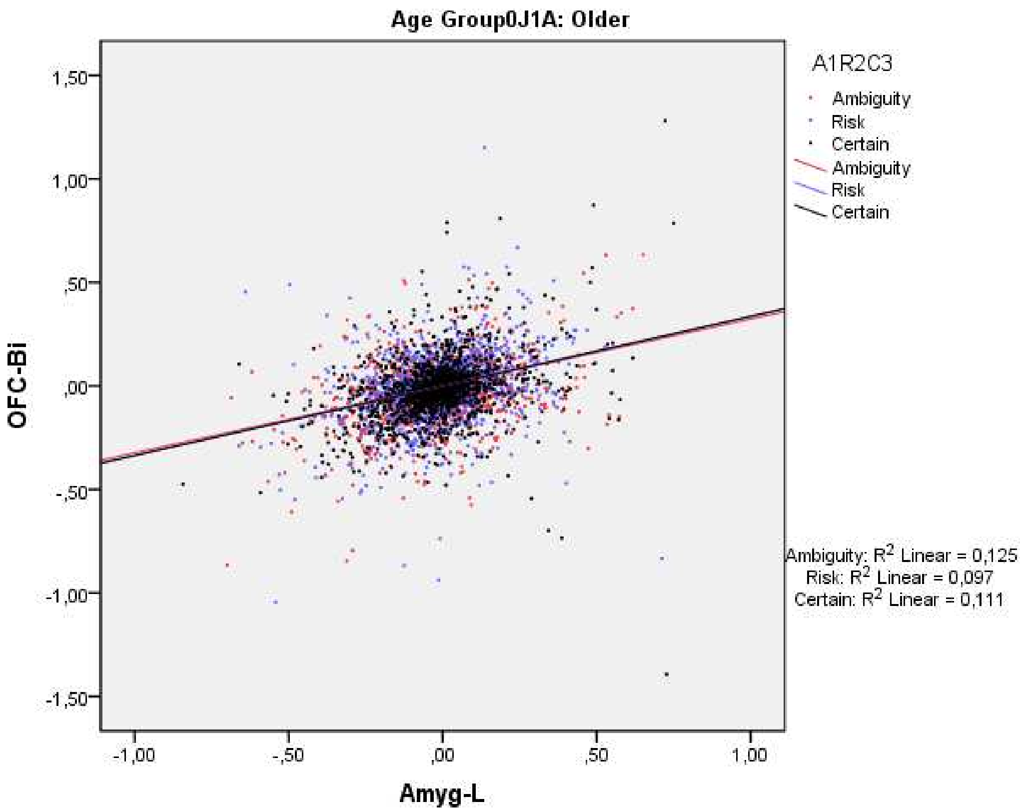
Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 0,042
Risk: R2 Linear = 0,057
Certain: R2 Linear = 0,031
OFC-R
AI-R
1,50
1,00
,50
,00
-,50
-1,00


Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: $R^2$ Linear = 0,425
Risk: $R^2$ Linear = 0,330
Certain: $R^2$ Linear = 0,376
Amyg-R
Amyg-L
,50
,25
,00
-,25
-,50
-,75
-1,00
-,50
,00
,50
1,00

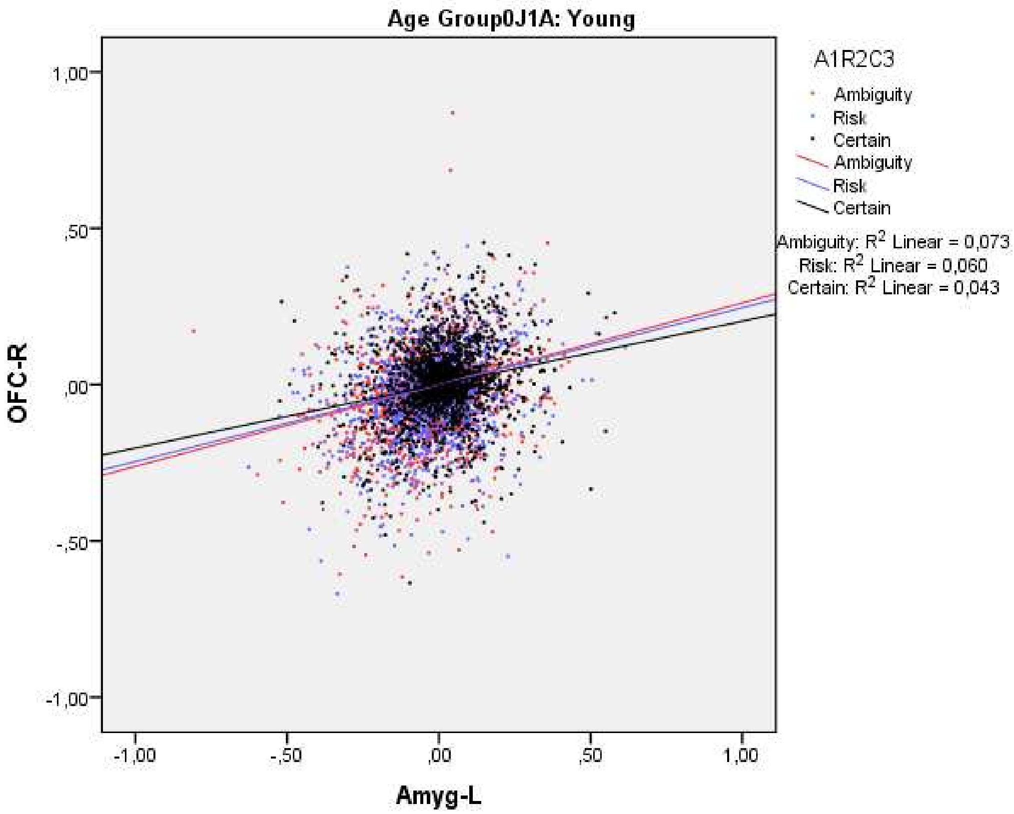

Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: $R^2$ Linear = 0,421
Risk: $R^2$ Linear = 0,467
Certain: $R^2$ Linear = 0,393
Amyg-R
Amyg-L
1,00
,50
,00
-,50
-1,00
-1,00
-,50
,00
,50
1,00



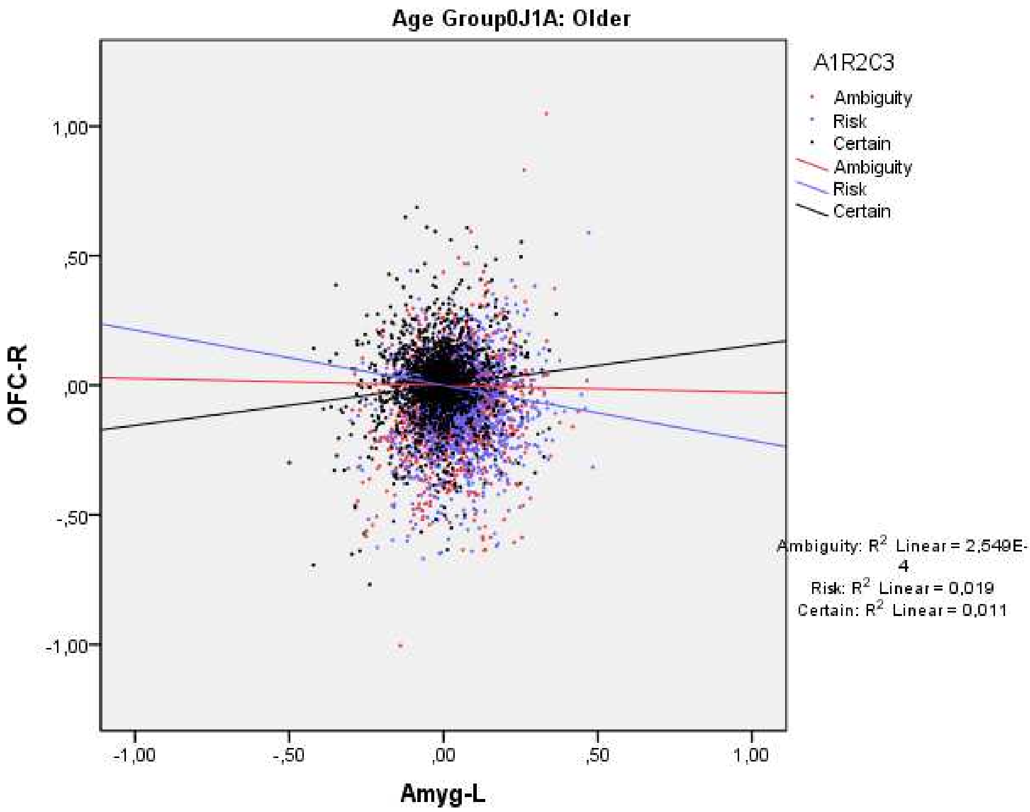
Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
OFC-Bi
1,00
,50
,00
-,50
-1,00
-1,00
-,50
,00
,50
1,00
Amyg-L
Ambiguity: R2 Linear = 0,169
Risk: R2 Linear = 0,179
Certain: R2 Linear = 0,061

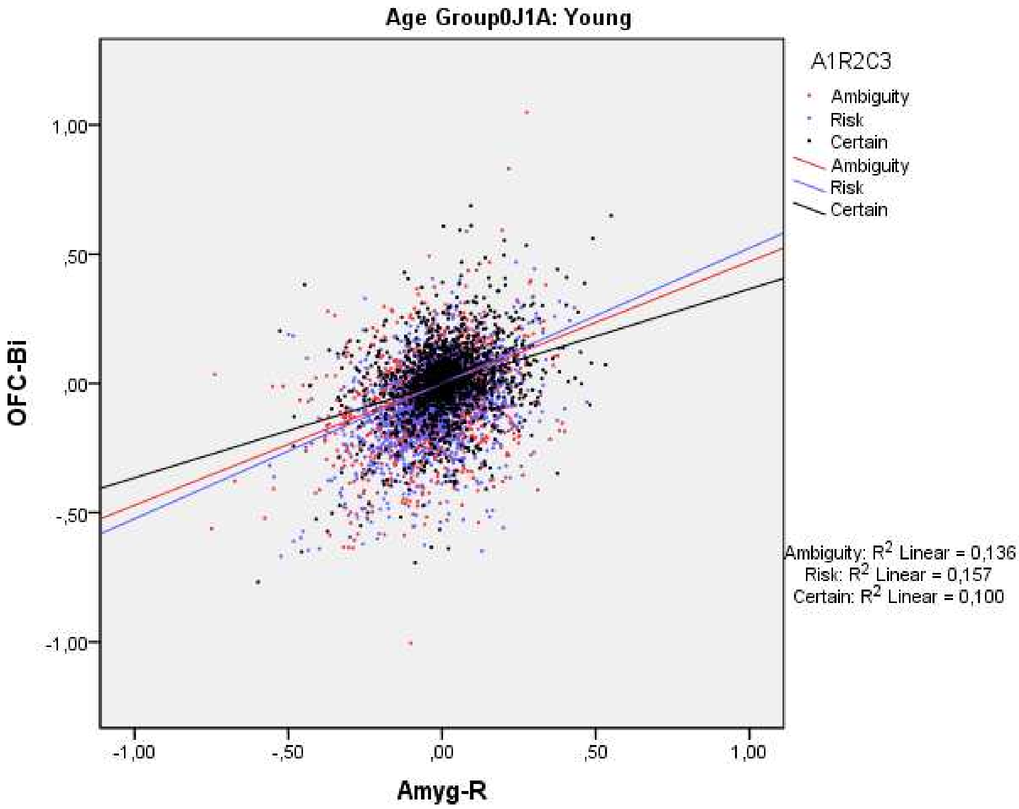
Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
OFC-Bi
1,50
1,00
,50
,00
-,50
-1,00
-1,50
-1,00
-,50
,00
,50
1,00
Amyg-L
Ambiguity: R2 Linear = 0,125
Risk: R2 Linear = 0,097
Certain: R2 Linear = 0,111

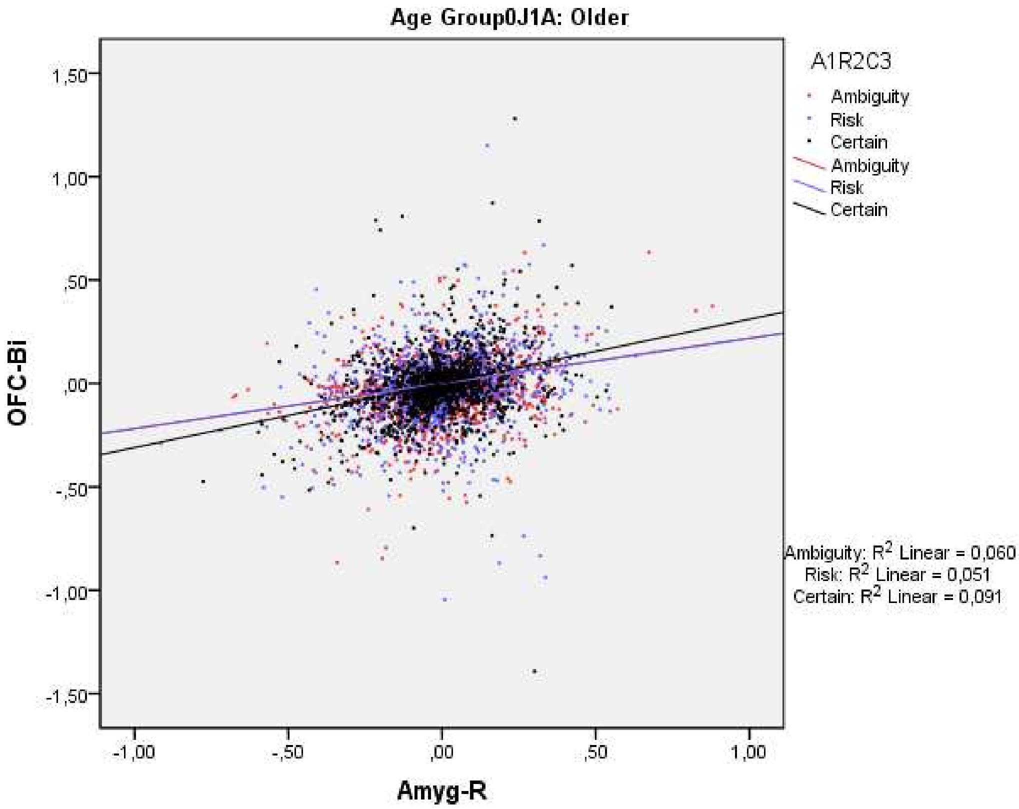


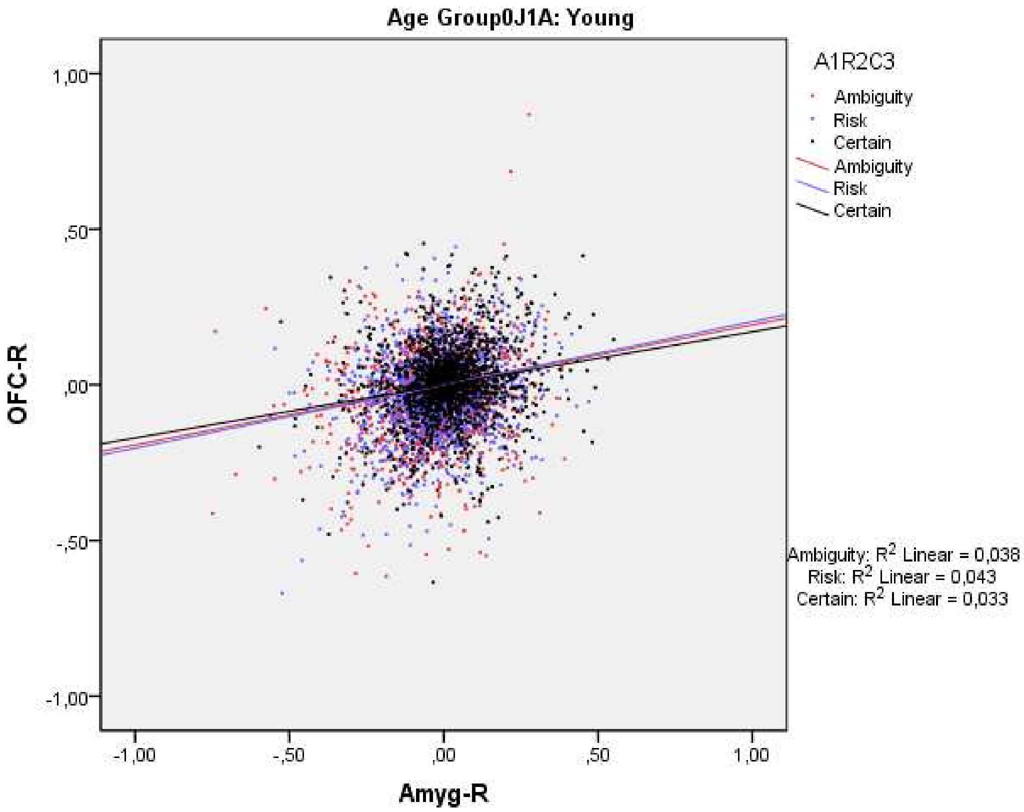
Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 0,073
Risk: R2 Linear = 0,060
Certain: R2 Linear = 0,043
1,00
,50
,00
-,50
-1,00
OFC-R
-1,00
-,50
,00
,50
1,00
Amyg-L

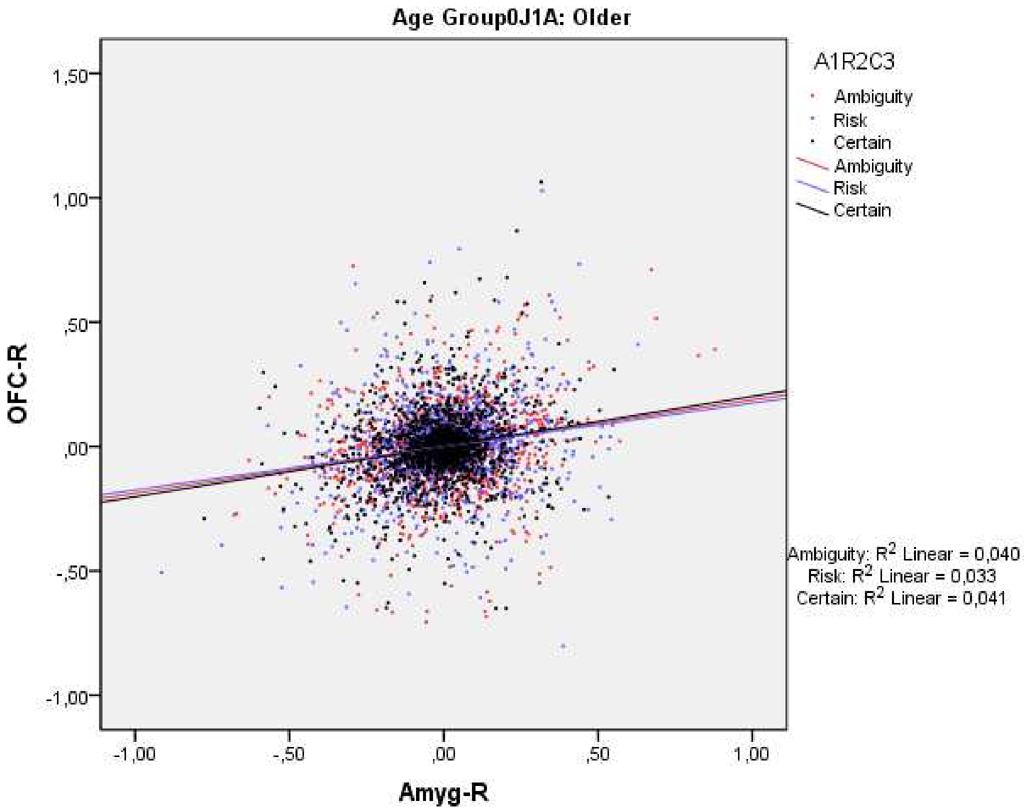



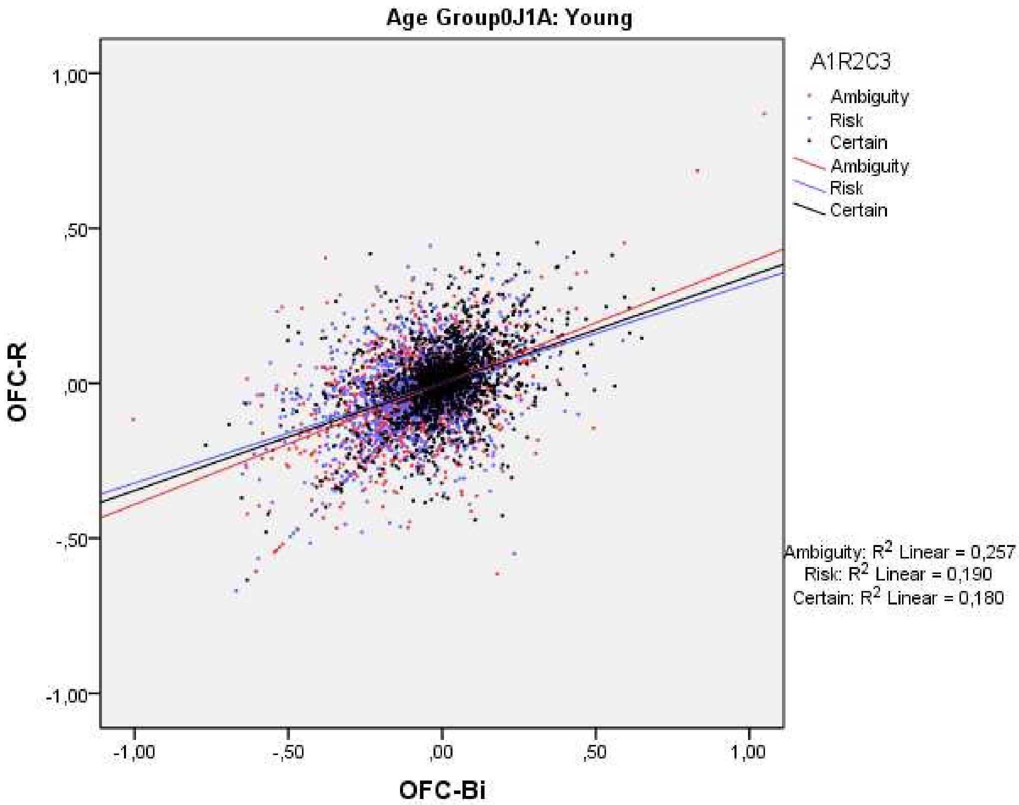
Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 2,549E-4
Risk: R2 Linear = 0,019
Certain: R2 Linear = 0,011
1,00
,50
,00
-,50
-1,00
OFC-R
-1,00
-,50
,00
,50
1,00
Amyg-L

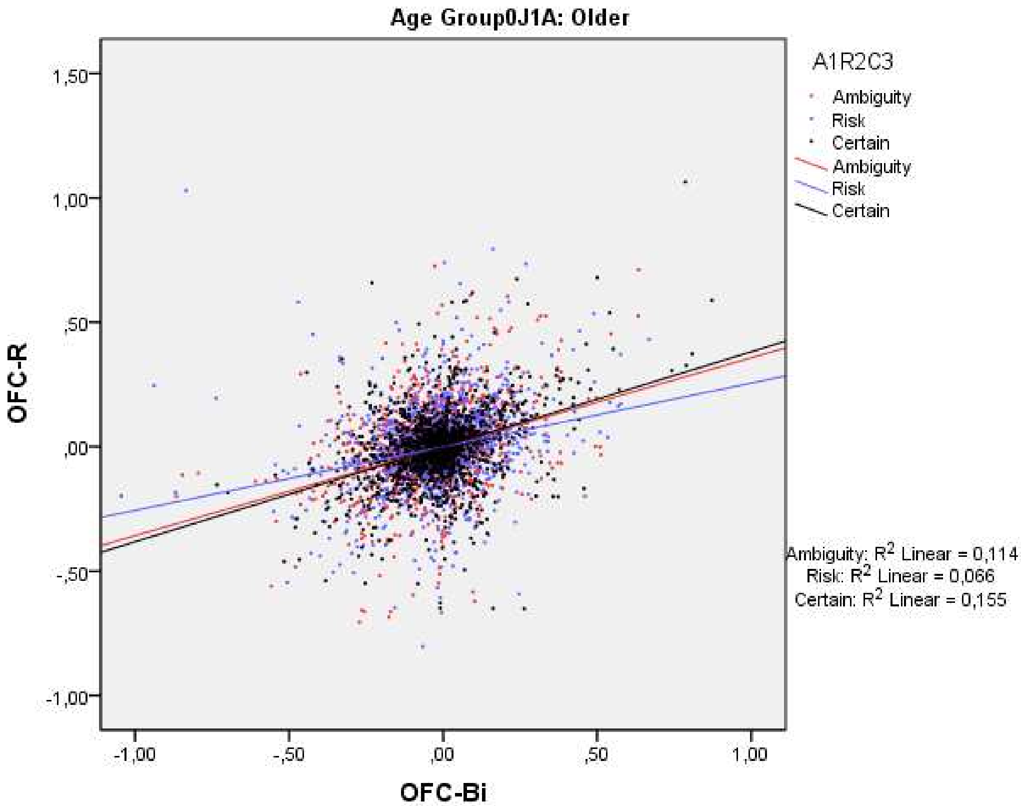

Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 0,136
Risk: R2 Linear = 0,157
Certain: R2 Linear = 0,100
OFC-Bi
Amyg-R


Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 0,060
Risk: R2 Linear = 0,051
Certain: R2 Linear = 0,091
OFC-Bi
Amyg-R


Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 0,038
Risk: R2 Linear = 0,043
Certain: R2 Linear = 0,033
OFC-R
Amyg-R
1,00
,50
,00
-,50
-1,00
-1,00
-,50
,00
,50
1,00


Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 0,040
Risk: R2 Linear = 0,033
Certain: R2 Linear = 0,041
OFC-R
Amyg-R
1,50
1,00
,50
,00
-,50
-1,00
-1,00
-,50
,00
,50
1,00


Age Group0J1A: Young
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 0,257
Risk: R2 Linear = 0,190
Certain: R2 Linear = 0,180
OFC-R
OFC-Bi
1,00
,50
,00
-,50
-1,00
-1,00
-,50
,00
,50
1,00


Age Group0J1A: Older
A1R2C3
Ambiguity
Risk
Certain
Ambiguity
Risk
Certain
Ambiguity: R2 Linear = 0,114
Risk: R2 Linear = 0,066
Certain: R2 Linear = 0,155
OFC-R
OFC-Bi
1,50
1,00
,50
,00
-,50
-1,00
-1,00
-,50
,00
,50
1,00

# To Take or not to Take an Advice? A Framework for Advice Taking and Delegation in Uncertain Decisions

Gil Sharvit Alec N. Sproten

## Abstract

*In an aging society, understanding the factors influencing age-related differences in decision making becomes increasingly important. In the current paper, we develop a framework for the study of decision making under uncertainty with the possibility do delegate the decision to, or to seek advice from an expert instead of betting directly on a choice option. We develop a novel decision making task and test it on a small group of young adults. We observe that unlike rational expectations would predict, participants value their own information much higher than the expert's information. The level of uncertainty of the trials predicts the choice to delegate and to seek for advice. Further, male participants choose more often than female participants to delegate the decision or to seek advice, and being male also predicts the choice of the advice option over delegation. Risk preference of the Holt and Laury risk elicitation task correlates negatively with the number of delegations participants perform, and positively with the number of direct bets. Risk preference on the occupation and career domain correlates positively with advice seeking, and negatively with decision delegation. We discuss these results in the light of the raising interest in age differences in decision making and establish, based on gerontological literature, hypotheses about age differences that can be expected in our framework.*

# Introduction

In an aging society (Vaupel, 2010), understanding age differences in decision making becomes increasingly important. It has been extensively shown that decision making and its underlying processes change in many ways with age. For example, age affects decision making in some but not all uncertainty contexts (R. Mata, Josef, Samanez-Larkin, & Hertwig, 2011; Sproten, Diener, Fiebach, & Schwieren, 2010), age affects social judgments and decisions (G Charness & Villeval, 2007; MacPherson, Phillips, & Della Sala, 2002), age affects emotional information processing (Halberstadt, Ruffman, Murray, Taumoepeau, & Ryan, 2011; Mather & Carstensen, 2005; Richter & Kunzmann, 2011), and more generally age affects dual-process models underlying decision making (Peters, Hess, Västfjäll, & Auman, 2007). One situation from young and older adults' everyday life that combines all these dimensions is receiving advice. Advice refers to a guidance or recommendation offered about what might be thought, said, or otherwise done to address a problem, reach a decision, or manage a situation. Advice has been classified into professional or expert advice and naïve advice (Schotter, 2005). The former is provided by experts in the field of interest, the latter is defined as advisory information that is not available from professional sources and is obtained from subjects in the local environment. We will focus in our experiment on expert advice, thus on advice provided by subjects that have more information on a specific question.  Advice taking is a topic that until now has not been systematically investigated in an aging context. Older adults, as young adults, in everyday decisions often rely on advice, because the integration of additional opinions is beneficial for subsequent decision making (Yaniv, 2004). Advice is closely related to factors as various as accepting help, improving judgment, sharing responsibility (Harvey & Fischer, 1997) or improving social learning (Biele, Rieskamp, & Gonzalez, 2009).

There are many situations in our lives in which we are using advice to share responsibility and to improve decision making, one of the strongest examples probably being health care. Imagine you have a serious issue with your health, and there are many possibilities to choose from that might contribute to a melioration of your condition. While thinking to make an appointment with a doctor, you look up your symptoms in the internet, and try to gather all the information you can get. The more information you are able to add up, the lower your subsequent uncertainty will be. After gathering the information, you are left with three choices. You can decide that with all the information you have, it is not necessary to consult a doctor, and try to treat yourself. You can also estimate your health as being too precious to just risk it by some self-treatments and you decide to consult a doctor. However, it happens that at your town, two doctors have expertise with your problems, and that you need to decide whom to consult. One of the physicians works at the local hospital where you get free treatment with your health insurance. He is known to be rather paternalistic and to decide in place of his patients. The other doctor runs a private office where you need to pay a little sum in addition to your health insurance. This doctor is known to have a different approach to his patients; he gives an advice based on the information he has or tells clearly if he is not sure what to advise, and in the end the patient needs to integrate the additional information and to decide himself whether to undergo a treatment or not. If you decide not to treat yourself without consultation of a physician, which of both would you want to consult? The hospital doctor who does not provide you with additional information, decides in your place, but whose consultation is free of charge, or the private doctor who gives you additional information in form of an advice about what to do, leaves you the freedom of choosing not to undergo a treatment, but where you need to pay a small sum for the consultation?

Another domain where one can imagine similar decisions is in the management of an enterprise. Suppose you are the manager of an enterprise, faced with a decision which can lead to a possible gain for your firm. The gain is however associated to some uncertainty, and personally you are lacking expertise in the field. If you are a rather uncertainty seeking manager, maybe you still decide to directly make the decision yourself. However, there are two additional options available. On one hand, you have an expert in the field working in your enterprise, to whom you can delegate the decision, in which case the decision outcome will be the responsibility of that expert. It happens that there is also an external consulting firm, which you can pay a small sum in exchange of an advice on the business. Buying the advice from the firm allows you to gather additional information, improving your assessment of the risk of the decision, and you do not need to entirely hand over the responsibility for the gain of your firm to somebody else.

In more general terms, the question is how people behave under uncertainty with the possibility of referring to an expert, and which factors predict whether a subject delegates or seeks an advice. Many decisions are made in contexts in which decision makers can gather additional exogenous information by observing others’ decisions or receiving advice from others (Biele, et al., 2009) and in which the presence of advice increases subjects’ welfare (Kariv, Schotter, & Çelen, 2011). Decision making is at least in part learned from others (Bandura, 1977; Henrich & McElreath, 2003; Laland, 2002; Schotter & Sopher, 2003; Simon, 1990) and in situations of uncertainty social information is especially valuable (Festinger, 1954). Advice, unlike delegation, is an important aspect in social learning: the information available to the judge is exogenous and the decision maker needs to search for and incorporate the available information. If someone delegates the decision to the expert, he discharges most of the responsibility of the decision outcome to that expert, increases the expected outcome of the decision, but does not reduce his uncertainty. If someone buys the advice of an expert on the other hand, he decreases the level of uncertainty and by that increases the expected outcome of the decision. The third, least beneficial, option would be not to consult any expert, and hence not reducing the uncertainty, not reallocating the responsibility of the decision outcome, and not increasing the expected outcome of the decision.

It has been shown that agreement with experts is rewarding per se; thus subjects retrieve utility out of the fact that their judgments are backed by experts (Campbell-Meiklejohn, Bach, Roepstorff, Dolan, & Frith, 2010). Hence in advice conditions, if someone receives an expert advice, agreement with that advice should contribute to the utility of the decision maker. Accordingly, Biele and colleagues show that following expert advice in itself is rewarding, even if the advice leads to negative outcomes (Biele, Rieskamp, Krugel, & Heekeren, 2011). Related to advice taking are other, more extensively researched social sampling strategies like imitating the best. Imitation of the best, for example, is comparable to advice taking in that it involves sampling the best, thus looking for information in others' behaviour that might increase ones' own chances to make good decisions; in our advice taking framework, the best is replaced by an expert, who should always perform better than the judge. Imitating the best has been shown to be a robust behaviour even if it is suboptimal, and to increase risk seeking (Offerman & Schotter, 2009).

It has also been shown that if there is disagreement with the informational source (i.e. the expert), subjects valuate their own information considerably higher than the external information. In situations where the empirically optimal behaviour would be to follow others that contradict ones' own information, only a small fraction of players does indeed follow them with the result to increase their payoff to above random behaviour expected payoff (Weizsacker, 2010). The weight of the players' own information is much higher than the information conveyed by other players. Rational expectations would predict that if the empirical odds ratio of being wrong is 1:1, players should contradict their own signal and follow the information of others. However, Weizsäcker shows in his meta-analysis that only if the odds ratio is above 2:1, conditional on all available information, the average player follows others' information. At our knowledge, even though a similar effect has been found in advice (Yaniv, 2004) it has at this point not been investigated which odds ratio exactly is necessary in advice conditions to contradict ones' own information; however, it has been shown that subjects prefer to follow an advice rather than to copy the actions of others if both are equally informative in equilibrium (Kariv, et al., 2011) and that people are more prone to consider an advice if it is linked to a cost rather than being free (Yaniv & Kleinberger, 2000).

In a delegation context, on the other hand, others' information is not followed as such. Indeed, delegation does not have a social learning dimension but rather a dimension of trust. The term strategic delegation goes back to Schelling (1960), following which delegation can be used as a commitment device in social contexts and be beneficial for the delegating principal. Since then, delegation has become increasingly researched in economics (Baik, 2007; Fershtman & Judd, 1987; Fershtman & Kalai, 1997; Katz, 1991). For example, it has been shown that delegation by all judges is preferred to competition by individual payoff maximizing judges (Wärneryd, 2000), and that delegation can prevent spiteful behaviour with respect to others (Rusche, 2011). It has been shown that decision making leads to impairments in subsequent self-control in presence of limited cognitive resources (e.g. due to stress; (Vohs et al., 2008)). Delegating the decision to someone else can help to cope with the situation. When one has the possibility to delegate a decision to a player with good performance (which one would expect of an expert), subjects delegate more often than when the subject is less expert (Leana, 1987).

Relating to our examples, if you decide to consult the first (hospital) physician or to delegate to the enterprises' own expert, you do it probably because you want to discharge the entire responsibility of the decision outcome to the expert (Anderson, 2003). This way, you do not reduce your uncertainty; you just reallocate the decision to somebody else. If you decide to consult the second physician or the consulting firm, you do it probably because you want to obtain information to make better decisions (Garvin, Huston, & Baker, 1992) and to alleviate your responsibility through the advice (Charness, 2000).

In our examples, you are supposedly stressed, because a medical intervention or far-reaching management decision does not happen often in your everyday life, which will render you receptive to information provided by others (Driskell & Salas, 1991). There is however the possibility that the expert, instead of giving you an advice, tells you: "I don't know, it's up to you to decide". Instead of sharing the responsibility with you – as you expected – he disappoints you by returning all the responsibility to you. By that, the expert increases even more the stress you are experiencing. This stress, in our example evoked by uncontrollable decision making situations, where one cannot fulfil all the requirements necessary to reach a decision, leads to a stronger tendency not to consider all the available alternatives, and to scan the alternatives in a non-systematic fashion. This can lead you to disadvantageous decision making if you do not find a way to cope with it (Starcke, Wolf, Markowitsch, & Brand, 2008). Unfortunately, redrawing from the decision about your health or the outcome of your enterprise will yield a lower expected outcome than making a choice. What would you do?

To improve understanding of decision making under uncertainty with the possibility to delegate and to seek advice, we developed a novel task. The aim of the current paper is to suggest a framework for the study of decision making with delegation and advice as well as to validate it with a small group of young subjects. We will discuss results of the validation and possible age differences that one might expect in further experiments where this task will be applied. We expect the amount of available information in the decision context as well as the uncertainty of the choice to have significant effects on the choices participants will perform. We also expect participants risk preferences to have an influence on the decision whether to delegate or to seek an advice. As gender differences in many social decision making tasks have been found (Balliet, Li, Macfarlan, & Van Vugt, 2011; Croson & Gneezy, 2009; Eagly & Wood, 1991), gender differences in decision making with advice and delegation may also be probable.

## The task

We developed a novel computerized two-player task based on urns to evaluate decision making under uncertainty with the options to delegate the decision to or to buy an advice from an expert. We give it the acronym 'BUDA', standing for Betting under Uncertainty with Delegation and Advice.

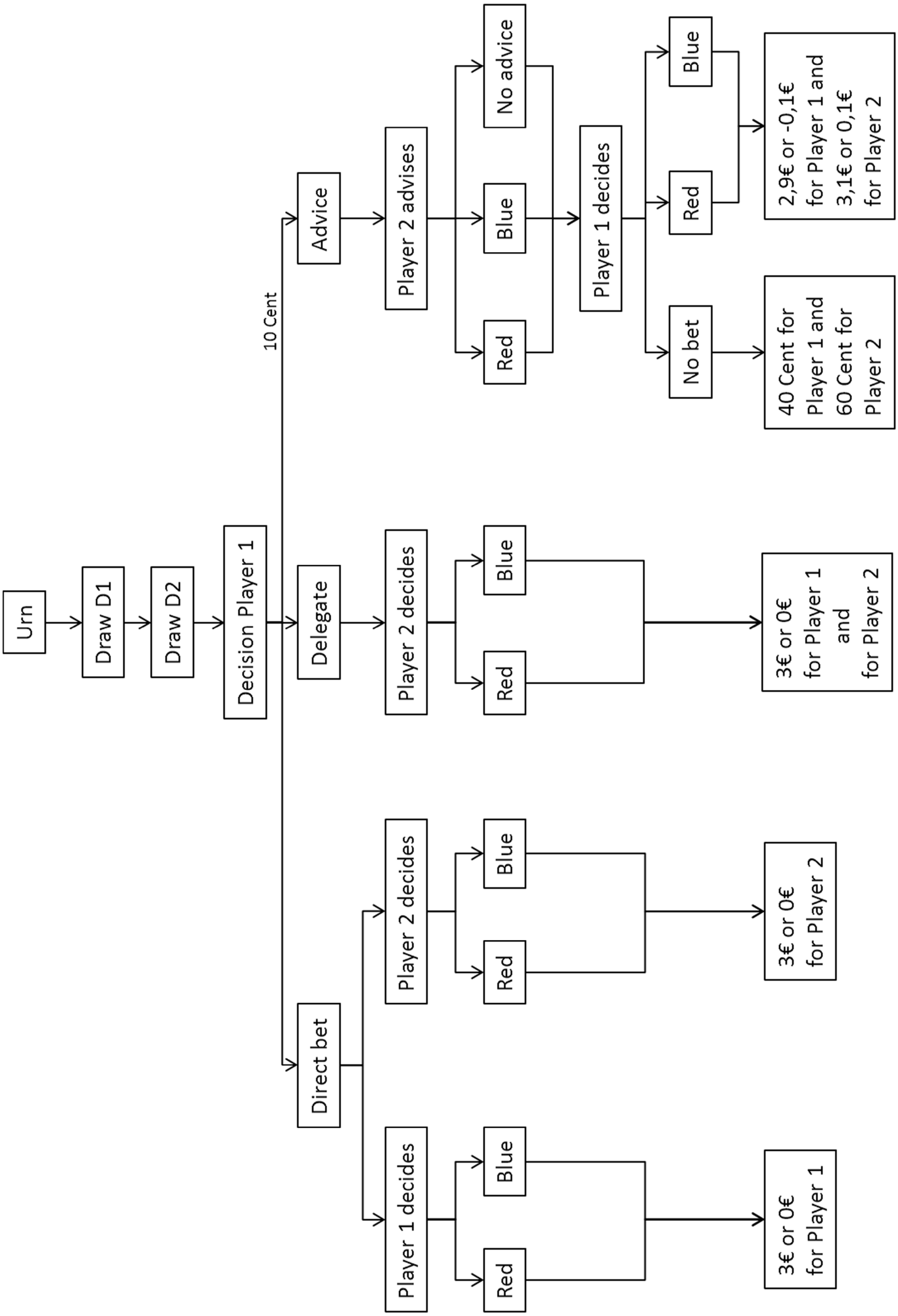
The BUDA is played for twenty rounds, with players at task onset randomly assigned to be a judge or expert over all rounds. A round begins with three draws of red and blue balls out of the urn (returning the balls after each draw). Draw 1 (D1) consists of a draw of a variable amount of balls (see Table 1) which is smaller than the total amount of balls in the urn. The second draw (D2) contains at least one more ball than D1. The third draw (D3) consists of a single ball. The aim of the game is to predict the colour of the ball in D3. In a first step, the number of balls in the urn and D1 are revealed to the judge, associated with three choices. The judge can choose either to bet directly on a ball colour, or to delegate the decision to the expert, or to buy an advice from the expert. Next, D2 and the total number of balls in the urn are revealed to the expert. In case the judge chose to bet directly, both judge and expert decide individually on which colour to bet, and the round ends. In case of a delegation, the expert needs to bet on a colour, with the experts' bet also being the judges' bet, and the round ends. In case of buying an advice, the expert receives 10 cents from the judge and can advise the judge to bet on red or blue. However, the expert can also decide not to give an advice (e.g., if he sees a 50:50 chance of winning or losing the game). Accordingly, the experts' advice or non-advice is revealed to the judge, who is offered to bet on either colour, or to decide not to bet and to receive a sure amount of money. The experts' outcome is also dependent on this choice.

Subsequently, the next round starts, with a different number of balls in the urn, new draws, and a new judge-expert matching.

Judges are expected to never directly bet in any of the rounds, as the expected payoff is lowest for the direct bet. Delegating the decision to an expert will yield in any case an expected payoff that is higher than the expected payoff of the direct bet, as the uncertainty with which the expert has to deal is always lower than the judges' uncertainty level. Choosing an advice also will always yield a higher expected payoff than the direct bet. Even though participants need to buy additional information, the price for this additional information amounts to only 3.33% of the possible gain, a price at which the expert gives an advice based on between 14.29 and 60 per cent more information than the judge has.

Table 1: Composition of the rounds

| | Urn | Judge | | | Expert | | | Judge-Expert |
|---|---|---|---|---|---|---|---|---|
| Round | Total | Red | Blue | Total | Red | Blue | Total | Δ Information |
| 1 | 5 | 1 | 2 | 3 | 1 | 4 | 5 | 40.00% |
| 2 | 12 | 3 | 6 | 9 | 5 | 6 | 11 | 16.67% |
| 3 | 10 | 1 | 1 | 2 | 6 | 2 | 8 | 60.00% |
| 4 | 9 | 2 | 1 | 3 | 3 | 2 | 5 | 22.22% |
| 5 | 12 | 4 | 4 | 8 | 8 | 3 | 11 | 25.00% |
| 6 | 8 | 2 | 4 | 6 | 2 | 6 | 8 | 25.00% |
| 7 | 11 | 6 | 3 | 9 | 7 | 4 | 11 | 18.18% |
| 8 | 6 | 1 | 4 | 5 | 2 | 4 | 6 | 16.67% |
| 9 | 7 | 3 | 2 | 5 | 3 | 3 | 6 | 14.29% |
| 10 | 11 | 4 | 1 | 5 | 7 | 0 | 7 | 18.18% |
| 11 | 5 | 2 | 2 | 4 | 3 | 2 | 5 | 20.00% |
| 12 | 6 | 3 | 1 | 4 | 3 | 3 | 6 | 33.33% |
| 13 | 8 | 1 | 3 | 4 | 5 | 1 | 6 | 25.00% |
| 14 | 12 | 6 | 2 | 8 | 5 | 5 | 10 | 16.67% |
| 15 | 6 | 2 | 2 | 4 | 2 | 3 | 5 | 16.67% |
| 16 | 10 | 2 | 3 | 5 | 1 | 8 | 9 | 40.00% |
| 17 | 12 | 2 | 6 | 8 | 5 | 6 | 11 | 25.00% |
| 18 | 9 | 4 | 2 | 6 | 4 | 5 | 9 | 33.33% |
| 19 | 3 | 1 | 1 | 2 | 1 | 2 | 3 | 33.33% |
| 20 | 10 | 4 | 4 | 8 | 5 | 5 | 10 | 20.00% |



Urn
Draw D1
Draw D2
Decision Player 1
10 Cent
Advice
Delegate
Direct bet
Player 2 advises
No advice
Blue
Red
Player 1 decides
Blue
Red
No bet
2,9€ or -0,1€ for Player 1 and 3,1€ or 0,1€ for Player 2
40 Cent for Player 1 and 60 Cent for Player 2
Player 2 decides
Blue
Red
3€ or 0€ for Player 1 and for Player 2
Player 2 decides
Blue
Red
3€ or 0€ for Player 2
Player 1 decides
Blue
Red
3€ or 0€ for Player 1

## The experiment

A total of 30 students of the University of Heidelberg took part in the study. The study began with the BUDA. The experimenter read aloud the instructions of the task, and participants had the possibility to ask questions in case of comprehension problems. Participants were randomly assigned to be a judge or expert for the entire duration of the game. After the BUDA, participants' risk preferences were assessed using the incentivized Holt and Laury risk elicitation task (Holt & Laury, 2002) and by administering the (non-incentivized) risk questions of the German socioeconomic panel (SOEP, (Burkhauser, Butrica, Daly, & Lillard, 2000)) for the general, car driving, financial investments, sports & leisure, occupation & career, health, and trust domains. Participants received a show-up fee of 3€. In addition, they were paid based on their performance in the study. Decisions on the risk elicitation task as well as two rounds of the BUDA were used for determination of the total gain.

## Results

In the current experiment, we were interested in the behaviour of the judge. Therefore, experts' choices are excluded of the analysis.

In all 300 observed decisions, there is a significant difference in how often participants chose the different options ($\chi^2_{(2)}$ = 71.540, p < .001), with 49.3% of direct bets (N = 148), followed by 39.7% of delegations (N = 119), and 11.0% of advice seeking (N = 33).

Multinomial logit regressions were performed to determine factors influencing choice behaviour. A risk coefficient was created representing the probability as shown to the judge in the draw. The risk coefficient ranged from .5 (lowest probability) to .8 (highest probability), with a mean of .64 (SD = .106). Also, an information coefficient was created, representing the number of balls seen in D1 in relation to the total number of balls in the urn. The information coefficient ranged from .2 (twenty per cent of balls known) to .833 (83.3 per cent of balls known), with a mean of .636 (SD = .161).
In a first step, the risk coefficient and the information coefficient were introduced as predictors into the regression. In a second model, gender was added (male participants coded as 1, female as 2). Model III contained the same predictors as model I, but the interaction between risk and information coefficient was added. This interaction term might be seen as the uncertainty-level of the decision, ranging from .1 (highest uncertainty) to .667 (lowest uncertainty) with a mean of .407 (SD = .121). In model IV, gender was reintroduced.

Table 2: Multinomial logistic regressions

| Choice | | Model I | Model II | Model III | Model IV |
|---|---|---|---|---|---|
| Delegation | Risk coefficient | -8.038*** | -8.266*** | 7.034 | 7.321 |
| | | (1.138) | (1.373) | (5.338) | (5.405) |
| | Inf. coefficient | -3.077** | -3.198** | 11.702* | 12.089* |
| | | (.966) | (.981) | (5.159) | (5.225) |
| | Risk*Information | | | -23.868** | -24.711** |
| | | | | (8.497) | (8.617) |
| | Male | | .690* | | .724* |
| | | | (.275) | | (.281) |
| | Constant | 6.902*** | 6.818*** | -2.482 | -2.891 |
| | | (1.164) | (1.179) | (3.282) | (3.326) |
| Advice | Risk coefficient | -5.774** | -6.227** | 9.224 | 9.827 |
| | | (1.954) | (2.009) | (7.118) | (7.328) |
| | Inf. coefficient | -4.286** | -4.522*** | 10.833 | 11.636 |
| | | (1.234) | (1.270) | (7.104) | (7.301) |
| | Risk*Information | | | -24.322* | -26.069* |
| | | | | (11.921) | (12.261) |
| | Male | | 1.474** | | 1.507** |
| | | | (.432) | | (.436) |
| | Constant | 4.954** | 4.600** | -4.424 | -5.423 |
| | | (1.525) | (1.566) | (4.308) | (4.446) |
| | $R^2$ | .198 | .244 | .226 | .272 |

* $p < .05$, ** $p < .01$, *** $p < .001$; $R^2$ = Nagelkerkes' pseudo $R^2$
Reference category: direct bet

The regressions reveal the following effects. When assessing the effects of the risk and information coefficient separately, it appears that the riskiness of the choice as well as the amount of information available significantly predict the choice to delegate and to buy an advice. The addition of the interaction between the risk and information coefficients to the model removes the significant contribution of the risk coefficient to both delegation and advice seeking. The information coefficient contributes significantly to the delegation decision, but the effect is reversed compared to model I. It does not contribute significantly to advice seeking. The interaction between risk coefficient and information coefficient does contribute significantly to the decisions; the smaller the value of the interaction (thus the higher the uncertainty), the more likely participants are to choose to delegate or to seek for advice. Gender of participants also has a significant influence on choice behaviour, with more male participants choosing to delegate and to get and advice.

A further logit regression with the same predictors was performed to directly compare delegation and advice trials. Neither the risk- nor the information coefficient or their interaction revealed to predict whether participants chose to delegate or to seek an advice. Gender, however, showed a marginally significant effect ($p = .057$, both when controlling for the risk- and information coefficients separately and when controlling furthermore for their interaction), with more male participants choosing to seek for advice.

Even though it is common practice in economics to treat multiple one-shot decisions from the same subject as independent measures, we decided to control for the robustness of our results by allowing for correlated residuals in the following generalized equation estimations (multinomial logit), with risk and information coefficient as separate regressors in model I, adding gender in model II, replacing gender by the interaction between risk and information in model III, and reintroducing gender in model IV (Table 3).

Overall, with correlated residuals, the results of the logistic regressions above still hold. We observe a significant effect of the risk and information coefficients in model I. In model III, the information coefficient as well as the interaction contributes significantly to the regression, with a sign reversal of the information coefficient compared to model I. The risk coefficient does not contribute significantly to model III. The significant role of gender cannot be reproduced in the current models, but a clear tendency towards more male participants choosing the advice or delegate options can still be observed in the 95% CI (model II: -1.932, .286; model IV: -2.018, .305).

Table 3: Generalized equation estimation

| | Model I | Model II | Model III | Model IV |
|---|---|---|---|---|
| Advice | 3.228** | 2.876** | -5.481* | -6.142* |
| | (1.015) | (1.113) | (2.528) | (2.659) |
| Delegation | 5.591*** | 5.315*** | -3.089 | -3.666 |
| | (1.247) | (1.317) | (2.594) | (2.721) |
| Risk coefficient | 6.031*** | 6.169*** | -8.689 | -9.063 |
| | (1.514) | (1.511) | (4.707) | (4.750) |
| Inf. coefficient | 2.698** | 2.719*** | -11.445* | -11.896** |
| | (.802) | (.781) | (4.486) | (4.578) |
| Risk*Information | | | 24.018** | 24.863** |
| | | | (8.398) | (8.538) |
| Male | | -.823 | | -.857 |
| | | (.566) | | (.593) |

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

Predicted category: direct bet

We also expected that participants' risk preferences influence choice behaviour. Therefore we correlate measures of individual risk preferences with the proportions of choices subjects performed. We are aware that with a small sample of 15 participants, correlation results are highly underpowered. However, as the aim of the study was to validate the task for further, more extensive studies, we are confident that results of the correlations can be interpreted as tendencies of what to expect in further experiments. We require correlation coefficients to be significant at a 10% level to be interpreted as a tendency. In the risk preference measures, the switch point of the Holt and Laury risk elicitation task correlates negatively with the proportion of direct bets a participant performs (r = -.394, p = .082) and positively with the number of delegations (r = .449, p = .054). That is, the more risk seeking a participant is, the more likely he chooses a direct bet. The less risk seeking he is, the more he delegates. There is no significant correlation with advice seeking. Advice seeking positively correlates with the occupation and career risk question of the SOEP (r = .406, p = .067). Thus, the more risk seeking a person is with respect to his occupation and career, the more likely he seeks for advice. We also observe a tendency in the other direction for delegation correlating with risk taking (r = -.340), however it does not match our (arbitrary) significance threshold (p = .107).

To investigate the effects of responsibility shift following advice on decision making, we evaluated how often participants chose a sure amount of money. Due to the small number of observations, we keep this part of the analysis at a purely descriptive level. Out of the 33 advice trials, advisors six times decided not to give an advice. Three times, judges decided following this decision to take the sure amount of money. In all 33 advice trials, judges chose 10 times to take a sure amount.

# Discussion

The aim of the current study was to describe and validate a new task designed to investigate decision making with advice and with the possibility to delegate. Furthermore, we wanted to establish a framework for studying age differences in advice and delegation decisions.

We expected the amount of available information in the decision context as well as the uncertainty of the choice to have significant effects on the choices participants would perform; the higher the uncertainty, the more likely participants seek advice or delegate the decision. We also expected participants risk preferences to have an influence on the decision whether to delegate or to seek an advice. As gender differences in many social decision making tasks have been found (Croson & Gneezy, 2009), gender differences in decision making with advice and delegation were also expected.

In the validation study of the task, we have confirmed the main hypotheses. First, we were expecting participants to react to the level of uncertainty by searching for advice or delegation of the decision. In fact, we can show that the level of uncertainty of the task (as measured by the interaction of the risk and information coefficients) influences participants' decision. The higher the uncertainty, the more likely participants delegate the decision or seek an advice. Interestingly, however, participants decide in a stupendous 49.3% of the trials to bet directly on one of the colours, while rational expectations would predict zero trials with direct bets. Indeed, expected value of trials is always higher for delegation and advice choices, as the level of information of the experts is in all cases higher than the judges' information. This result is similar to the studies of Weizsäcker (2010) and Yaniv (2004), who show that the principals' own information is usually valued higher than external information.

In older adults, various factors may lead to a change in decision proportions. For example, it has been shown that older adults look up less information and take more time to process it than young adults (Berg, Meegan, & Klaczynski, 1999; Henninger, Madden, & Huettel, 2010; Rui Mata, Schooler, & Rieskamp, 2007). Thus, one might expect that older adults less often will seek an advice than young adults, as seeking an advice equals looking up more information. Indeed, to get back to our medical example from the introduction, Zwahr and colleagues found that after reading a vignette about a medical decision, young adults were more likely to decide to seek a second opinion or gather more information than were older adults (Zwahr, Park, & Shifren, 1999). It also has been shown that when the possibility exists to avoid making a decision or to delegate the decision, older adults choose this possibility more often than young adults (Löckenhoff & Carstensen, 2004, 2007). When faced with medical decisions, older adults have been shown to be more likely than younger adults to indicate that they would rather not make the decisions themselves, instead leaving them up to their doctors (Cassileth, Zupkis, Sutton-Smith, & March, 1980; Curley, Eraker, & Yates, 1984; Ende, Kazis, Ash, & Moskowitz, 1989; Steginga & Occhipinti, 2002). Similarly, older adults were more likely than younger adults to say they preferred not to have the responsibility for choosing a Medicare health plan (Finucane et al., 2002). However, it also has been shown that older managers' business decisions are more aggressive and less uncertainty averse than younger managers' business decisions (Brouthers, Brouthers, & Werner, 2000), hence one might hypothesize more direct bets in older adults on the BUDA. We cannot rule out that such an effect will occur on the task, but evidence does rather point in other directions. For example, it has been shown that in risky decisions with a priori probabilities, older and young adults do not differ in risky decisions (R. Mata, et al., 2011). Uncertain decisions on the BUDA do not correspond entirely to risky decisions with a priori probabilities, as no full information is provided about the content of the urn, but rather lie somewhere in between risky and ambiguous decisions on the uncertainty spectrum. As we have shown in our own research (Sproten et al., this volume), older and young adults do not differ in decision making under risk with a priori probabilities, but well in decision making under ambiguity. Age differences in decisions under uncertainty on the BUDA may hence depend on the level of uncertainty of each trial.

We also can show that when controlling for overall uncertainty, the information coefficient has a significant, somehow paradoxical, effect on decision making. The less information available, the more direct bets compared to delegations subjects perform. If not controlling for the interaction between risk and information coefficient however, the information coefficient shows the opposite effect; the less information available, the more delegations happen.

Gender has an effect on advice taking and delegation as well. We can show that male participants are more prone to delegate and to receive an advice than female participants. This result may at a first glance be counterintuitive, as women are stereotypically believed to be more prosocial and trusting than men (Eagly & Wood, 1991), with men shying away from asking for help (Venkatesh & Morris, 2000) and being more autonomy oriented than women (Statham, 1987). Greene and Grimsley (1990) have for example shown that adolescent girls are more likely than boys to seek and follow their mothers' advice. Also, women are believed being more apt to seek input from others (Irby & Brown, 1995). However, the aforementioned studies report questionnaire evidence, and in the experimental studies on advice, gender effects have not been systematically investigated at our knowledge. In delegation, a context and role dependence has been found, with men and women delegating in different contexts (home versus work) and in dependence on their gender role (traditional vs. nontraditional; (Somech & Drach-Zahavy, 2007)). A similar effect may appear in the advice condition of the BUDA. Though necessitating further investigation, it is possible that depending on their gender role and on the specific context of the decisions, male participants are more prone than female participants to seek advice in the current experiment. When turning to the management literature, it also has been shown that men are more prone than women to delegate in management decisions (Atwater, Brett, Waldman, DiMare, & Hayden, 2004; Irby & Brown, 1995), but no other contexts or varying gender roles have been investigated. Finally, when investigating which factors influence whether a participant delegates or seeks an advice, it appears that being male predicts if a participant chooses an advice instead of the delegation option. One might hypothesize a gender difference in responsibility attitude or in risk preferences to be underlying this result. However, further testing will be needed (together with gender role and management style scales) to fully understand the observed effect.

When comparing young to older adults, we hypothesize that an interaction effect between age and gender will be found. It has been shown that aging affects men and women differentially on various domains of cognitive processing, with some studies showing a stronger homogeneity in cognitive processing and gender, while others find an age-related increase in heterogeneity (Kryspin-Exner, Lamplmayr, & Felnhofer, 2011). Literature on aging and gender differences in emotion processing is even sparser than on age and gender differences in cognitive aging, with results tending slightly in the direction of less gender differences in older adults in emotion processing and a generally stronger focus on positive emotions (Mather & Carstensen, 2005). As evidence on age and gender differences in both cognitive and emotion processing is rare and contradictory, it is impossible to predict in what direction the gender differences will tend when comparing young to older adults; however, evidence is large enough (cf. (Kryspin-Exner, et al., 2011)) to expect significant effects.

Correlating each participants' overall behaviour with measures of risk preferences, we observe that the more risk seeking a participant is on the Holt and Laury risk elicitation task, the more likely he is to directly bet on the BUDA. The effect goes in the other direction for delegation; the more risk averse a participant, the more likely he delegates. For advice seeking, we cannot conclude at a significant correlation between this risk preference measure and choice behaviour. Assuming stable preferences, it is not surprising to find correlations between two different uncertainty measures (it would be rather surprising not to). As a direct bet is by far the most uncertainty seeking behaviour in the BUDA, the more risk seeking a participant is on the Holt and Laury lottery, the more risk seeking he is on the BUDA (thus the more often he chooses the direct bet). The opposite effect is observed for delegation; the more risk averse a participant, the more he delegates. It may be questioned then, why advice seeking and risk preference on the risk elicitation task do not, or only extremely weakly, correlate. One possible explanation may be domain specificity.

When it comes to domain specific risk measures, we observe that risk preference in the occupation and career domain correlates with delegation and advice. The more risk seeking a person is on this domain, the more likely he seeks for advice; the correlation goes in the opposite direction for delegation. It seems, thus, that advice seeking correlates with a different risk domain than is measured by the Holt and Laury measure. Unfortunately, extensively interpreting these correlations is not yet possible, as the number of observations is too small to reach clear conclusions. We are aware that with the small sample size, type 2 error risk is relatively high. If taking the correlation of delegation with occupational risk taking as a benchmark for effect size, in future studies a minimum of 52 participants will be needed to achieve a power of .80 with an $\alpha$ level of .05. Nevertheless, the observed tendencies in the correlations seem to bear interesting results for management research.

We were also interested in the reaction of the judge if the responsibility is turned back to him by the advisor, thus when the advisor decides not to give an advice. We expected that in case of responsibility shift, the judge decided more frequently to take a sure amount of money. In the current study, the number of observations is too low to draw conclusions on behaviour; in a total of 33 advice choices, six times the responsibility was shifted back. Three times, judges decided following this advice to take the sure amount, thus we observe a frequency of 50% sure amounts following the

“I don’t know” advice. In the other, informative, advice trials, the sure amount was chosen in 25.93% of the trials, thus almost half as often as when responsibility was shifted back. Even though purely descriptive, this result is in line with our hypotheses. Responsibility is a factor that is associated with strong emotions (Schoeman, 1987), and advice is in part sought to share the responsibility (Gary Charness, 2000; Harvey & Fischer, 1997). Hence if the responsibility is shifted back to the judge, the emotional load that the judge wanted to alleviate is returned back to him, which might be a stressful event, leading to the choice of the sure option. Older adults are more experienced in emotion regulation and in maintaining a positive emotional state (Mather and Carstensen, 2005), which might enhance coping with the situation when responsibility is shifted back. On the other hand, there is evidence that older adults have a preference to avoid responsibility (Finucane et al., 2002). This may lead older adults to choose more often the sure option than young adults would do. In both cases, we would expect age-related differences in reaction to this responsibility shift, but with opposite results. Only empirical testing can reveal which effect takes the lead.

When developing the BUDA, we had two aims. First, we wanted to create a research framework to study advice taking and delegation in uncertain decisions. Second, our aim was to create a task that can be easily implemented in ageing research (but also in other fields, like e.g. management research), and that at the same time is general enough to allow for further sophistications. In the current study, we reached both goals. Not only the BUDA has been validated and the observed effects have been connected to a broad literature of gerontological research. Also, we are confident that the task can easily be extended and adapted to further research questions. Some ideas of easy to implement modifications that can be made to the task include judges that may choose the expert based on various factors (such as gender, age group, level of information, game experience, risk preferences, etc.), varying prices for the advice, adding confidence intervals about the advice, multiple advisors, framing conditions (e.g., gain and loss frames), and social interactions prior to the game. In the next, most important step, the task will be administrated to a larger subject pool consisting of young and older adults. We aim at confirming our hypotheses on age differences, and with the increased subject pool at reducing the risk of type I and II error and at collecting supplementary data to investigate more robustly the responsibility shift condition.

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# Conclusion

The current thesis had one central aim: contributing to the understanding of age differences in decision making under uncertainty. Three studies were dedicated to investigate age differences in uncertain decisions in individual contexts. A fourth study aimed at developing a framework for the study of age differences in uncertain decisions with a social dimension.

In the first study, we have shown the existence of age differences in ambiguous decisions, but not in risky decisions. More specifically, we can show that young adults are more ambiguity averse than older adults, and that young adults are more ambiguity than risk averse, whereas no such effect appears in older adults.

In the second study, I could reproduce the results of the first study. Further, I provide the first direct experimental evidence that whereas no age differences appear for risky decisions with a priori probabilities, there are age differences when it comes to risky decisions with statistical probabilities, with older adults being more risk averse than young adults. I also have shown that feedback on decision outcomes increases risk- and ambiguity seeking in both young and older adults, even if this feedback cannot help predicting future decision outcomes. Finally, I also have shown that the level of education may counteract age effects on decision making.

The aim of the third study was to investigate the link between age differences in decision making under uncertainty and age differences in its underlying brain mechanisms. Unlike in the two precedent studies, we do observe a higher level of risk aversion in older adults than in young adults, and no age difference in ambiguity aversion. However we still reproduce the finding that whereas young adults are more ambiguity- than risk-averse, no difference appears in older adults. Within the brain, we observe clear age differences in brain regions responsible for different mechanisms involved in uncertainty processing. We also observe an age group x uncertainty condition interaction effect in connectivity between two brain regions.

In the fourth study, we have developed a framework for studying decision making under uncertainty with the possibility to delegate the decision to an expert, or to seek an advice from that expert. We developed a computerized task to investigate these decisions. In this task, it appears that decision makers valuate their own information much higher than the experts' information. The level of uncertainty of the task has an effect on the decision whether to consult the expert or whether to make a decision that does not involve the expert. We also observe gender differences on the task, with male participants choosing more often to seek an advice or to delegate the decision than female participants. Choice behavior on this task also correlates with the risk preferences of the decision maker. Based on the literature on aging and delegation or advice, we make predictions about the results we might expect when administrating the task to an older population.

In a greying society, understanding the influences of age on decision making becomes increasingly important. In fact, with increasing life expectancy, it is likely that retirement age will increase, and that people need to work and make decisions until a higher age. Many everyday life decisions involve some amount of uncertainty, and understanding how age affects these decisions can contribute to the conservation and improvement of older adults' of decision making abilities. The aim of this thesis was to contribute to the understanding of age effects on uncertain decisions.

Contrary to the common stereotypes of older adults being generally more uncertainty averse than young adults, I could show throughout this thesis that various factors influence whether young and older adults differ with respect to decision making under uncertainty. It appears for example that the type of uncertainty involved in the decision has an impact on whether age differences appear, and that whereas young adults behave differently under risk and under ambiguity, older adults do not make a difference and have similar risk and ambiguity preferences. Hence, in everyday life decisions where one might expect people to behave differently if a problem is framed as risky or as ambiguous, our results point in the direction of older adults not differentiating between risk and ambiguity and behaving similarly in both frames. Furthermore, in two of the three experiments comparing young to older adults, we have shown that older adults are less ambiguity averse than young adults. These findings can for example be beneficial in work settings where a low level of ambiguity aversion is required, or where it is preferable if decision makers behave similarly under risk and ambiguity.

In risky decisions, the type of risk in the decision plays a role too. If probabilities of winning or losing in a decision are explicitly shown to older adults, it is likely that no age differences in decision making will appear. If however older adults need to learn from experience about the riskiness of a choice, one might expect older adults to be more risk averse than young adults would be. We also have shown that the learning requirements are not the underlying factor of this effect. Rather it seems that young adults are less "careful" and rather use strategies that allow making many decisions in a short amount of time. Hence one possibility to minimize age differences in risky decisions is to make the probabilities as explicit as possible. Another possibility might be (in conditions where a higher risk aversion is disadvantageous) to act on older adults' decision strategies, and teach them to use younger adults' strategies.

Two additional factors that have been shown in this thesis to influence uncertainty preferences are feedback and education. Feedback per se acts by reducing subjective uncertainty of the decision, even if it does not influence the objective uncertainty. Therefore, providing feedback on decisions decreases the uncertainty aversion of the decision maker, and led in our experiment to a higher amount of bets. Hence, if a reduced uncertainty aversion of the decision makers is beneficial for the decision outcome, feedback can be used both in young and in older adults to reduce their uncertainty aversion. Education also has, at least in self-reported risk preferences, an effect on uncertainty preferences; the more years of education, the less risk averse the decision maker. Further, the level of education of the decision maker counteracts the age effects in self-reported risk preference; whereas age increases risk aversion, education decreases it.

Besides describing behavioral age differences, we also looked at the processes underlying these differences. When understanding the underlying processes, influencing behavior gets much easier. We therefore investigated brain mechanisms underlying age differences in decision making under uncertainty. We observed that brain regions involved in various processes important in decision making under uncertainty, such as risk and value processing, and cognitive and emotion processing, show age differences. This suggests that the processes underlying age differences in decision making change with age. It is at this point however not trivial to draw strict conclusions on how the age differences in brain functioning influence behavior. In fact, this study was the first at investigating age differences in brain mechanisms not only under risk but also under ambiguity, and further research will be needed to clarify how exactly the effects observed in the brain relate to behavior. What we can tell at this point is that various processes are underlying the age differences in behavior, and that not only age differences in overall brain activation appear, but also that the way the brain regions connect to each other changes.

One of the potential downsides of the studies on age differences performed within this thesis is the impossibility to rule out cohort effects. That is, to account for cohort effects and the most accurately describe development of the observed effects, one would need to observe the same subjects over a prolonged time (in the best case over the entire lifespan). However, besides the non-feasibility of such an effort within a Ph.D. project, our societies are rapidly getting older, and there is an immediate need to describe and understand age differences in decision making behavior. How these differences develop certainly is also an interesting question, but at the moment, describing the age differences and understanding their underlying processes is a more urgent question.

The aim of the last study of this thesis was to develop a framework for the study of decision making under uncertainty with the possibility to seek an advice or to delegate a decision. In fact, research results point in the direction of age differences in both, delegation and advice. We developed a novel task which we validated with a small sample of young participants, and reviewed the literature relating to age differences that might be expected on the task. The next step will be to administrate the task to a group of older participants and to increase the size of the young sample to test whether our hypotheses about age differences in decision making with delegation and advice hold. As the task is general enough to allow for various sophistications, we expect it to be a first building block in a larger series of studies.

In summary, throughout this thesis we observed age differences in decision making under uncertainty in a number of different settings. As the age effects not always appear in the way intuition predicts, one should always in a first step think of the type of uncertainty and the mechanisms involved in the decision, and not just start from a deficit perspective in decision making when dealing with older adults. Many questions about the nature of the age differences in decision making have been answered, and future work will contribute to a full understanding of the processes that lead to age differences in decision making.

ALFRED-
WEBER-
INSTITUT

## Check-up Sheet

Dear Madam! Dear Sir!

In preparation of the experiment, we kindly request you to read attentively the following pages and to answer the contained questions with accuracy. The exact acquisition of these data is of great importance for the accomplishment of our study.
The appraisal of the data happens anonymously and exclusively with a scientific purpose. To guarantee your anonymity, we kindly ask you to answer the following questions and to write the resulting code on each sheet of the questionnaires.

| | **Code** |
|---|---|
| Third letter of the forename of your mother: …........................................ | _ |
| Third letter of the family name of your mother: ........................................ | _ |
| Day of birth of your father (e.g., 17): ........................................................ | _ _ |
| Second letter of your forename: ………………................................................ | _ |

*Was the name of your mother for example Pe**t**ra Mü**l**ler, the day of birth of your father the **03**.09.1900 and you forename P**e**ter, your code would be* **TL03E**.

**The results of the questionnaire naturally are subject to professional secrecy.** A transfer of your data to third party will not take place.

Thank you for your collaboration!

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## Questionnaire

**About this questionnaire:**

Please try to answer as many questions as possible. If you do not know the answer to a question or if you prefer not to respond, skip it and go on with the next one.

**General:**

Code: _ _ _ _ _

Date of birth: …………………….. Gender: ○ female ○ male

Mother tongue: …………………….. Nationality: …………………

Marital status:

○ single/single parent ○ divorced ○ stable relationship

○ living apart ○ married ○ widowed

Number of children: …...

**Occupation/Formation:**

*Highest graduation:*

○ Abitur/Fachabitur ○ Realschule/Mittlere Reife

○ Volks-/Hauptschule ○ special school ○ no graduation

How many years did you go to school until graduation? ………

*Formation:*

○ academic ○ still in formation ○ Meister/Fachschule

○ special school ○ no formal formation

○ apprenticeship

Formal formation: ………………………………………….

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*Occupation (or last occupation):*

○ Worker/employee ○ unemployed ○ self-employed

○ unable to work ○ active in household ○ other

○ in formation (also studies or retraining)

*Labour time (or labour time of last occupation):*

○ full-time ○ part-time (less than half-day)

○ half-day ○ not employed

(Last) Profession: ……………………………………………………

*Computer knowledge:*

How often do you use a computer?

○ every day ○ several times a week ○ once weekly

○ several times a month ○ once a month

**Health:**

*Vision:*

Do you have eye diseases? YES NO

If yes, which? …………………………………………………….

Amblyopia:

○ myopia ○ far-sighted ○ none

Do you wear eyeglasses or lenses? YES NO

Do you have past or present **psychiatric disorders**?

○ No ○ anxiety disorder ○ OCDs

○ eating disorder ○ affective disorder (depression, mania, bipolar)

○ schizophrenia ○ substance abuse/dependency

○ other: …………………………………

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Do you have past or present **neurological affections**?

○ No

○ brain trauma; when? …………………………………………………

○ stroke; when? ……………………………………………………..

○ encephalitis; when? …………………………………………………

○ migraine; when? ……………………….……………………………

○ epilepsy; when? ………………..……………………………………

○ brain tumor; when? …………………………………………………

○ multiple sclerosis; when? …………..…………………………………

○ other; when? ……………………….……………………………...

Do you have any **chronic or current diseases or physical impairments**?

○ Yes …………………………..……………………………...

Do you take **drugs** on a regular basis (e.g., contraceptives)? YES NO

Have you taken any drugs today? YES NO

Drug(s): ……………………………………………………………

**Handedness:**

Is the mobility of your hands or fingers impaired? YES NO

Are you relearned right hander? YES NO

Are you left hander (L), right hander (R) or ambidextrous (A)? ○L ○R ○A

# Instructions:

In the current game, you are requested to resolve decision problems. You are getting paid for two of the decisions chosen at random. Your possible gain is presented to you on the screen in experimental credit units (ECU). 10 ECU correspond to 1€ – at the end of the experiment, the ECU will be converted into euro. If you have won for example 70 ECU, your payment would be 7€.

In the current game, card decks will be presented to you. These card decks always contain some amount of red and of blue cards. In some situations, the exact amount of red and blue cards in the deck is revealed to you, in other situations, you only will know the total amount of cards in the deck.

In the game, you have always the choice either to bet that a certain colour will be drawn out of the deck, or to receive a sure amount of money. If you bet, you will receive the indicated amount of ECU if the colour you chose is drawn; otherwise you don't receive anything. If you choose the certain amount, you will get the amount automatically, without any influence of the drawn card colour on your gain.

Prior to the game, you will have the possibility to get familiar with the task on two examples.

The amount which you will be paid within each trial will be presented to you on the computer screen during the experiment.

If you have questions, please raise your hand. One of the experimenters will come to your table and answer the question privately.

| Condition | Nr. | Red | Blue | Total | ECU bet | ECU certain |
|---|---|---|---|---|---|---|
| Risk | 1 | 2 | 18 | 20 | 12 | 8 |
| | 2 | 18 | 12 | 30 | 16 | 12 |
| | 3 | 9 | 1 | 10 | 19 | 12 |
| | 4 | 3 | 9 | 12 | 16 | 13 |
| | 5 | 3 | 12 | 15 | 20 | 10 |
| | 6 | 21 | 9 | 30 | 20 | 15 |
| | 7 | 8 | 32 | 40 | 16 | 10 |
| | 8 | 5 | 10 | 15 | 12 | 8 |
| | 9 | 6 | 14 | 20 | 18 | 12 |
| | 10 | 16 | 24 | 40 | 16 | 8 |
| | 11 | 4 | 36 | 40 | 20 | 14 |
| | 12 | 18 | 9 | 27 | 15 | 10 |
| | 13 | 26 | 13 | 39 | 12 | 8 |
| | 14 | 10 | 20 | 30 | 12 | 10 |
| | 15 | 3 | 2 | 5 | 18 | 12 |
| | 16 | 27 | 3 | 30 | 14 | 11 |
| | 17 | 12 | 28 | 40 | 16 | 14 |
| | 18 | 4 | 1 | 5 | 14 | 8 |
| | 19 | 8 | 12 | 20 | 18 | 9 |
| | 20 | 7 | 21 | 28 | 12 | 8 |
| | 21 | 24 | 8 | 32 | 19 | 13 |
| | 22 | 8 | 2 | 10 | 16 | 10 |
| | 23 | 7 | 3 | 10 | 13 | 10 |
| | 24 | 15 | 5 | 20 | 12 | 6 |
| Ambiguity | 1 | | | 20 | 20 | 10 |
| | 2 | | | 10 | 16 | 7 |
| | 3 | | | 40 | 20 | 12 |
| | 4 | | | 30 | 13 | 7 |
| | 5 | | | 40 | 17 | 7 |
| | 6 | | | 30 | 18 | 6 |
| | 7 | | | 20 | 20 | 11 |
| | 8 | | | 30 | 12 | 7 |
| | 9 | | | 15 | 20 | 12 |
| | 10 | | | 30 | 20 | 12 |
| | 11 | | | 12 | 19 | 6 |
| | 12 | | | 15 | 16 | 7 |
| | 13 | | | 40 | 14 | 8 |
| | 14 | | | 28 | 18 | 8 |
| | 15 | | | 40 | 20 | 11 |
| | 16 | | | 10 | 16 | 9 |
| | 17 | | | 32 | 19 | 9 |
| | 18 | | | 39 | 16 | 6 |
| | 19 | | | 10 | 20 | 11 |
| | 20 | | | 27 | 20 | 8 |
| | 21 | | | 5 | 17 | 8 |
| | 22 | | | 20 | 12 | 5 |
| | 23 | | | 5 | 18 | 11 |
| | 24 | | | 20 | 16 | 6 |

## BART: text on the instructions screen

Now you're going to see 20 balloons, one after another, on the screen. For each balloon, you will use the mouse to click on the button that will pump up the balloon. Each click on the mouse pumps the balloon up a little more.

BUT remember, balloons pop if you pump them up too much. It is up to you to decide how much to pump up each balloon. Some of these balloons might pop after just one pump. Others might not pop until they fill the whole screen.

You get MONEY for every pump. Each pump earns 0.05 ECU. But if a balloon pops, you lose the money you earned on that balloon. To keep the money from a balloon, stop pumping before it pops and click on the button labeled "Collect €€€".

After each time you collect €€€ or pop a balloon, a new balloon will appear.

At the end of the experiment, you will be paid the amount earned on the game.

Click the left mouse button to see the summary.

## BART: text on the summary screen

You make 0.05 ECU for each pump.

You save the money from a balloon when you click "Collect €€€".

You lose money from a balloon when it pops.

There are just 20 balloons.

You will be paid the exact amount you earned on the game.

Now, do you have any questions?

Click the left mouse button to begin.

# Instructions Game 1

Dear participant,

in the current experiment, you will play individually with another randomly assigned player in this room. You will be either player 1 or player 2. You will not find out with whom you played, neither before, nor after the study. You will play the game for 20 rounds. During the entire experiment, you will stay player 1 or player 2. Each round, you will be randomly assigned anew to another player. The aim of the game is to predict the colour of a ball that will be drawn out of an urn filled with red and blue balls in each round.

The maximum amount a player can earn per round is 3€. At the end of the game, two rounds will be chosen at random and played. The gain will be paid out to you. All participants received the same instructions as you.

**Course of the game:**

There is an urn containing a certain amount of red and blue balls. How many balls are in the urn changes with every round. The proportion of red and blue balls also changes every round.

*Example: The urn contains 50 balls. You do however not know how many balls of which colour are in the urn.*

In a first step, a number of balls will be drawn of the urn. This number of balls is smaller than the total amount of balls in the urn. In the game, this number is called D1.

*Example: The draw D1 contains 18 balls.*

In the next step, all balls are put back into the urn. Then, a second draw of the urn happens: D2. The number of balls in D2 is always at least one more than in D1, with a maximum of the total amount of balls in the urn.

*Example: The draw D2 contains 39 balls.*

Then, the result of D1 is revealed to player 1.

*Example: The urn contains 50 balls. In D1, 18 balls have been drawn. Thereof, 9 balls are blue and 9 balls are red.*

Player 1 now has the choice between 3 alternatives:

1. Player 1 can directly bet on a colour.
2. Player 1 can delegate the decision on which colour to bet to player 2.
3. Player 1 can ask player 2 for advice. This advice costs ten cents, which will be credited to player 2.

In the next step, D2 is revealed to player 2.

*Example: The urn contains 50 balls. In D2, 39 balls have been drawn. Thereof, 18 balls are blue and 11 balls are red.*

Player 2 now reacts to player 1's choice:

1. Player 1 bet directly on a colour: Player 2 bets directly on a colour.
   *Example: Player 2 bets on blue.*
2. Player 1 decided to delegate: Player 2 decides for himself and for player 1.
   *Example: Player 2 bets on blue.*

3. Player 1 asked for advice: Player 2 can advise the following to player 1:
    a. Player 2 advises player 1 to bet on blue.
    b. Player 2 advises player 1 to bet on red.
    c. Player 2 decides not to give an advice to player 1.

In the first and second case, the round ends with the decision of player 2. In the third case, player 1 needs to react to the advice of player 2. In that case, the gain of player 2 depends on the decision of player 1. Player 1 has the choice:

1. to bet on red,
2. to bet on blue,
3. to receive a sure amount of 50 cents (minus the 10 cents cost for the advice).

Afterwards, the next round starts. All rounds of the game are build up the same way.

Important: Nor does player 1 know the result of D2, neither does player 2 know the result of D1. Both players only know the result of their own draw.

At the end of the game two computer-drawn rounds are played out. Within each round of the game, you will not know whether you won or lost.

**Payment rules:**

In case player 1 decided to directly bet: player 1 receives 3€ in case he bet on the drawn colour. The same applies for player 2. If a player bet on a colour that has not been drawn, he receives 0€.

In case player 1 decided to delegate: player 1 and player 2 receive 3€ in case player 2 bet on the colour that has been drawn. If player 2 bet on the colour that has not been drawn, both players receive 0€.

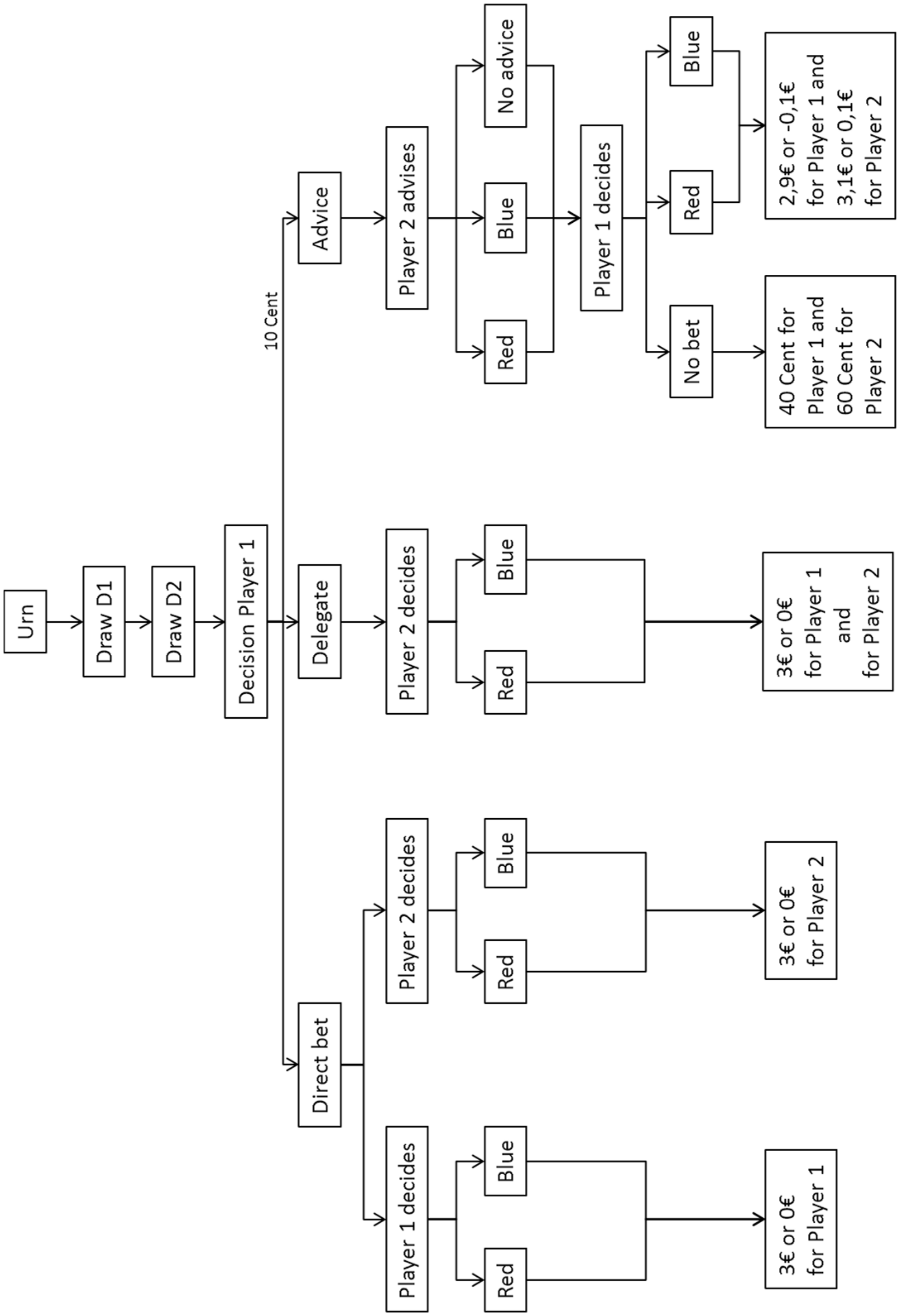
In case player 1 decides to seek an advice: player 1 pays 10 cents for the advice.

1. If player 1 decides, after the reception of the advice, to bet, and he wins the bet, he earns 3.00-0.10 = 2.90€.
2. If player 1 does not win the bet, he earns 0.00-0.10 = -0.10€.
3. If player 1 decides not to bet, he earns 0.50-0.10 = 0.40€.

The gain of player 2 is in this case dependent on player 1's decision.

4. If player 1 decides to bet and wins, player 2 receives 3.00+0.10 = 3.10€.
5. If player 1 loses the bet, player 2 receives 0.00+0.10 = 0.10€.
6. If player 1 decides not to bet, player 2 receives 0.50+0.10 = 0.60€.

On the next sheet, you'll find a summary of one round of the game. Use this as an aid!



Urn
Draw D1
Draw D2
Decision Player 1
10 Cent
Advice
Player 2 advises
Red
Blue
No advice
Player 1 decides
No bet
Red
Blue
40 Cent for Player 1 and 60 Cent for Player 2
2,9€ or -0,1€ for Player 1 and 3,1€ or 0,1€ for Player 2
Delegate
Player 2 decides
Red
Blue
3€ or 0€ for Player 1 and for Player 2
Direct bet
Player 2 decides
Red
Blue
3€ or 0€ for Player 2
Player 1 decides
Red
Blue
3€ or 0€ for Player 1