1 Introduction

Everybody wants to grow old, but nobody wants to be old and over the hill. Although old age is often associated with wisdom and having valuable life experience, being old also comes with challenges. According to the World Health Organization, 22% of the world’s population will be 60 years or older by 2050 (World Health Organization, 2018a). When people grow older, not only their physical appearance changes, but also their brain (e.g., Fjell & Walhovd, 2010; Jansen et al., 2015; Raz et al., 2005). In turn, these age-related changes in the brain have been associated with declines in cognitive functioning, such as memory performance (e.g., Rodrigue & Raz, 2004; Walhovd et al., 2004) or the speed at which information can be processed (e.g., Gunning-Dixon & Raz, 2000). As more and more people will have to deal with the effects of being old, increasing our knowledge of the cognitive consequences of aging is an urgent matter. In the context of aging research, much attention has been paid to age-related diseases, such as dementia. This is important, as dementia has been marked as the number three cause of death in high-income countries (World Health Organization, 2018b). However, to enable improvement of diagnosis and treatment for patients who suffer from neurodegenerative diseases we need to have a proper baseline. In other words, in order to know when cognitive difficulties mark the onset of a disease, we need to gain insight in how the healthy elderly mind functions. One of the important functions of the human mind is that it enables people to use language to communicate with each other. Many studies have investigated changes in elderly adults’ domain-general cognitive functions. However, much less is known about the way in which the specific cognitive function of language typically changes in elderly adults. Therefore, the present thesis investigates the effects of age-related cognitive decline on language abilities in healthy aging adults.

1.1 Cognitive aging

In many studies cognitive capacities have been shown to decline with age. Most of the findings on cognitive aging come from adults from the age of 60 and older, but some studies suggest that cognitive decline already starts around the age of 45 (e.g., Singh-Manoux et al., 2012), or even earlier, around the age of 25 (e.g., Salthouse, 2009; Thompson, Blair, & Henrey, 2014). A typical example of age-related cognitive decline is that elderly adults are generally found to be slower in their processing of information (e.g., Kail & Salthouse, 1994; Salthouse, 1996, 2000). For example, when elderly adults are asked to compare strings of letters, they need more time to decide whether the letters are the same or different (Salthouse, 1994). However, the majority of studies on cognitive aging focuses on decline in so-called executive functions, a set of high-level cognitive skills that enable planning and control of thoughts and behaviors. Two important aspects of executive functions are working
memory and inhibition (e.g., Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000). Working memory refers to an individual’s ability to remember and manipulate information so that it can be used in subsequent actions. Inhibition is a collective term for the set of abilities that allow individuals to suppress responses or stimuli that interfere with thinking or goal-directed behavior (e.g., Friedman & Miyake, 2004). In elderly adults, decline in working memory capacity has been found to limit the number of words or digits that they can recall in a row (e.g., Bopp & Verhaeghen, 2005; Hultsch, Hertzog, Small, McDonald-Miszczak, & Dixon, 1992; Park et al., 2002). Age-related decline in inhibition, on the other hand, hampers elderly adults’ ability to suppress active information that is no longer relevant (Hasher, Quig, & May, 1997; Hasher & Zacks, 1988; Van Hooren et al., 2007).

Thus, based on the multitude of studies on cognitive aging, we know that cognitive abilities decline with age, even in the absence of neurodegenerative diseases. The question is how this decline in healthy elderly adults’ general cognitive capacities affects one of the most important specialized functions of the brain: language.

1.2 Language and cognitive aging

When it comes to language abilities, increased age can be both an advantage and a disadvantage. On the one hand, elderly adults have more knowledge than young adults. For example, elderly adults generally know more words than young adults (e.g., Brysbaert, Stevens, Mandera, & Keuleers, 2016; Verhaeghen, 2003). Because of their larger verbal knowledge elderly adults have more words and more sentence constructions available to express their thoughts and to help them interpret other people’s verbalized thoughts. In this way, the increase in elderly adults’ verbal knowledge could create a buffer against the effects of cognitive aging. However, although elderly adults’ language abilities may be protected by the large amount of linguistic knowledge that they have acquired over the years, the potential beneficial effect of increased knowledge may be cancelled by the detrimental effects of increased age on language skills, due to the decline in elderly adults’ cognitive abilities (Baum & Titone, 2014).

The hypothesis of a relationship between age-related cognitive decline and language abilities is motivated by the finding that in young adults, the ability to successfully process and comprehend language is closely related to their domain-general cognitive abilities. More precisely, it has been suggested that the connection between language and cognition is driven by the dependency of language abilities on executive functions. In particular working memory and inhibition have been found to play an important role in successful language processing and comprehension in young adults. A large working memory capacity supports young adults’ reading comprehension by allowing them, for example, to remember the contents of a text or to resolve pronouns such as he or she on the basis of the
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preceding linguistic discourse (e.g., Daneman & Carpenter, 1980; Palladino, Cornoldi, De Beni, & Pazzaglia, 2001). Furthermore, young adults’ working memory helps them to predict upcoming words in the sentence (e.g., Huettig & Janse, 2016) and supports their ability to process grammatically complex sentences, such as ‘The cardiologist who the physician consulted checked the files in the office’ (e.g., Fedorenko, Gibson, & Rohde, 2006; Vos, Gunter, Schriefers, & Friederici, 2001). Together with working memory capacity, young adults’ inhibition skills have been shown to be important in the efficient processing of ambiguous words and sentences (e.g., Gadsby, Arnott, & Copland, 2008; Gunter, Wagner, & Friederici, 2003; Hoenig & Scheef, 2009; Salisbury, 2004). Take for example the word organ, which can refer both to an organ in the human body or a musical instrument similar to a piano. Similarly, a sentence such as ‘Clean the pig with the leaf’ (e.g., Hsu & Novick, 2016; January, Trueswell, & Thompson-Schill, 2009) can refer to the action of cleaning the pig that is holding a leaf or cleaning the pig by using the leaf as a cleaning instrument. In both cases, readers require sufficient cognitive resources to resolve the ambiguity. Given the tight link between executive functions, such as working memory and inhibition, and language processing in young adults, age-related decline in executive functions is expected to negatively affect elderly adults’ ability to successfully process and comprehend language.

1.3 Idiom processing

To investigate the extent to which age-related decline affects healthy elderly adults’ language abilities, we focus on a type of language that is expected to particularly depend on executive functions, namely idioms. Idioms are short, figurative expressions, such as the Dutch expression tegen de lamp lopen (word-by-word translated as ‘against the lamp walk’) that make up an important part of everyday conversations (e.g., Jackendoff, 1995). A special feature of idioms is that they are ambiguous between a literal, compositional meaning (‘to walk against the lamp’) and a figurative meaning (‘to get caught’). Yet, the literal meanings of the words forming the idiom (i.e., the idiom constituents, ‘to walk’ and ‘the lamp’) are often irrelevant to the figurative meaning of the idiom as a whole (Weinreich, 1969). This property has led researchers to debate the role of literal meaning in idiom processing. Early accounts of idiom processing state that the idiom’s figurative meaning is retrieved directly without activation of the literal meanings of the idiom constituents (Bobrow & Bell, 1973; Gibbs, 1980), thus viewing an idiom as one long and complex word. However, more recent idiom models state that literal word meanings are also activated during idiom processing (Cacciari & Tabossi, 1988; Laurent, Denhières, Passerieux, Iakimova, & Hardy-Baylé, 2006; Libben & Titone, 2008; Sprenger, Levelt, & Kempen, 2006; Swinney & Cutler, 1979). These latter models are supported by empirical findings on idiom processing in young adults, which indicate that they show priming for target words that are related to the literal
meaning of an idiom constituent (e.g., Beck & Weber, 2016; Cacciari & Tabossi, 1988; Holsinger & Kaiser, 2013; Kessler, Weber, & Friedrich, 2020; Konopka & Bock, 2009; Peterson, Dell, Burgess, & Eberhard, 2001; Sprenger et al., 2006; Swinney & Cutler, 1979; Titone & Connine, 1994, 1999). As the literal meanings of idiom constituents are often unrelated to the idiom’s intended figurative meaning, readers or listeners will have to suppress them to avoid interpretation difficulties further down the processing stream. In other words, idiom processing requires the resolution of ambiguity between an idiom’s figurative meaning and its literal, compositional meaning. It is this ambiguity that makes idiom processing relevant to study in the context of healthy aging.

In young adults, the processing of ambiguity has been found to depend on inhibition skills (e.g., Gunter et al., 2003; Hoenig & Scheef, 2009; January et al., 2009; Mason & Just, 2007; Zempleni, Renken, Hoeks, Hoogduin, & Stowe, 2007), likely because selecting the meaning of a particular word or sentence out of multiple options requires the inhibition of the irrelevant interpretations. Similar to the processing and comprehension of ambiguous words, the processing and comprehension of idioms has also been shown to depend on executive functions such as working memory and inhibition (Cacciari, Corradini, & Ferlazzo, 2018; Galinsky & Glucksberg, 2000). These findings are in line with the idea that idiom processing involves the suppression of the irrelevant, literal meaning.

Just as strong inhibition skills support the processing of ambiguity in young adults, elderly adults with reduced inhibition skills find it more difficult to process ambiguous words or phrases. (e.g., Lee & Federmeier, 2012; Meyer & Federmeier, 2010; Morrone, Declercq, Novella, & Besche, 2010; Stites, Federmeier, & Stine-Morrow, 2013). Thus, it is conceivable that the ability to quickly suppress the literal meanings of idiom constituents during idiom processing decreases with age. This may lead to potential difficulties in communication if idioms are misinterpreted or if the idiom’s figurative meaning cannot be retrieved fast enough to be able to integrate this meaning during the processing of the remainder of the sentence or discourse.

In sum, given the fact that successful idiom processing and comprehension depend on executive functions, idioms provide the ideal testing ground for investigating how age-related decline in these executive functions affects elderly adults’ language abilities.

1.4 Thesis chapter outline

The main research question of this thesis is: How does cognitive aging affect language abilities in healthy aging adults? To clarify the effects of age-related cognitive decline on elderly adults’ language abilities, four empirical studies are conducted that each approach the main research question from a different angle.
These studies do not only investigate whether and how idiom processing changes due to cognitive aging, but also aim to provide insight in when these changes occur, both as a function of increasing age and during the time course of a sentence. Below, each chapter is discussed in terms of the specific research question that is investigated and the methodology that is used to answer it.

First, **Chapter 2** investigates whether and how Dutch-speaking young (aged 18-30 years) and elderly adults (aged 60-75 years) differ in the way in which they use context information when reading an idiom. To answer this question, we measure event-related potentials during reading. The high temporal precision of ERPs enables us to investigate the processes that underly readers’ interpretation of a sentence. Additionally, the different ERP components within the overall brain signal provide insights in the different stages of sentence processing, such as lexical retrieval and integration. Regarding the use of context in language processing, previous studies have shown that elderly adults are less able than young adults to retain context information and use it to facilitate sentence processing by predicting and pre-activating upcoming words (e.g., Dagerman, MacDonald, & Harm, 2006; Federmeier, McLennan, de Ochoa, & Kutas, 2002; Federmeier, Schwartz, Van Petten, & Kutas, 2003; Federmeier & Kutas, 2005; Payne & Silcox, 2019). Therefore, we expect that elderly adults will be less able than young adults to benefit from contextual information when processing idioms. Our findings show a difference between young and elderly adults’ use of context in language processing, but not when processing idioms, but instead when processing literal sentences. We discuss how this unexpected finding can be explained.

**Chapter 3** describes a follow-up study to the study presented in Chapter 2. This study puts the spotlight on the phase of old age (60 to 75 years) itself and investigates whether in healthy elderly adults linguistic processing abilities show age-related changes across a time period of several years. To this end, the same group of elderly participants who also participated in the study described in Chapter 2 was tested again after three years. Between the age of 60-65, cognitive functions are known to decline more rapidly (e.g., Hatta et al., 2020; Hultsch et al., 1992; Schaie, 2013). This study investigates whether elderly adults’ ability to benefit from context information in the processing of literal and idiomatic sentences has decreased during the three years between the two test sessions. Thus, the study may shed light on the slope of potential decline in elderly adults’ language abilities, while accounting for individual differences that may influence results in cross-sectional designs. The findings of this study suggest that the age-related decline of language abilities progresses at a slow pace. Furthermore, the findings suggest that language experience can compensate for the effects of cognitive aging on language abilities.

**Chapter 4** presents an event-related potential study that examines how the suppression of literal word meanings in Dutch idiom processing changes across the adult lifespan. Instead of comparing a group of young adults with a group of elderly adults with respect to their language processing abilities, this study investigates
adults from a broad age range between 20 and 80 years old. By using age as a continuous factor, we do not only gain insight in whether age-related changes take place in idiom processing, but also when these changes start to occur across the adult lifespan. We record the event-related potentials of Dutch native speakers while they read idiom sentences that are presented in two word orders (SVO and SOV, both of which are possible in Dutch). The event-related potentials are recorded in response to the target word that was an object (O) and that was either the idiom’s final noun (e.g., lamp ‘lamp’, for to walk against the lamp or to get caught), a word that is semantically related to the literal meaning of the idiom’s final noun (e.g., kaars ‘candle’), or a semantically unrelated word (e.g., vis ‘fish’). By varying the word order in the idiom sentences, the target word is either presented before or after the idiom verb. As a result, the degree of idiom activation at the target word, and therefore the degree of inhibition of literal word meanings, varies with sentence order. The findings of this study show that idiom processing changes across the adult lifespan and that changes already start to occur from the age of 40 onwards.

Chapter 5 discusses a study that uses a visual-world eye-tracking paradigm (e.g., Cooper, 1974; Tanenhaus et al., 1995) to investigate the effects of cognitive aging on the time course of activating an idiom’s figurative meaning relative to its literal meaning while processing the sentence. When do young and elderly adults switch from processing an idiom’s literal meaning to its figurative interpretation? In the experiment, young (aged 18-30 years) and elderly adults (aged 55-75 years) listen to idioms that they have to match to one of two pictures presented on a computer screen: one showing the figurative meaning and the other showing another meaning. The use of eye-tracking allows us to determine the exact moment in the sentence at which participants switch from one interpretation of the idiom to the other. We expect both young and elderly adults to show initial activation of the idiom’s literal meaning, and to subsequently switch to the idiom’s figurative meaning. However, we expect elderly adults to be delayed in their ability to inhibit the literal meaning, possibly because of their reduced inhibition skills (Hasher et al., 1997; Hasher & Zacks, 1988; Van Hooren et al., 2007). Indeed, we found that elderly adults are slower in activating an idiom’s figurative meaning over its literal interpretation. This delay in literal meaning inhibition may lead to difficulties with interpreting the idiom’s figurative meaning.

Finally, Chapter 6 presents a general discussion of the findings of the previous chapters in connection to the main research question of the thesis. Furthermore, Chapter 6 discusses the theoretical implications of the findings in the thesis and will provide directions for future research.
Door de mand vallen

‘To fall through the basket’

‘To get caught’