Chapter 6

General Discussion

The aim of this thesis was to investigate whether and how speaking multiple languages can influence cognitive flexibility and how this relates to mental and cognitive health in older adulthood. Our focus was on studying the relation between multilingualism and mental and cognitive health in (older) adults by combining perspectives and methods from multiple fields of research. In the first part of this dissertation, we studied how exposure to multilingualism and other cognitively challenging experiences relate to cognition, using cross-sectional experimental and observational data. In the second part of this dissertation, we studied the unique effects of foreign language training on cognitive flexibility in older adults, using an experimental approach. In the following paragraphs, main findings of the different chapters in this dissertation are summarized, interpreted, and integrated. Limitations and considerations of our study designs and methods are subsequently described. Finally, possible avenues for future research are outlined.

6.1 SUMMARY OF CHAPTERS

In Chapters 2 and 3 we studied how variation in multilingual life experiences relates to cognitive flexibility and mental health. We investigated how certain multilingual experience factors in isolation, and a multilingual experience as opposed to no experience, relate to enhanced cognition. Chapters 3, 4, and 5 focused on how speaking multiple languages can uniquely influence cognitive flexibility and mental health in older adults. This was studied by comparing speaking multiple languages to another cognitively complex skill: playing musical instrument. We investigated how these two cognitively complex experiences differentially and cumulatively influence cognition and whether different experiences also lead to diverse effects.

There is great diversity and dispersion in individual multilingual experiences. In **Chapter 2**, we investigated the relation between individual differences in multilingual language experiences and cognition. Specifically, we investigated how language entropy as a multilingualism index related to attention and prefrontal cortex functioning in adults in late adolescence (i.e., students). Language entropy is an index of the relative balance (i.e., language diversity) in multilingual language use. We related individual differences in language entropy to selective attention, measured by means of an attentional blink (AB) task, and to AB task-related brain activity in the lateral prefrontal cortex, measured using functional near-infrared spectroscopy (fNIRS) in 53 multilingual individuals. Results did not show that language entropy modulated selective attention, derived from blink-performance on the AB task, nor did other factors pertaining to the multilingual language experiences, or indeed all of these factors cumulatively. At the same time, however, the results of Chapter 2 did show that a higher language diversity index (i.e., a higher entropy score) was related to

greater brain activity in the prefrontal cortex during target detection in general. With that, when looking beyond behavioral performance alone, also incorporating underlying brain mechanisms, results of Chapter 2 indicated that a higher level of language diversity may be related to better efficiency in information monitoring, as evidenced by generally greater alertness and attention. This suggests that the degree to and manner in which multilingual individuals use multiple languages are important for attentional resources.

In **Chapter 3**, we studied whether multilingual language experience, as opposed to no experience, related to improved cognition and mental health. We also investigated whether there were any differences between multilingual and musical experiences, and crucially, whether these two different complex experiences taken together rendered a cumulative effect on cognitive and mental health. More than 10,000 older adults from the population-based Lifelines Cohort Study completed a musical and multilingual background and experience questionnaire. Using Latent Class Analysis (LCA), four groups emerged on the basis of multilingual and musical life experiences: (1) a low-multilingual group without musical experience; (2) a low-multilingual group with music experience; (3) a high-multilingual group without music experience; and (4) a high-multilingual group with music experience. We examined whether cognition and affect, as indicators of cognitive and mental health, could predict to which of these groups participants belonged. Cognition was measured using the Ruff Figural Fluency Test (RFFT), as a broad measure of executive functioning. Results showed that, compared to low-multilingual individuals, high-multilingual individuals produced better RFFT scores. Additionally, we demonstrated that the groups with a single experience, either musical or high-multilingual, showed similar cognitive performance, and both groups outperformed their peers without any such experience. As expected, when these two complex experiences were combined, cognitive performance was even more enhanced. Mental health was assessed using the Positive and Negative Affect Schedule (PANAS), which measures positive and negative affect and serves as an index of emotional well-being. The results, reported in Chapter 3, showed that there were no differences between being multilingual or not with regard to positive and negative affect, nor was an effect of musical experience attested. The two groups with a single experience, similarly, showed comparable levels of positive affect. Crucially, however, when these two complex experiences were combined, higher levels of positive as well as negative affect were found compared to having only one of the experiences. Based on these results, we concluded that high-multilingual experiences seem to be associated with better cognitive functioning. Furthermore, the results indicate that the accumulation of multiple life experiences, and perhaps specifically the more complex experiences, relates to better cognitive performance and higher levels of emotional affect.

To specifically study the effects of a multilingual experience on cognitive flexibility and whether this effect differed from the effect of musical experience, we designed a randomized controlled trial. Participants in the trial were individuals who did not *a priori* have multilingual life experiences but were instead taught a new language later in life. The research protocol for this FlexLang study was described in **Chapter 4**. Participants were randomly assigned to the foreign language intervention, where they were taught English, to the music intervention where they learned to play the guitar, or a social intervention in which creative workshops were offered but no complex new skill was mastered. The FlexLang study was promoted as a study targeting new skill learning. The music group served as a high-level active control group, where a complex skill other than language was learned. The social group served as a low-level active control group, to control for social activation but without new skill learning. Participants were measured before (pre/baseline), immediately after (post), and six months after (follow-up) the intervention period. During these assessments, cognitive flexibility was assessed using an extensive test battery. Additionally, mental health was assessed, including assessment of quality of life, depressive symptoms, loneliness, apathy, and rumination. The outcomes on these socio-affective measures served as secondary outcomes. Finally, to explore cognitive flexibility on a neural level, electroencephalography (EEG) and fNIRS measurements were recorded for a subset of participants during pre and post assessments while they completed a cognitive flexibility task. Finally, for this same subset of participants, an eyes-open EEG/fNIRS resting state session was included.

Results of the FlexLang study on how learning a complex skill affects cognitive flexibility and mental health were presented in **Chapter 5**. The sample described in this chapter included 99 participants with subjective cognitive decline (SCD). Of the 99 participants at baseline, 88% participated in the post-assessment, and 82% in the follow-up assessment. The attrition rate differed per intervention condition and ranged from 5% in the social intervention to 16% in the language intervention. Multilevel analyses revealed that cognitive flexibility (measured through performance on the TMT B task and digit span backward task) improved over time. However, the improvement in cognitive flexibility was not uniquely found for the language intervention. TMT B performance was improved for all interventions. Digit span backward performance was improved for the language and the music intervention, but not for the social intervention. In other words, our study failed to show unique effects of language learning on cognitive flexibility when compared to music learning. Additionally, and similar to the cognitive outcomes, most of the mental health outcomes did not change as a result of the intervention, with some exceptions: multilevel analyses revealed that feelings of loneliness were greater at follow-up, after an initial decrease post-intervention, across all interventions. Participants may have felt lonelier at the follow-up measurement because the

intervention had stopped, and a social activity had been lost as a consequence. The outcome may also have been related to the COVID-19 pandemic, a possibility that extends to self-perceived depressive symptoms: results showed that feelings of depression increased over time and were greater for measurements that were taken during the pandemic, compared to those taken before. Additionally, quality of life in the physical domain improved, but only for the music intervention. This is striking as learning to play a musical instrument was also the most physical intervention of the three conditions.

6.2 INTEGRATION AND INTERPRETATION

6.2.1 Is cognitive flexibility uniquely related to multilingual experiences?

Overall, based on our findings, lifelong multilingual experiences but also a short-term multilingual experience both relate to enhanced cognitive flexibility in older adults, although not in a unique manner. Other complex lifelong and short-term learning experiences, specifically related to playing a musical instrument, rendered similar effects: results of Chapter 3 and Chapter 5 collectively show no differences between language experience and music experience in shaping cognitive flexibility. Speaking multiple languages does seem to have the potential to exert an influence on cognition, albeit that the precise nature of this influence follows less clearly from our results. It most likely is one of many experiences that can affect cognitive flexibility. Engaging in activities that are cognitively demanding and require cognitive control in general, or cognitive flexibility specifically, may advance these cognitive processes (Valian, 2015).

Music and multilingualism are similar in that both are skills – or experiences – that require complex coordination of multiple cognitive processes, sensory systems, and underlying brain networks (Asaridou & McQueen, 2013; Jäncke, 2009, 2012). Additionally, they are both shaped as a function of context and culture, can be an expression of emotion, and they both contain pitch and hierarchical structures, as well as a written notation/form. However, there are also notable differences between the two experiences. For multilinguals, increased cognition is suggested to result from the need to switch between speaking different languages and for higher levels of interference control to resolve conflict between different languages (Green & Abutalebi, 2013; Kroll & Gollan, 2013). These kind of production-related constraints are different for musicians. Instead, musical experience may train selective attention and sensorimotor coordination, which in turn may lead to an improvement in other cognitive processes (Schroeder et al., 2016). Any difference between the two experiences may not have a markedly different effect on cognitive performance, as both train cognitive control, which is precisely what is found in the different studies in this dissertation. After all, it is not

just these two experiences but also many other factors that influence cognition and, taken together, make up a person's identity and how someone performs cognitively.

Although musical and multilingual experiences may thus produce similar results with regard to cognitive performance, the manner in and mechanisms by which this is achieved may differ for the different experiences. Differential recruitment of brain regions involved in cognitive flexibility and executive functioning have indeed been found between people with musical versus multilingual experience during performance of cognitive tasks (Alain et al., 2018; Moreno & Bidelman, 2014). That is why it is important to include brain measures as well as cognitive tasks to study the 'how' as well as the 'what'. Chapter 2 and supplement 5.E in this thesis also show that brain measurements can tell a different story than the behavioral measurements, or at least add something extra to the story. Brain measurements can thus therefore be of great added value.

While it may not make much difference in terms of cognition which specific complex activity is undertaken, as there are no particular cognitive benefits to multilingualism, a number of unique benefits may still be attributed to multilingualism. Multilingualism or language learning is a relatively easy and cheap experience that can be done anywhere, online or in-person or even hybrid, and requires no tools the way learning to play a musical instrument does. Additionally, learning a new language can be invaluable as a personal and social experience; it can aid communication in a multilingual society, increase diversity of social exposure, and encourage traveling. Therefore, there is something to be said for speaking multiple languages as an as invaluable lifelong experience or late-life learning experience as an easy to implement life experience overriding potential other experiences. On the other hand, emotional involvement and multisensory integration characteristic of musical expression and experience may be unrivalled and may and induce other unique advantages.

6.2.2 How to capture the complexity of multilingual life experiences?

Different multilingual experiences seem to relate differently to cognitive flexibility. Based on the (weak) evidence in Chapter 2 and the factors that could best distinguish and describe a multilingual individual in Chapter 3, we can tentatively conclude that the dynamic variable of language use modulates cognitive flexibility. Individuals with what can be termed a higher multilingual load, related to factors such as number of spoken languages and extent of language use in daily life, showed more cognitive enhancement compared to those with a lower load.

In recent years, it is increasingly acknowledged that a multilingual experience is not a static, easily definable experience that an individual may or may not have. Multilinguals are most commonly defined as people able to communicate fluently in more than one language but language dominance and use patterns may change substantially throughout life (Surrain & Luk, 2019). The question of whether multilingual individuals have enhanced cognition had, before that acknowledgment, most conventionally been studied by comparing two groups (multilingual versus non-multilingual [i.e., monolingual]), but this approach failed to yield clear-cut results. The binary division of multilingual vs. non-monolingual experiences does not encompass or do justice to the complexity of the multilingual experience (Salig et al., 2021; Woumans & Duyck, 2015). Instead, the recent tenet has been to ask which individuals, with which multilingual experiences, show cognitive enhancements. This paradigm shift calls for a rich characterization and description of an individual's multilingual experience (de Bruin, 2019; Poarch & Krott, 2019).

The studies in this dissertation showed that it can be difficult to fully and completely capture the multilingual experience. A single factor to describe the multilingual experience might not do justice to its complexity, nor may it relate to cognition. Ideas have been coined to create variables that include multiple factors. For example, a bilingual quotient has been put forward, which includes multiple facets of multilingualism (Marian & Hayakawa, 2021), comparable to the intelligence quotient (IQ) including multiple facets of intelligence. However, the question remains how to best capture such a complex experience as multilingualism into one single variable. A language entropy index may be an important step in this respect (Gullifer & Titone, 2020), although this multifaceted factor may still be too simplistic. It is likely that a potential effect on cognition is mediated by a complex combination of and interaction between factors (Pot et al., 2018), which was partly evidenced in Chapter 3 as well where a complex combination of factors could best specify a multilingual individual.

Should all possible factors that could make up a multilingual experience be combined to see how they – together – affect cognition? Chapter 2 showed that all factors combined could not statistically predict cognitive performance. Multilingual load or intensity is most likely determined by a delicate balance of factors, which may differ per individual. Within the richness of the multilingual experience, language use seems to be important (DeLuca et al., 2019; Green & Abutalebi, 2013; Pliatsikas et al., 2020). Factors related to multilingual language use determine (in part) how the brain is taxed and therefore influence cognition (DeLuca et al., 2019; DeLuca, Rothman, et al., 2020; Sulpizio et al., 2020). However, language use itself is challenging to define, as it can relate to the frequency of multilingual language use, the percentage of time different languages are used, language switching behavior, or

the number of languages mastered throughout a person's lifetime. To further complicate the story, these factors may differ per interactional context (e.g., work, school, home). How different languages are used in different contexts is of great importance for cognitive control demands (Beatty-Martínez et al., 2020; Bice & Kroll, 2019; Green & Abutalebi, 2013; Gullifer & Titone, 2020).

Only recently has there been a greater focus on the various language use factors that make up a multilingual experience. Much remains to be discovered and discussed as to how to best characterize and specify these factors and the experience as a whole. It would be interesting to study which factors together as well as their interplay are relevant for cognition. Additionally, studies focusing on the effect of lifelong multilingualism on cognition can continue to contribute to a deeper understanding which multilingual language experience factors drive any effect on cognition and aid to optimize language learning training interventions.

6.2.3 Can cognitive flexibility be stimulated in older adulthood through language training?

The premise has been put forward in this dissertation that cognitive flexibility may be stimulated by language learning in older adulthood. However, so may other cognitive training activities. In term of cognition, Chapter 5 showed that learning to use a new language might indeed improve set-switching and working memory, with the latter forming a scaffold on which cognitive flexibility builds. However, we found no evidence as to the benefit of learning to use a new language as a cognitive training activity over other activities.

Despite the result of our studies that language learning does not uniquely enhance cognition in older adults, there are reasons, as mentioned above, to prefer language learning training over other cognitive training programs to stimulate cognitive flexibility. Important at the outset is that older adults proved able to learn a new skill at an advanced age. Participants in our study showed improvements in English language proficiency and improved in playing the guitar as a result of their three-month language and music training, respectively. It is often assumed that "you can't teach an old dog new tricks" – that the older adult brain is no longer capable of learning a new skill (Andrews, 2012). This is a persistent view in society and older adults often adopt this view, they self-actualize the status quo (Andrews, 2012; Sibai & Hachem, 2021). However, our study (Chapter 5) showed that skill learning at an older age is possible and, indeed, probable. The learning itself may be of great personal value and, in addition, improve self-esteem and well-being (Kliesch et al., 2018, 2021; Pfenninger & Polz, 2018; Ware et al., 2017, 2021), although no such results were found in Chapter 5. How

language learning affects the individual may greatly depend on the person. If learning turns out to be too difficult and one feels like failing, it may lower self-esteem and emphasize the feeling of not being able to learn anything anymore at old age.

Motivation is likely to play a role in being able and willing to learn a new skill. In Chapter 5, it was shown that motivation during the course period was not related to the training effect on cognitive flexibility or working memory. However, participants with a higher motivation during the course more often chose to extend the course duration. Furthermore, baseline motivation to participate was high for all interventions, meaning that participants were motivated to take part in the different courses. This is likely related to the fact that the study sample had no to little previous multilingual and musical experience. Having no previous experience with the skills learned during the courses increased the likelihood that the courses were cognitively challenging, but perhaps also increased motivation. Previous experiences therefore likely play a role in how effective a training intervention can be. Which experiences a person has had in life are important in optimizing a late-life intervention in terms of cognitive, neural, and socio-affective effects (Park & Bischof, 2013). Also, personality, for example openness to new experiences, may play a role here (Pot et al., 2018), although this was not evidenced in Chapter 5. Different interventions may be most effective for different individuals, which should be explored by forthcoming work. In the future, then, we could work towards a situation in which it is possible to predict in advance which intervention will work best for whom, based on individual characteristics such as previous experiences, personality, and motivation. Additionally, increasing motivation to learn something new can also serve as a reinforcing intervention. Perhaps, since multiple experiences combined yield larger cognitive effects (Chapter 3), it should even be considered to perform multiple interventions simultaneously or integrate them into one combined intervention (Klimova et al., 2017; Krivanek et al., 2021).

Though it might not work for everyone, language learning might result in (small) cognitive improvements in attentional or executive functions (Bak et al., 2016; Bubbico et al., 2019; Kliesch et al., 2018; Long et al., 2020; Meltzer et al., 2021; Wong et al., 2019). Therefore, as studying language learning as a cognitive training intervention aimed to contribute to healthy aging is very much an emerging field, it would be good to build on the foundations currently in place for further research. More work could be done on optimizing the language intervention itself. For example, given that language use seems of great importance as opposed to static language knowledge, as evidenced by our Chapter 2 and 3 results, it would seem important for language learning interventions to focus on language use inside and outside the classroom rather than merely presenting grammar and or vocabulary drills (c.f.

Hejazi et al., 2019; van der Ploeg et al., 2020). Although we have made an effort to tailor our language intervention to the older learner by focusing more on the social aspects related to language learning and less on the grammatical aspects, there are still steps to be taken here. For example, the degree of interaction and collaboration with peers, the degree of use of technology, or the exercises and their speed and content (van der Ploeg et al., n.d.). Additionally, to further challenge learners and keep motivation levels high, language learning interventions could benefit from adding an adaptive component to the training (Buitenweg et al., 2012). In an adaptive training, the training material would vary as a function of how well the learner performs and therefore tailors to the needs and abilities of the individual. Future work would do well to further explore the potential of language learning interventions as well as other (complex) new skill learning in connection to cognitive (and wellbeing) improvements in older adulthood.

6.2.4 What other cognitive mechanism may be boosted by multilingual experiences?

This dissertation was focused on how multilingualism as a broad experience in itself could boost cognitive flexibility. Cognitive flexibility was considered to be a broad concept, encompassing multiple cognitive processes. Throughout the different chapters, different tasks were used to measure cognitive flexibility. We found indications for enhanced cognitive flexibility in relation to multilingual experiences, but not all tasks aimed to measure cognitive flexibility demonstrated an effect. This could indicate that perhaps it is not cognitive flexibility per se that is the cognitive process enhanced by multilingual experiences. The brain data from Chapter 2 indicated that prefrontal cortex (PFC) activation is related to multilingual experiences which suggests that positive effects of multilingualism run through the PFC. However, a different mechanism than cognitive flexibility may be involved.

The construct of attention is interesting to discuss in this regard. Indeed, instead of cognitive flexibility, attention has recently been suggested as a key process enhanced following multilingual experiences (Bialystok, 2017; Bialystok & Craik, 2022). Results of Chapter 2 in this dissertation emphasize this by showing that multilingualism is related to better attentional resources in general. Bilinguals must exert attentional control over different languages in a way that is not required for monolinguals. This is suggested to result in an adaptation of the attentional system, which in turn confers a domain-general benefit to attentional control and enhance processes of cognitive flexibility and executive functioning (Bialystok & Craik, 2022).

Attention and cognitive flexibility have been argued to be closely related. As discussed before, attention can be considered a key building block of cognitive flexibility (Garon et al., 2008) and both are broadly construed constructs. In addition, cognitive flexibility is highly dependent on brain networks in the parietal and prefrontal cortex (Dajani & Uddin, 2015; C. Kim et al., 2012; Uddin, 2021), and so is attention (Diamond, 2013; Johnston et al., 2012; Slagter et al., 2010). The prefrontal cortex (PFC) is, in the context of multilingualism and aging, relevant because it can be considered as a hub for cognitive control (Diamond, 2013; Miller & Cohen, 2001; Nyberg, 2018). Chapter 2 indicated a positive relation between activity in the prefrontal cortex and multilingualism. This could indicate that high-intensity multilingual individuals engage PFC-regulated processes to a greater extent than 'less' multilingual individuals. While some earlier work has also found greater PFC activation for multilinguals (Arredondo et al., 2017; Garbin et al., 2010; Rodríguez-Pujadas et al., 2013), other studies have found the opposite that is more in line with the neural efficiency hypothesis (Anderson et al., 2021; Gold et al., 2013; Kałamała et al., 2022). The neural efficiency hypothesis states that higher functioning individuals show lower brain activity in the PFF; they need fewer resources to perform the same cognitive task (Dunst et al., 2014). How multilingualism relates to PFC functioning is therefore inconclusive; however, that the PFC is relevant is clear. The difficulty is that the PFC comprises of multiple subregions, themselves involved in many cognitive control processes, such as attention, cognitive flexibility, inhibition and working memory. The question is whether and how the different sub-regions cooperate to mediate cognitive processes, or whether they each bring about different cognitive processes (Friedman & Robbins, 2022; Nyberg, 2018). This adds to the complexity of studies attempting to pinpoint the process (es) enhanced by multilingualism. In order to understand how multilingualism and language training could affect cognitive control, we need to more closely understand what cognitive control is and understand its underlying neural mechanisms, beyond looking at different functions and brain areas (Hartsuiker, 2015). For example, more precise theories will have to be formulated about skill generalization and cognitive control, specifying which functions can be improved by such generalization. Brain connectivity and network structure of regions within the PFC, possibly with other cognitive control supporting areas, can be of great added value here.

6.2.5 Do complex (learning) experiences contribute to enhanced brain health in older adults?

The chapters in this dissertation tentatively suggest that complex (learning) experiences are related to better cognition and therefore potentially also to better brain health: "the preservation of optimal brain integrity and mental and cognitive function at a given age in

the absence of overt brain diseases that affect normal brain function" (Wang et al., 2020, p. 1). Brain health pertains to, amongst other things, cognitive as well as emotional functioning. The brain is shaped by many experiences and processes and is adaptable and resilient, also in older age (Aron et al., 2022). Although some small effects on cognitive functioning were found in this dissertation, multilingual (or musical) experiences, either as short-term learning experiences or lifetime experiences, were not attested to exert great influence on emotional functioning. This is striking especially for multilingual experiences because apart from being a cognitively challenging experience, multilingualism is also primarily a social experience. Social performance, in turn, is a key predictor of many health outcomes (Umberson & Karas Montez, 2010). The socio-affective component of the multilingual experience and the importance hereof for language learning as an intervention has been shown in earlier work (Pfenninger & Polz, 2018). Additionally, learning experiences and feelings of well-being have been found to be closely related (Klimova & Pikhart, 2020). It is important for any learning experience aimed at older adults to focus on social factors, as older adults have been found to suffer disproportionally from social isolation and loneliness compared to their younger peers, and this finding is highly related to emotional functioning and depression in elderly (Chang et al., 2016; Hays et al., 1998). The learning experiences in our studies included classes with fellow students to promote the formation and development of social connections. However, due to the COVID-19 pandemic, these classes were forced to move online. Perhaps because of that, social variables were not stimulated as much as anticipated before the study onset, nor was it possible to control for other social deprivation effects or for the effect that reduced mood has on learning.

One possible indicator of better brain health may regard improved cognitive reserve. However, based on the studies in this dissertation alone, we cannot straightforwardly conclude that language learning or multilingualism had an effect on cognitive reserve. Cognitive reserve can only be assessed indirectly. A commonly used method to estimate cognitive reserve is based on previous education, job occupancy and leisure activities throughout one's adult life (e.g., Nucci et al., 2012). Therefore, these focal areas taken together present a relatively stable measure of cognitive reserve that does not change much after a six-month learning experience. Cognitive reserve may also be indicated by task performance, but one needs to take into account brain pathology (Stern et al., 2020). Additionally, cognitive reserve can be demonstrated if cognitive decline is averted, again in relation to brain pathology, for which participants need to be assessed multiple times over a long period of time. In the studies in the current dissertation, brain pathology was not measured, nor were participants followed for a sufficiently long period of time to conclude how the complex (learning) experiences help in staving off cognitive decline. It is therefore difficult to draw conclusions how

language learning or other complex learning experience contribute to cognitive reserve and prevent future cognitive decline. The findings in this dissertation therefore question the clinical benefit of a language learning intervention for older adults, as previous studies have done as well (Berggren et al., 2020; Ramos et al., 2017).

6.3 METHODOLOGICAL CONSIDERATIONS AND AVENUES FOR FUTURE RESEARCH

Reflecting on the findings in this dissertation necessitates several methodological considerations and limitations. Important aspects that warrant discussion relate to outcome measures and the study design in general. Before going into this, it is important to mention that the COVID-19 pandemic started while the intervention study was running. This unintentionally made the trial incredibly complex, especially because social deprivation and anxiety are related to the pandemic (von Mohr et al., 2021). Due to measures taken in the Netherlands, participants were unable to visit our laboratory. As a result, we have missing brain activity data, which meant that some of the initially hypothesized assumptions could not be tested. Other measurements could be continued, but via video calling, which strongly influenced some of the data.

Pertaining more fundamentally to theoretical underpinnings we see great importance in characterizing in a detailed manner multilingual language experience and use. Without going into too much detail here, having already discussed this topic in the sections above, we would like to emphasize the importance of interactional context. In this dissertation, we did not investigate different interactional, or social, contexts and networks (e.g., work, school, home) in which languages are used, nor was it the aim. However, specifying the contexts in which multiple languages are used and specifying language use within and between contexts seem to be of great importance, as such settings partly determine the demand for cognitive control (Beatty-Martínez et al., 2020, 2021; Gullifer & Titone, 2020; Pot et al., 2018). Similarly, when learning to speak a new foreign language, the interactional context is also important: brain networks constantly respond to changes in the language context and adapt to the stage of language learning and multilingual language use (Pliatsikas, 2020). It would therefore be interesting to investigate whether individuals who use the language they learn in more contexts, or use the language more within a given context, have greater learning effects and, with that, perhaps larger effects on cognition.

6.3.1 Outcome measures

A consideration that is common to every chapter, and essentially to all work related to cognitive functioning in general, is how to best measure cognitive functioning. The focus of this dissertation has been on cognitive flexibility. In the introduction, we attempted to make clear that cognitive flexibility itself can be a difficult construct to define, and therefore a difficult construct to measure. Cognitive processes are most often measured by means of behavioral tasks. However, it is difficult to find tasks that capture the cognitive processes that are enhanced by multilingual experiences, given that "tasks are simplified constructs that each have their own impurity" (Mishra, 2018, p.11). It is therefore questionable to what extent a particular task resembles the cognitive process it is assumed to measure. In addition, different tasks may be used to measure a certain cognitive process in different studies, rendering it an almost impossible task to compare results across studies. Rather than let the task define which cognitive constructs are measured, it is therefore important to define the cognitive processes that form the primary object of investigation. Additionally, in the context of cognitive enhancement, improved cognitive functioning measured in one task does not necessarily mean that there is improvement in the cognitive domain the task in question is assumed to measure. Correlations between tasks that are assumed to measure the same domain are sometimes low (Lehtonen et al., 2018; Miyake et al., 2000).

What are limitations regarding the outcome measures?

A limitation for this specific dissertation is that the use of different tasks throughout the different chapters makes it difficult to draw a clear conclusion on how cognitive flexibility is affected by speaking multiple languages. Some tasks may tap cognitive flexibility more than others and/or tap different facets of cognitive flexibility. For example, the cognitive task used in Chapter 2, the attentional blink task, is generally considered to tap attentional control (Dux & Marois, 2009; Martens & Wyble, 2010; Shapiro et al., 1994; Taatgen et al., 2009), which can be taken to be an essential component for cognitive flexibility and executive functioning (Garon et al., 2008). The task i**n** Chapter 3, the RFFT, is a broad measure of cognitive functioning that involves cognitive flexibility but may more strongly engage higher order executive functions such as initiation, planning and divergent reasoning (Gardner et al., 2013; Kuiper et al., 2017). The tasks in Chapter 5, then, are suggested to be more 'pure' measures of cognitive flexibility, as they have most commonly been and continue to be used to measure cognitive flexibility (Dajani & Uddin, 2015). However, even in more 'pure' measures of cognitive flexibility, it is difficult to assign any effect emerging as a result of a given task to a specific and single cognitive process that supposedly underlies the task at hand. That is why, in order to reach definite conclusions as to any effect on cognitive flexibility, it is important to include multiple measures to index cognitive flexibility. That is what we

aimed to do in Chapter 5. However, even then we cannot say with complete certainty that an effect on cognitive flexibility was found as a function of our interventions, given that not all cognitive flexibility tasks showed an effect. Additionally, there is also some element of attentional component involved in each task, further complicating a comprehensive account. What furthermore should be noted here is that many neuropsychological tasks are 'artificial' in that they do not resemble everyday practical situations which often require more complex integration. Future studies investigating cognitive functioning should use more ecologically valid assessments (Jansari et al., 2014).

Difficulties in understanding how certain tasks relate to cognitive processes is partly the reason why we included measures of brain activity. A specific behavioral task may not capture the cognitive processes affected by speaking multiple languages. Therefore, if no effect is observed for a certain task, one may be missing effects that did occur because no one task can measure all cognitive processes. Measures of brain activity could, in that respect, be considered as more general measures of cognitive functioning. Additionally, neural measures may be more sensitive to changes within individuals, and differences between individuals. Looking at task performance, there can be only limited variation between optimal and very poor task performance. By contrast, every brain is different. As the brain is responsible for task performance, task performance may be affected in numerous ways. Different individuals may activate different networks to a different degree (Pessoa, 2014). However, these different ways of using the brain can result in similar task performance for different people. This may be why a given effect is observed at the neural level, but not on cognitive tasks, as is commonly reported in multilingualism research (DeLuca, Rothman, et al., 2020; Kousaie & Phillips, 2017; McLaughlin et al., 2004). In Chapter 2 of this thesis, we also failed to detect individual differences in attentional control emerging from the cognitive task, but differences were observed in brain activity, measured with fNIRS. Results in the supplements of Chapter 5 also indicated that neural effects might emerge after language learning, also in the absence of behavioral effects. Unfortunately, due to the COVID-19 pandemic, we collected EEG and fNIRS data for only a small subset of participants. This prohibited us from carrying out detailed statistical analyses on the neuroimaging data. We therefore could not fully determine the effects of language learning as protocoled in Chapter 4. Future studies would do well to integrate neural measures to measure cognitive processes, such as EEG, fNIRS, fMRI, or eye tracking with behavioral cognitive tasks. This may prevent potential effects from being lost and allow for more holistic assessments.

6.3.2 Study design

A consideration that is worth discussing in detail is the use of control groups. If speaking multiple languages is truly unique in influencing cognition, this should emerge when comparing this skill to an experience that is very similar in nature yet distinct from it. For this reason, in Chapter 3 and Chapter 5, we decided to compare speaking multiple languages to playing a musical instrument and in particular the different effects that ensue from either learner a new language versus learning to play a musical instrument. Language and music are very similar in many aspects. Music and language are both used to exchange ideas and feelings, both are organized in sound units, both are compositional, and they are both processed in the same underlying brain regions (Jäncke, 2009, 2012). The main difference is that learning to speak a new language results in competition between the new language and earlier acquired and learned language. Control processes and cognitive flexibility are needed to resolve such competition (Bice & Kroll, 2015; Kroll & Gollan, 2013), while such an effect is not known to occur in mastering a musical instrument. Especially in the absence of ever having learned to play a musical instrument, this is a new skill that does not enter into competition with earlier stored representations. Chapter 3 has indeed shown that musical and multilingual experiences both result in improved cognition, but no differences between the two experiences were attested. Results reported in Chapter 5 and its supplement also show that learning a new language may not be unique in establishing effects on cognition. Instead, any effect may result from learning a new complex skill in general.

What are limitations regarding the study design?

A randomized controlled trial (RCT) was used in Chapter 5 to determine the effect of the language intervention compared to other interventions. We consider the use of the RCT as an asset to our study, by means of which we can compare language learning to learning a closely related skill in a highly controlled manner. However, it could also be considered as a limitation. For example, it makes it impossible to determine how important it is that the skill that is learned is complex, or whether there should be a social or emotional component to the intervention. Partly for this reason, we have also included a passive control group in our RCT. However, the passive control group was not truly passive as it included social group meetings and creative activities. While the intention was not to learn anything, the meetings themselves may have stimulated the participants' creativity and especially also social interaction, which in turn could boost cognitive flexibility (Mortimer et al., 2012). We see some indications for this in the results reported in Chapter 5. Including an additional passive control group without meetings (only measurements) could therefore be of great value. To study whether language learning yields specific or unique effects compared to other skill learning and compared to social interaction, as the main goal of the studies in

this dissertation, the included control groups were well chosen. Although there are many practical reasons why we did not do this, it would be interesting to set up an even more elaborate RCT study to compare language learning to other complex skill learning and to non-complex skill learning as well as to increasing social interaction and no intervention at all.

An RCT is considered the benchmark for establishing causality in scientific research, but there are also ample downsides to its use (Hariton & Locascio, 2018). In medical sciences, RCTs are considered to render the highest level of evidence. However, compared to medical sciences, studying lifetime experiences and lifestyle interventions the way we have in this study using an RCT brings with it with many complex social factors, making the RCT a costly tool. Although randomization controls balancing of baseline systematic differences between groups, it is also costly because participant attrition is a real threat (Deaton & Cartwright, 2018). Particularly for lifestyle interventions, people may want to choose the intervention they participate in. Randomization, then, might prevent people from participating or abort their participation in the study even before the intervention has started; they may also be more likely to drop out during the intervention because they do not like it; or participants do not put effort into the intervention because of lack of motivation (although an RCT also serves as a way to rule out these effects). In addition, results of an RCT for lifestyle interventions may not be relevant in a clinical context because of the limited generalizability of study findings due to restrictive selection criteria (Deaton & Cartwright, 2018). It should therefore be questioned whether an RCT is the best way to answer the research question at hand. Consideration should be given to what can result in the best scientific evidence, what results in a substantial number of participants, what is most clinically relevant, what ensures good adherence to the intervention itself.

6.3.3 Language training design

In the studies presented in the second part of this dissertation, in Chapters 4 and 5, we aimed to investigate the effects of the FlexLang intervention study. A prominent consideration in the design of this intervention study has always been the design of the language training itself. In order to design a language intervention study, decisions have to be made pertaining to some of the following considerations: the nature and pedagogical approach of the language training, the language to be learned, the intensity of the language instruction, and the comparability of a control training (i.e., music), among other things. One aspect that further complicates these questions is that there may be differences between younger and older adults. Since third age language learning is an emerging research field, there are no clear answers to these questions (van der Ploeg et al., 2020). As long as these questions

remain under-investigated, even in a well-designed RCT study, results may depend on the choices that are made.

What are limitations regarding the language training design?

Regarding the design of the language training, the choice of language (English) that was taught in the language intervention in Chapters 4 and 5 could be considered a limitation. To some, English might seem the worst possible option, as we see and use a considerable amount of English in the Netherlands. For example, English is taught from primary education onwards, many TV series and movies are available in English, and English is used in advertisements. In other words, English is part of the wallpaper of every Dutch household. It is estimated that around 90% of the Dutch population has some degree of knowledge of the English language (European Commission, 2012). Teaching the English language to Dutch elderly therefore introduces confounds related to hard-to-control differences in previous knowledge in and exposure to the English language. However, the choice of language might not be as important as it may seem. The language intervention as set up in Chapter 4 and discussed in Chapter 5 is used as a tool rather than means to an end: the most important aspect about the language training is that participants start using two languages on a daily basis instead of merely one; they move from being functionally monolingual to using two languages. By no means is the aim of the intervention to become bilingual, though results of Chapter 5 show that people indeed become more proficient in English as a function of the language training. It would be interesting for future studies to design an RCT with two language learning groups where two different languages are taught. One language could be one that people have absolutely no knowledge of and are not exposed to in daily life. The other language could be a language that people are highly motivated to learn, but more familiar with and are exposed to more in daily life. In our case, the choice to teach English was based on an earlier survey that indicated that most elderly were interested in learning English (Assen & Busstra, 2018).

Another consideration is the nature, duration, and intensity of the language training. Little is known about what training intensity older people prefer, what they can handle, and what is ideal for establishing effects on cognition (van der Ploeg et al., n.d.). Although not the aim of the chapter, the results of Chapter 5 in this dissertation could provide the field with useful information on some of these parameters. The study allowed for some investigation of the exposure-response relationship between language learning and its effects through the possibility of extending the training period to six months and assessing training investment through diary measures. Earlier work has suggested that an intensive language training is more efficient (Bak et al., 2016). However, results of Chapter 5 do not directly show

that a longer intervention has a larger effect on cognition. Chapter 5 also does not provide conclusive evidence that people who spend more time on the intervention, and thus had a greater intervention intensity, improved more cognitively. It is very well possible that the lack of evidence for an effect of training intensity here follows from incomplete diary data as a result of which the intensity with which the intervention was followed has not been fully recorded. However, it could also be that the intervention was not successful in establishing an effect on cognition, and that duration and intensity therefore did not matter.

6.4 CLINICAL AND SOCIETAL IMPLICATIONS

The combined results reported in the individual chapters that make up this dissertation have several implications for different groups. Generally, the results implicate that it is important to seek out (multiple) complex life experiences. Accumulated complex life experiences might induce more substantial positive effects on cognition and mental health in older adults compared to single experiences. Therefore, taking on multiple complex experiences throughout life might result in improved cognitive functioning and the slowing down of cognitive aging effects. It does not seem to matter much which complex activity is undertaken. Instead, it is potentially most important to do something, as opposed to doing nothing, to stimulate the brain in any way and more complex experiences render the greatest results, as evidenced in Chapter 3.

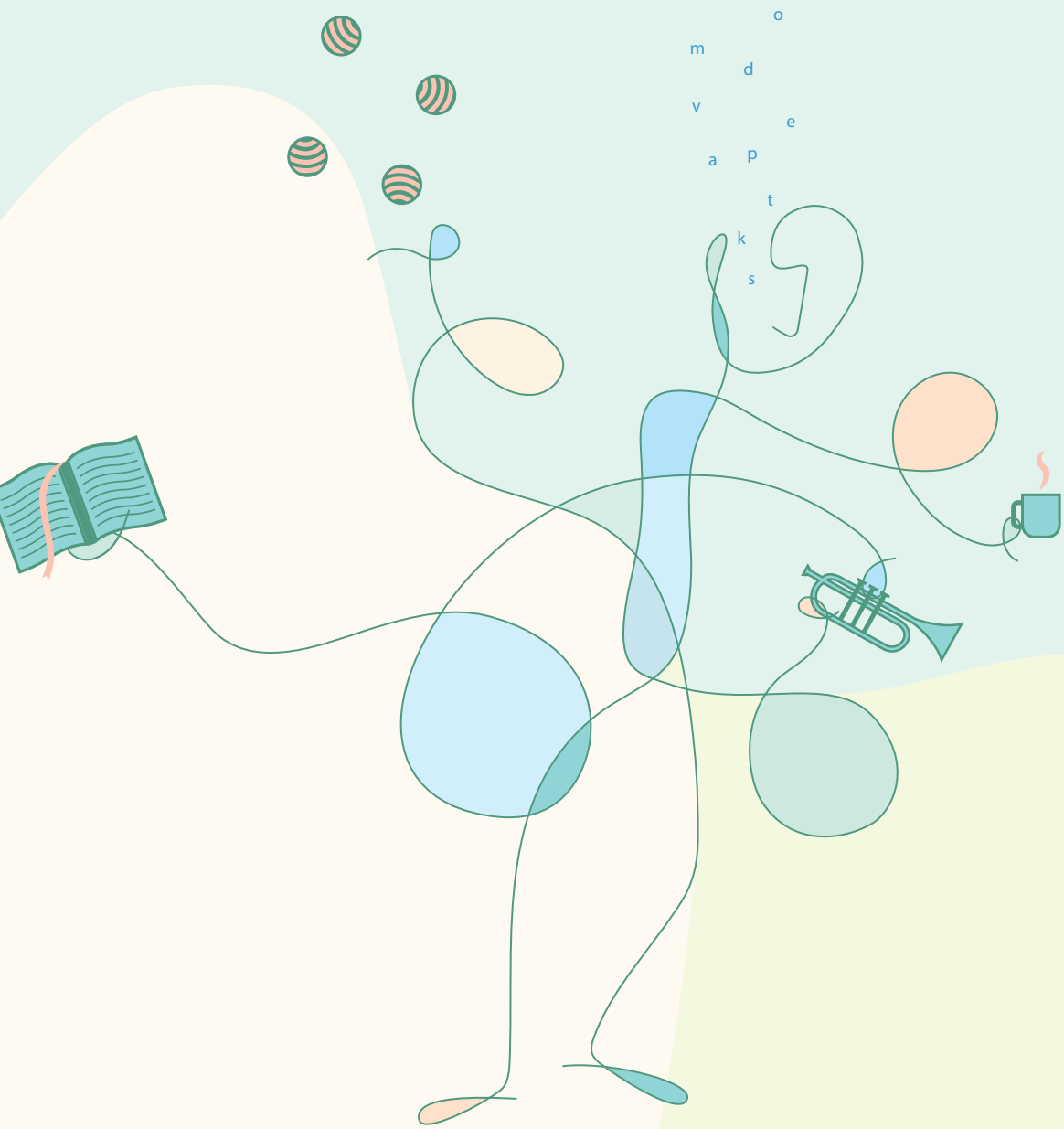
For older adults specifically, the results implicate that complex skill learning at an older age might be beneficial. Therefore, older adults should be motivated to start (or continue) learning. Contrary to what elderly often think themselves and contrary to prevalent societal views, elderly can still learn new skills at an older age. Additionally, taking on new skills learning through tailored courses at an older age may benefit cognition, but it may also offer opportunities for older adults for more social interaction and connections and therefore less loneliness, which can be positive for general well-being and therefore indirectly also cognition. Based on the results in this thesis, it cannot be said that one activity is better than another. For a clinically relevant effect on healthy aging, it makes little difference which activity is undertaken. Therefore, older adults should focus on something that is fun and enjoyable for them personally, that can be sustained for a longer period of time, and for which they are willing to put in effort. At best, cognitive aging is slowed down or at least maintained; at worst – in the absence of any cognitive effect - older people would do something they enjoy.

This dissertation also has implications for clinicians working with elderly. Given that the benefits of a multilingual experience, either as lifelong experience or short-term training,

were found to be only small, it is questionable whether this effect is clinically relevant for insights into cognitive reserve and slowing down cognitive aging. We found no clinically relevant effect for individuals with SCD, who are at risk for depression and further cognitive decline (Dufouil et al., 2005; Mitchell et al., 2014; Reisberg et al., 2010). However, as there is currently still no medicine for cognitive decline, cognitive training interventions and other ways of stimulating mental activity such as physical activity (Entezari et al., 2018; Ji et al., 2019) are the only available treatments or preventative measure we have and are, if they do not induce an effect, otherwise harmless. Clinicians could more actively encourage elderly patients to seek out (complex) learning experiences and keep their brains active.

For multilingualism research, the results imply that language learning has a potential in contributing to healthy (cognitive) aging. As language learning in older adults is only an emerging field, much more research needs to be done. There is still much learn about learning to speak a second language at a later age and how this contributes to better mental health. As discussed above, language use seems to be of great importance and other studies can be performed with a different intervention or study design. Specifically related to how language learning can interfere with cognitive decline, it is important to study in more detail the effects of a language intervention in a group of people with more severe cognitive decline (MCI or onset dementia), or depression. There are indications from recent studies that individuals with a lower level of cognitive performance at study onset benefit more from a language intervention as compared to an active control intervention (Kliesch et al., 2021). More research is needed to discover for whom in particular late-life language learning might be beneficial in terms of cognition and mental health (upcoming research projects include a number of current PhD projects of the University of Groningen).

Importantly, this dissertation makes the case that knowledge, perspectives and methods of multilingualism, cognitive and neuroscience research need to be combined in order to study how speaking multiple languages influences cognition in older adults. The neuropsychological concepts that are studied and the tasks used to measure them matter a great deal in the research outcomes. Similarly, it has been shown in several chapters of this dissertation that measures of brain activity may be an important contribution. Combined, the strengths of the different disciplines can shed more light on the role of foreign language learning in older adulthood and its influence on cognitive and emotional mental health, ultimately illuminating how to age flexibly.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