Simultaneous interpreting, brain aging, and cognition

Elmer, Stefan ; Giroud, Nathalie

DOI: https://doi.org/10.1075/tcb.00082.elm

Simultaneous interpreting, brain aging, and cognition

A review and future directions

Stefan Elmer[1] & Nathalie Giroud[1, 2]
[1] University of Zurich | [2] ETH Zurich

Aging is associated with a high prevalence of neural and cognitive changes, which may impair life quality while placing a significant burden on the healthcare system and the economy. Nevertheless, diverse daily activities as well as deliberate practice in several domains have been proposed to benefit brain plasticity and cognition as well as to have the potential to counteract age-related decline through neuroprotective and/or compensatory mechanisms. In this review article, we will provide a summary of the gray matter alterations that have commonly been documented in simultaneous interpreters over the past twenty years. Furthermore, we will review the main literature that examined associations between simultaneous interpreting training and cognitive functions for assessing possible practice-related cognitive benefits in older age. We will also outline future directions for research in this area and highlight interventions aimed at mitigating the effects of aging on neurocognition.

Keywords: structural plasticity, gray matter, brain aging, cognitive and neural reserve, cognitive functions

1. Introduction

The accelerated aging of the population in the coming decades will pose enormous challenges for the healthcare system and the economy (Wimo et al. 2013). Currently, there is little doubt that the human brain undergoes linear and non-linear maturational trajectories from childhood to older adulthood which are characterized by prominent gray and white matter changes (Bethlehem et al. 2022; Gogtay et al. 2004; Ziegler et al. 2012). What is commonly found in older individuals is that gray and white matter parameters generally deteriorate in several brain areas, including the prefrontal cortex (Fjell et al. 2009; Raz et al. 2005),

https://doi.org/10.1075/tcb.00082.elm
Translation, Cognition & Behavior 6:2 (2023), pp. 118–140. ISSN 2542-5277 | E-ISSN 2542-5285

the medial and lateral temporal lobe, the hippocampus (Fjell et al. 2013; Rodrigue & Raz 2004), the parietal lobe (Resnick et al. 2003) as well as the basal ganglia (Ziegler et al. 2012). These age-related structural changes have also been associated with a decline in several cognitive functions, such as short-term memory, working memory, episodic memory, problem-solving, inhibition, and processing speed (Harada et al. 2013; Hedden & Gabrieli 2004). Given these circumstances, any advance in developing strategies to counteract neuronal and/or cognitive decline would make a significant contribution to the public health system. From an optimistic point of view, a pragmatic solution would be to find suitable drugs that could directly prevent, stop, or cure the degradation process. Although such a perspective still seems a long way off, there are currently at least a number of behavioral interventional approaches, including various leisure activities, which can already be tested for their suitability (Bamidis et al. 2014; Foubert-Samier et al. 2012; Kramer et al. 2004).

To date, many research groups have endeavored to identify specific lifestyle factors that may help counteract neurocognitive decline and promote public health. Among such factors, bilingualism (Bialystok et al. 2016; Bialystok et al. 2014; Zhang et al. 2020), aerobic exercise (Colcombe et al. 2006; Erickson et al. 2011), musical training (Rogenmoser et al. 2018; Sutcliffe et al. 2020; White-Schwoch et al. 2013), cognitively engaging activities (Anguera et al. 2013; Binder et al. 2015; Jaeggi et al. 2011), dancing (Porat et al. 2016; Rehfeld et al. 2018) as well as foreign language learning (Bak et al. 2016; Li et al. 2014) have been proposed as promising daily-life interventions, but some of them have also been questioned (Lehtonen et al. 2018; Paap & Greenberg 2013; Paap et al. 2015). Despite the large body of literature on this specific topic, in this review we will consider a relatively new niche in this field and focus solely on potential neuroanatomical and cognitive benefits across the lifespan associated with simultaneous interpreting practice.

The few existing functional neuroimaging studies on simultaneous interpreting emphasize that it is more than just language processing *per se*. In fact, although some activation patterns were localized in brain areas supporting classical language functions such as phonetic, syntactic and semantic processing, and articulation (e.g., posterior superior temporal cortex, inferior frontal gyrus), a significant amount of brain activity was also found in regions commonly associated with domain-general cognitive functions such as the dorsolateral prefrontal cortex (Hervais-Adelman et al. 2015; Hervais-Adelman et al. 2015; Rinne et al. 2000). Still, very little is known on how aging affects simultaneous interpreting. Attempting to look into this issue, a single qualitative study interviewed simultaneous interpreters (SIs) from the International Association of Conference Interpreters (AIIC) who were over 70 years old (Liu et al. 2020). The SIs reported that they experienced various age-related changes resulting in challenges during

simultaneous interpretation. Among other aspects, SIs mentioned that they experienced more difficulty with language comprehension in adverse listening situations, concentration, and memory issues as well as a slowing in lexical retrieval with aging, all of which apparently led to a leave of the profession in several cases. A quantitative behavioral study confirmed these results: Signorelli et al. (2012) investigated age effects on cognitive performance in SIs and showed that younger interpreters (but not non-interpreters) outperformed older SIs in non-word repetition and cued recall. Thus, the previously reported cognitive benefits of simultaneous interpreting in younger adults might be partially overshadowed by age-related cognitive decline in older SIs. Still, we do not know how such a combinatorial cognitive and language-based activity may to some degree also counteract age-related neural and cognitive changes.

Nevertheless, we are not claiming that training-related brain alterations and potential cognitive benefits associated with simultaneous interpreting are more profitable than other activities. However, we believe that there are several main arguments for using cognitively demanding language-based interventions (of which simultaneous interpreting is one example of many) as appropriate tools to try to counteract age-related cognitive and neural decline. For example, learning language-related skills can have the side effect of encouraging social interactions (Li & Jeong 2020), which often decrease with age, leading to negative psychological outcomes and brain atrophy (Elliott et al. 2014; Orben et al. 2020). Another argument is that language and communication are highly satisfying and rewarding activities (Ripolles et al. 2018; Ripolles et al. 2016), which are therefore particularly suitable for maintaining high levels of motivation, especially in older individuals.

This review is an attempt to provide an overview of the major breakthroughs of the past twenty years that led to a better understanding of the neural correlates underlying simultaneous interpreting, with a specific lens on gray matter structural plasticity in younger and middle-aged cohorts, which have already been studied. The articles included in this review were selected based on a comprehensive search in the PubMed and Google Scholar electronic databases. Thereby, we exclusively focused on papers written in English and published in peer-reviewed journals using the keywords "simultaneous interpreters" and "brain" or "plasticity" or "cognitive functions". In addition, we reviewed the abstracts to check compatibility with the content of our review article.

Drawing on this background, we will examine whether simultaneous interpreting practice can have a positive impact on cognitive functions, and possibly provide a protective effect against cognitive and neural decline. We will also attempt to bring together what we have learned over the past two decades of neuroscientific research in the field of interpreting and discuss how this knowledge

can be used to design training protocols that may benefit brain health and cognition in older age. Since the focus of our article is on structural plasticity and cognition in association with training, expertise, and aging, we will not go into detail about the numerous linguistic advantages that have been documented in professional or trainee SIs. Instead, we refer the interested reader to relevant literature in the field (Dottori et al. 2020; Elmer et al. 2010; Fabbro et al. 1991; Garcia, Munoz, & Kogan 2020; Santilli et al. 2019).

2. Simultaneous interpreting and gray matter plasticity

Up to now, only a handful of studies have addressed gray matter changes in trainee (Hervais-Adelman et al. 2017) or professional (Becker et al. 2016; Elmer et al. 2014) SIs using structural magnetic resonance imaging (MRI) protocols. While some of them used longitudinal experimental designs to gain insight into cause-and-effect relationships (Hervais-Adelman et al. 2017), others relied on cross-sectional group comparisons (Becker et al. 2016; Elmer et al. 2014). Furthermore, to control for structural changes generally related to the mastery of multiple languages (Abutalebi & Green 2007; Pliatsikas 2020), most of these studies compared professional or trainee SIs with multilingual control participants who were at best comparable in terms of age of language acquisition, proficiency, and exposure to foreign languages (Perani et al., 2003; Perani et al., 1998).

In a first cross-sectional study aiming at comparing gray matter volumes between professional SIs and multilingual control participants, Elmer et al. (2014) consistently revealed reduced gray matter parameters in SIs in brain regions closely associated with cognitive functions and language processing, namely in the left middle-anterior cingulate gyrus, bilateral pars triangularis, left pars opercularis, bilateral middle-anterior insula, as well as in the left supramarginal gyrus. Furthermore, gray matter volume in left pars triangularis, right pars opercularis, middle-anterior cingulate gyrus, and in the bilateral caudate nucleus negatively correlated with the cumulative number of estimated interpreting hours. In a second cross-sectional study, Becker et al. (2016) compared professional SIs to a sample of written translators and found increased rather than decreased gray matter volume in a cluster located in the left frontal pole. In the only longitudinal anatomical study conducted with a sample of trainee interpreters and multilingual control participants over a period of 14 months, Hervais-Adelman et al. (2017) observed increased cortical thickness in SIs in brain regions associated with phonetic processing and domain-general executive functions. These structural plasticity effects were restricted to the left posterior superior temporal gyrus, left supramarginal gyrus, left planum temporale as well as to the right superior pari-

etal lobule, right angular gyrus, right intraparietal sulcus and to the right superior frontal gyrus.

While all studies were apparently sensitive enough to detect gray matter differences between professional or trainee SIs and multilingual control participants, the results also exhibited a certain degree of anatomical variability. Furthermore, the cross-sectional comparisons did not provide a definitive statement as to whether the between-group gray matter differences truly reflected experience-dependent plasticity or rather pre-existing anatomical features. Also, the actual meaning of increased or decreased gray matter parameters in association with training and expertise needs to be further clarified. While increased gray matter indices are commonly thought to reflect a larger number or size of neurons, dendrites and glial cells (van der Meer & Kaufmann 2022; Zatorre et al. 2012; Zilles et al. 1988), reduced gray matter parameters may potentially indicate an experience-dependent removal of superfluous neural entities or other types of structural reorganization processes (Giorgio et al. 2010; Gogtay et al. 2004; Paus 2005). Nevertheless, both increased and decreased gray matter indices due to training are reconcilable with the "Dynamic Restructuring Model" hypothesis proposed by Pliatsikas (2020). This three-stage model posits that the exposure to a new language or the acquisition of language-related skills are initially manifested in increased gray matter parameters in brain regions subserving phonetic and semantic learning and implicated in exercising cognitive control. Afterwards, in the consolidation phase, the model postulates a return of gray matter parameters to baseline, particularly for those brain regions that underwent plastic changes in the initial phase. One possible mechanism beyond such a gray matter reduction is pruning, which refers to the removal of superfluous neural connections while leaving the most efficient ones intact. Finally, in the third phase characterized by bi/multilingual peak efficiency, the model acts on the assumption that highly efficient and automated language control is mediated by maximally efficient structural connectivity in association with a shift of gray matter changes from anterior to posterior and subcortical brain areas.

3. Simultaneous interpreting and cognitive functions

Based on the gray matter anatomical studies reviewed above, it appears that simultaneous interpreting has an impact on brain anatomy that goes beyond the effect of bi/multilingualism (Abutalebi & Green 2007; Bialystok et al. 2012; Pliatsikas 2020). Accordingly, one way to try to understand what differentiates between structural plasticity in professional SIs and polyglot individuals is to characterize the specificity of SIs at a process-based level. Given that SIs have to

handle multiple tasks in parallel, it could be argued that simultaneous interpreting is a very demanding form of bilingual activity that places greater linguistic and cognitive demands than bi/multilingualism *per se* (Abutalebi & Green 2007; Garcia et al. 2020). In fact, in their daily routine, SIs have to encode speech information in short-term and working memory, access phonological and semantic representations across languages, switch between linguistic codes, and articulate in the target language while paying attention to both the speech input and their own translation (Elmer 2012; Hervais-Adelman & Babcock 2020). Moreover, inhibitory functions and cognitive control mechanisms are required to prevent unwarranted language-mixing situations (Garcia et al. 2020). Grounded on such a process-oriented taxonomy, one would at least expect SIs to train a specific set of cognitive operations more than bi/multilingual individuals in everyday life, namely verbal short-term and working memory, language switching, inhibition and auditory attention functions (Elmer 2012; Garcia et al. 2020; Hervais-Adelman et al. 2011). Furthermore, it is conceivable that these cognitive benefits are not just limited to the verbal realm. Drawing on this background, we will next focus on the main corpus of behavioral studies which examined possible relationships between simultaneous interpreting practice and this specific set of cognitive functions. For an alternative perspective on this topic, the interested reader is also referred to the review articles by Garcia et al. (2020), Köpke and Signorelli (2012), Moser-Mercer (2000) and Nour et al. (2020).

3.1 Short-term and working memory

Several research groups used cross-sectional (Christoffels et al. 2006; Injoque-Ricle et al. 2015; Morales et al. 2015; Nour et al. 2020; Signorelli et al. 2012; Stavrakaki et al. 2012) or longitudinal (Nour et al. 2020) approaches to address the question of whether different levels of interpreting practice may have an impact on short-term and working memory. These studies generally showed a moderate effect of interpreting practice on verbal working memory capacity, while a positive influence on short-term memory seems to be rather controversial (Nour et al. 2020; Signorelli et al. 2012). However, most studies were conducted with relatively small sample sizes, which can prevent the extrapolation of results and lead to false positive outcomes that overestimate the magnitude of an affect (Button et al. 2013).

To counteract such limitations, some authors harked back on meta-analyses, and re-evaluated the influence of interpreting training on short-term and working memory functions (Ghiselli 2022; Mellinger & Hanson 2019; Wen & Dong 2019). For example, Mellinger and Hanson (2019) used random-effects models to examine differences between professional SIs or trainee interpreters and control par-

ticipants in working memory and short-term memory tests that relied on both visual and auditory stimuli. The authors revealed a general benefit of interpreting practice on verbal working memory capacity across modalities, and, also, found a positive correlation between working memory metrics and qualitative measures of interpreting performance. In a further meta-analysis, Ghiselli (2022) examined behavioral indices in professional SIs, interpreting students and non-interpreters on four verbal and non-verbal working memory measures, namely reading span, listening span, n-back task and dual tasks. Ghiselli confirmed a working memory advantage in those individuals with interpreting practice. However, the significant effect was limited to tasks that included verbal material. Also Wen and Dong (2019) re-evaluated working memory and short-term memory functions in SIs and bilinguals by including studies that relied on both verbal and non-verbal material, and again found an overall benefit of SIs in working memory capacity covering also non-verbal tasks (numerical, letter, or spatial tasks). In addition, the authors provided evidence of increased short-term memory span in SIs, although any memory-related benefit tended to be more pronounced on verbal versus non-verbal items. The results also showed an influence of amount of interpreting practice on both memory parameters, with no advantage for interpreting students and a comparable benefit in intermediate and expert SIs. The latter result is particularly interesting insofar as it indicates a discrete influence of interpreting training on verbal memory functions.

3.2 Attention and inhibition

To the best of our knowledge, there is a paucity of meta-analyses that examined the effects of simultaneous interpretation practice on cognitive functions other than short-term and working memory, and only a handful of studies addressed associations between simultaneous interpreting, inhibition functions, and attention. In the only behavioral study examining attention functions in SIs and bilingual control participants, Morales et al. (2015) made use of the Attention Networks Test for Interaction (ANTI) to assess three major subcomponents of attention, namely alertness, orientation, and executive control. Similar to the flanker task (Sidarus & Haggard 2016), in the ANTI participants have to decide whether a target arrow situated in the middle of a sequence and surrounded by concordant or discordant items points either to the left or to the right. Furthermore, target presentation could be preceded by a warning tone and/or a visual cue (Roca et al. 2011). Reaction time (RT) data showed that control participants exhibited larger visual cueing effects (orientation) when an additional alerting tone was presented, whereas in SIs the orientation network was unaffected by warning tones. Although some additional studies attempted to use electroen-

cephalography (Yagura et al. 2020, 2021) or functional MRI (Elmer et al. 2011) to address the neural signature of attention functions in SIs, this specific cognitive function is clearly understudied. Hence, future studies should rely on powerful experimental designs that enable to test whether interpreting practice has effectively the potential to alter selective or divided attention functions in both the auditory and visual domains.

To date, a few studies also addressed the possible influence of simultaneous interpreting on inhibitory functions (Aparicio et al. 2017; Dong & Zhong 2017; Van de Putte et al. 2018; van der Linden et al. 2018; Yudes et al. 2011). For example, Yudes et al. (2011) applied a Simon task and compared behavioral data between professional SIs, bilinguals and monolingual participants. The Simon task is typically used to infer inhibition and conflict resolution (Van der Lubbe & Verleger 2002), consists of two colored squares which are presented either on the left or the right side of a screen, and the participants have to press the button on the right in response to the red target and the one on the left for the blue target. Importantly, in some trials the spatial position of the squares is incongruent with the location of the response button, and in such a case the participants have to suppress their tendency to react towards the spatial location of the target by engaging inhibition functions. Although the authors were able to replicate the Simon effect with slower RTs and more errors to incongruent compared to congruent trials, they did not reveal any behavioral advantage in SIs. In a further study, Dong and Zhong (2017) administered a classical flanker task in two groups of university students with different interpreting experience, and found that the students with more practice showed a smaller interference effect in terms of RT (incongruent minus congruent trials), suggesting a discrete impact of interpreting training on inhibitory control. Also Van der Linden et al. (2018) used a flanker as well as a Simon task to assess inhibitory functions in professional SIs, monolinguals and second language teachers. However, in both experiments the authors did not reveal any behavioral group differences. In summary, the few available studies that examined attention and inhibitory functions did not provide compelling evidence for a benefit of simultaneous interpreting practice. However, it is noteworthy to mention that the majority of these studies did not use verbal material and that the tasks were mainly restricted to the visual modality.

3.3 Language and set-switching

Since language switching is a central part of the interpreting process, one would expect this highly trained skill to translate into a behavioral advantage, especially in experimental conditions requiring to shift between linguistic (Aparicio et al. 2017; Boos et al. 2022; Dottori et al. 2020; Elmer et al. 2010; Proverbio et al. 2004)

or even non-linguistic codes (Van de Putte et al. 2018; Yudes et al. 2011). In this context, Aparicio et al. (2017) investigated L1-to-L2 and L2-to-L1 switching mechanisms in SIs and highly proficient bilinguals, while participants had to select to which language visually presented French and German words belong to. Results showed an influence of interpreting training on language switching that was generally manifested in a lower discrepancy in response accuracy in SIs between within-language repetition trials and mixed trials. Furthermore, bilinguals but not SIs demonstrated longer RTs in response to switch compared to non-switch trials. In another language switching study, Boos et al. (2022) used a mixed (English and German, from L1-to-L2 and L2-to-L1) and unmixed lexical decision task where SIs, trainee interpreters, foreign language teachers, and Anglistics students had to decide whether successively presented auditory items were words or pseudowords. The RT but not the accuracy data yielded a group x switch interaction effect that originated from larger differences between the two conditions in professional SIs compared to Anglistic students.

In a further study, Van de Putte et al. (2018) made use of a longitudinal design to examine switching effects in a sample of interpreting students and a control group of translators while the participants completed a non-linguistic color-shape switching task. In the unmixed condition, participants had to assess either the color or the shape of the target, whereas in the mixed condition they had to alternate between the two tasks based on a specific cue. However, the authors did not reveal any between-group differences in terms of accuracy or RT before or after the training session. Also Yudes et al. (2011) analyzed non-linguistic switching mechanisms in SIs, bilinguals, and monolinguals using a card sorting task that relied on changing rules that needed to be implicitly recognized. In this so-called Wisconsin card sorting task, SIs made fewer errors and produced less previous-sorting-category perseveration errors compared to bilingual and monolingual participants.

From the studies reviewed in this article, it can be concluded that the most persuasive results point to an advantage of individuals with interpreting practice in verbal working memory tasks in the auditory and visual modality, while the other psychological functions examined appear to be characterized by higher variability and do not allow any firm conclusions. Nevertheless, before making a final assessment, for future studies and meta-analyses it would be desirable to work with larger sample sizes, take into account publication bias, reconsider inclusion and exclusion criteria, and to more strongly focus on longitudinal approaches.

4. Discussion

4.1 Future directions for studies on SIs in the field of aging

As mentioned above, very little is known about how aging affects SIs and their interpreting performance. Such information would be helpful in our rapidly aging society which has increasing numbers of older adults who will remain in the workforce and continue to interpret professionally. Aging certainly poses challenges for cognitive abilities such as processing speed, memory, and reasoning (Salthouse 2019) as well as sensory functioning, for example, in the auditory domain (Giroud et al. 2018; Giroud et al. 2021). Both cognitive functioning and auditory processing are, however, at the core of simultaneous interpretation suggesting that aging affects SIs tremendously (Liu et al. 2020; Signorelli et al. 2012). It is therefore important to better understand the experiences of SIs across their lifespan into old age. Still, previous studies which have investigated gray matter plasticity as a function of simultaneous interpretation training have included younger and middle-aged adults in the age range of about 20–50 years (Elmer et al. 2014; Hervais-Adelman et al. 2017), while the inclusion of older groups (50 years and above) has been neglected so far.

An interesting and relevant open research question is therefore if and to what degree the practice of simultaneous interpreting in old age, despite its cognitive challenges, can effectively support cognitive and neural stability in late life. Does the extended language, cognitive experience and cognitive demands of SIs lead to more sustained cognitive functioning in older adults compared to non-interpreters? Does the unique verbal and cognitive training in professional SIs provide sustained cognitive functioning above and beyond multilingual experience in old age or are the challenges leading to a breakdown of cognitive performance? These are research questions that need to be addressed in future research and we here provide a framework to do so.

For example, a previous study reviewed above addressed similar questions in younger adults and investigated effects of training in simultaneous interpretation on gray matter plasticity (Hervais-Adelman et al. 2017). The study employed a longitudinal setting which allows to directly investigate neuroanatomical and cognitive changes as a function of the intense training process. Longitudinal settings are necessary to identify developmental trends over time (e.g., increases or decreases in gray matter parameters and improvement or worsening in cognitive functioning). Comparing such trajectories between trainees in simultaneous interpretation and untrained multilingual individuals allows to selectively identify neuroanatomical or cognitive changes that occur due to the training in simultaneous interpretation above and beyond multilingual exposure. However, when

attempting to study older SIs, many SIs will likely have already gone through training many years ago and we assume that it might be difficult, if not impossible, to find older participants who are going through simultaneous interpretation training for the first time in later life.

Thus, we propose an alternative approach to study older SIs. A longitudinal research paradigm should be designed to include two groups of experienced older SIs, one which is still actively practicing simultaneous interpretation (experimental group), while the other one is not (control group). Both groups should be matched for factors potentially influencing outcome measures (i.e., cognition and neuroanatomy) such as age, sex, years of training, years and frequency of professional experience, type of intercepting (Ferreira et al. 2020), education, relevant health-related variables (e.g., degree of hearing impairment), and multilingual experience (e.g., age of L2 acquisition, frequency of language use, etc.; for a continuous and multidimensional manner to describe multilingual experience see also Gullifer et al. 2021).

Furthermore, the choice of the control task will be of utmost importance for a good study design. While the experimental group will be active in simultaneous interpretation, the control group should perform another task at the same interval and intensity as the experimental group. Including such an active control group has several advantages: First, generally, including control groups allows to measure and subtract the degree of test-retest effects on the outcome measures. Second, including active control groups specifically controls for effects that may arise from adherence to the training protocol (Schmitt et al. 2023; von Bastian & Oberauer 2014). Third, active control tasks can be chosen to address potential effects of specific aspects of an intervention on outcome measures. For example, if researchers want to test to what degree the simultaneity of interpreting is the most benefitting factor for cognition and neuroanatomical stability in old age, then a control task could be to perform non-simultaneous translations (e.g., from recordings) in the active control group. If stronger positive effects on cognitive and neuroanatomical development can be shown in the experimental group compared to the control group, it can be deducted that simultaneity of receptive and productive language translation is the isolated factor leading to the presented outcome. Obviously, using such an active control group has the advantage that many more research questions about the factors influencing positive outcomes in aging can be addressed.

Another important aspect of such a design is the time interval at which pre-training and post-training outcome measures are tested. In studies with older adults investigating cognitive and neuroanatomical changes, the intervals should span over several months. For example, a study by Fjell et al. (2009) has shown that brain atrophy is evident after one year in healthy aging, suggesting that a 12

months interval could be enough to see age-related changes in neuroanatomy and potentially cognition which can then be compared between groups in its degree of change. In terms of behavioral outcome measures which were reviewed above, we suggest focusing on verbal working memory tasks, which can be administered in the visual or auditory domain. We would expect to see most effects of cognitive stability as a function of simultaneous interpretation training in such a task. However, as described above, other cognitive aspects such as attention and set switching could also be included as transfer effects onto these domains are possible.

4.2 Why should interpreting practice benefit cognition and counteract brain aging?

The prevalence of cognitive impairment in aging due to Alzheimer's dementia is expected to rise globally. Estimations by the WHO suggest that the numbers are going to double or even triple until 2050, which leads to huge and increasing costs for patients, their families, the economy, and the healthcare system.[1] Research is becoming focused on prevention and behavioral interventions rather than pharmacological treatments which are currently not efficient (Livingston et al. 2020; Livingston et al. 2017). One promising approach is to find risk factors of cognitive decline which are potentially modifiable such as hearing impairment, diabetes, hypertension, social isolation, cognitive inactivity, and others, which in total might prevent or delay up to 40% of dementias on a population-level if treated (Livingston et al. 2020). Thus, increasing, for example, cognitive activity and treating hearing impairment (i.e., improving speech communication) in older adults might already be very beneficial for individual aging, but also for population-level cognitive aging. The challenge is therefore to find effective, low-cost, and motivating behavioral interventions to keep cognition challenged and speech communication trained (Giroud et al., 2017).

Here we argue that simultaneous interpretation should be used as a model to study such language, speech, and cognitive engagement in older adults, with study protocols outlined above, for several reasons. First, there is already existing evidence that multilingualism, which is a key part of the interpreting practice, has positive effects on cognition in older adults as well as brain aging (Bialystok et al. 2016; Bialystok et al. 2014; Zhang et al. 2020) suggesting that SIs might show benefits in cognition and brain aging as well. Second, as reviewed above, simultaneous interpretation goes beyond using multiple languages and being exposed to a multilingual environment. The simultaneity of interpretation leads to increased cognitive demand and more simultaneous activation of neural resources in the

1. https://www.who.int/publications/i/item/9789241550543

auditory-receptive, motor-productive, language and cognitive networks in the brain (Hervais-Adelman et al. 2015; Hervais-Adelman et al. 2015; Rinne et al. 2000) as compared to being part of a conversation in a second or third language. In general, we expect that simultaneous interpretation is therefore more multifaceted and poses stronger demands onto the cognitive and language system in the brain as compared to multilingualism. Importantly, previous research on behavioral cognitive interventions in aging has pointed out that a combination of receptive training with active, social, and multimodal aspects is most beneficial and shows strongest transfer effects onto untrained cognitive tasks such as episodic memory (Park et al. 2014; Ping, Li, & Hyengjeong Jeong. 2020). SIs combine all those aspects in their practice. Moreover, we believe that at least three modifiable risk factors of dementia can be targeted with simultaneous interpretation practice, namely hearing impairment by keeping the auditory system challenged and engaged in communicative situations, social isolation by staying professionally active and being in multilingual conversations, and cognitive disengagement by keeping up with the cognitive demands of simultaneous interpretation. Apart from those expected benefits we further believe that simultaneous interpretation can also be used as a model to study the specific aspects of cognitive-language trainings that are most beneficial for dementia prevention in aging with study designs outlined above. For example, it provides a unique window into the question to what degree the simultaneity, the high cognitive demand, and/or the multimodality is the most important factor in designing effective behavioral interventions to support cognitive aging, which is a huge goal in our aging society.

5. Conclusion

In addition to brain structural plasticity, cognitive benefits of simultaneous interpretation practice in young professionals have been shown in verbal working memory tasks. Given our aging society and the challenges posed by age-related sensory and cognitive decline, research on potential positive effects of simultaneous interpretation on sensory and cognitive health should be investigated with the goal to develop personalized interventions to support communication functions across the lifespan. We suggest performing studies in longitudinal settings that allow for assessing developmental trends over at least 12 months, and to compare trajectories to individuals with multilingual experience (but no experience in simultaneous interpretation). Furthermore, because it might be difficult to find older participants who are going to complete a serious and professional simultaneous interpretation training, studies should compare two groups of older adults who are professional SIs, one which is still involved in professional simultaneous

interpretation and the other one which is not, while controlling for other influencing factors discussed in this review. We also believe that the choice of the outcome tasks is highly relevant and that active control groups need to be included in such a study. Knowing the underlying components that benefit verbal communication abilities in cognitively demanding situations will provide essential knowledge for aging-related interventions to support stabilization of sensory and cognitive functioning as well as brain health more generally across the lifespan.

Funding

Open Access publication of this article was funded through a Transformative Agreement with University of Zurich.

References

Abutalebi, J., & David Green. 2007. "Bilingual Language Production: The Neurocognition of Language Representation and Control." *Journal of Neurolinguistics* 20 (3): 242–275.

Anguera, J.A., J. Boccanfuso, J.L. Rintoul, O. Al-Hashimi, F. Faraji, J. Janowich, E. Kong, Y. Larraburo, C. Rolle, E. Johnston, & A. Gazzaley. 2013. "Video Game Training Enhances Cognitive Control in Older Adults." *Nature* 501 (7465): 97–101.

Aparicio, X., K. Heidlmayr, & F. Isel. 2017. "Inhibition Efficiency in Highly Proficient Bilinguals and Simultaneous Interpreters: Evidence from Language Switching and Stroop Tasks." *Journal of Psycholinguistic Research*, 46 (6): 1427–1451.

Bak, T.H., M.R. Long, M. Vega-Mendoza, & A. Sorace. 2016. "Novelty, Challenge, and Practice: The Impact of Intensive Language Learning on Attentional Functions." *Plos One* 11 (4).

Bamidis, P.D., A.B. Vivas, C. Styliadis, C. Frantzidis, M. Klados, W. Schlee, A. Siountas, & S.G. Papageorgiou. 2014. "A Review of Physical and Cognitive Interventions in Aging." *Neuroscience and Biobehavioral Reviews* 44: 206–220.

Becker, M., Torsten Schubert, Tilo Strobach, Jürgen Gallinat, & Simone Kühn. 2016. "Simultaneous Interpreters vs. Professional Multilingual Controls: Group Differences in Cognitive Control as well as Brain Structure and Function." *Neuroimage* 134: 250–260.

Bethlehem, R. A. I., J. Seidlitz, S. R. White, J. W. Vogel, K. M. Anderson, C. Adamson, S. Adler, G. S. Alexopoulos, E. Anagnostou, A. Areces-Gonzalez, D. E. Astle, B. Auyeung, M. Ayub, J. Bae, G. Ball, S. Baron-Cohen, R. Beare, S. A. Bedford, V. Benegal, F. Beyer, J. Blangero, M. Blesa Cábez, J. P. Boardman, M. Borzage, J. F. Bosch-Bayard, N. Bourke, V. D. Calhoun, M. M. Chakravarty, C. Chen, C. Chertavian, G. Chetelat, Y. S. Chong, J. H. Cole, A. Corvin, M. Costantino, E. Courchesne, F. Crivello, V. L. Cropley, J. Crosbie, N. Crossley, M. Delarue, R. Delorme, S. Desrivieres, G. A. Devenyi, M. A. Di Biase, R. Dolan, K. A. Donald, G. Donohoe, K. Dunlop, A. D. Edwards, J. T. Elison, C. T. Ellis, J. A. Elman, L. Eyler, D. A. Fair, E. Feczko, P. C. Fletcher, P. Fonagy, C. E. Franz, L. Galan-Garcia, A. Gholipour, J. Giedd, J. H. Gilmore, D. C. Glahn, I. M. Goodyer, P. E. Grant, N. A. Groenewold, F. M. Gunning, R. E. Gur, R. C. Gur, C. F. Hammill, O. Hansson, T. Hedden, A. Heinz, R. N. Henson, K. Heuer, J. Hoare, B. Holla, A. J. Holmes, R. Holt, H. Huang, K. Im, J. Ipser, C. R. Jack Jr, A. P. Jackowski, T. Jia, K. A. Johnson, P. B. Jones, D. T. Jones, R. S. Kahn, H. Karlsson, L. Karlsson, R. Kawashima, E. A. Kelley, S. Kern, K. W. Kim, M. G. Kitzbichler, W. S. Kremen, F. Lalonde, B. Landeau, S. Lee, J. Lerch, J. D. Lewis, J. Li, W. Liao, C. Liston, M. V. Lombardo, J. Lv, C. Lynch, T. T. Mallard, M. Marcelis, R. D. Markello, S. R. Mathias, B. Mazoyer, P. McGuire, M. J. Meaney, A. Mechelli, N. Medic, B. Misic, S. E. Morgan, D. Mothersill, J. Nigg, M. Q. W. Ong, C. Ortinau, R. Ossenkoppele, M. Ouyang, L. Palaniyappan, L. Paly, P. M. Pan, C. Pantelis, M. M. Park, T. Paus, Z. Pausova, D. Paz-Linares, A. Pichet Binette, K. Pierce, X. Qian, J. Qiu, A. Qiu, A. Raznahan, T. Rittman, A. Rodrigue, C. K. Rollins, R. Romero-Garcia, L. Ronan, M. D. Rosenberg, D. H. Rowitch, G. A. Salum, T. D. Satterthwaite, H. L. Schaare, R. J. Schachar, A. P. Schultz, G. Schumann, M. Schöll, D. Sharp, R. T. Shinohara, I. Skoog, C. D. Smyser, R. A. Sperling, D. J. Stein, A. Stolicyn, J. Suckling, G. Sullivan, Y. Taki, B. Thyreau, R. Toro, N. Traut, K. A. Tsvetanov, N. B. Turk-Browne, J. J. Tuulari, C. Tzourio, É. Vachon-Presseau, M. J. Valdes-Sosa, P. A. Valdes-Sosa, S. L. Valk, T. van Amelsvoort, S. N. Vandekar, L. Vasung, L. W. Victoria, S. Villeneuve, A. Villringer, P. E. Vértes, K. Wagstyl, Y. S. Wang, S. K. Warfield, V. Warrier, E. Westman, M. L. Westwater, H. C. Whalley, A. V. Witte, N. Yang, B. Yeo, H. Yun, A. Zalesky, H. J. Zar, A. Zettergren, J. H. Zhou, H. Ziauddeen, A. Zugman, X. N. Zuo, 3R-BRAIN, AIBL, Alzheimer's Disease Neuroimaging Initiative, Alzheimer's Disease Repository Without Borders Investigators, CALM Team, Cam-CAN, CCNP, COBRE, cVEDA, ENIGMA Developmental Brain Age Working Group, Developing Human Connectome Project, FinnBrain, Harvard Aging Brain Study, IMAGEN, KNE96, The Mayo Clinic Study of Aging, NSPN, POND, The PREVENT-AD Research Group, VETSA, E. T. Bullmore & A. F. Alexander-Bloch. 2022. "Brain Charts for the Human Lifespan." *Nature* 604 (7906): 525–533.

Bialystok, E., Jubin Abutalebi, Bak, Thomas H. Bak, Deborah M. Burke, & Judith F. Kroll. 2016. "Aging in Two Languages: Implications for Public Health." *Ageing Research Reviews* 27: 56–60.

Bialystok, E., Fergus I. M. Craik, & Gigi Luk. 2012. "Bilingualism: Consequences for Mind and Brain." *Trends in Cognitive Sciences* 16 (4): 240–250.

Bialystok, E., G. Poarch, L. Luo, & F. I. M. Craik. 2014. "Effects of Bilingualism and Aging on Executive Function and Working Memory." *Psychology and Aging* 29 (3): 696–705.

Binder, Julia C., Jacqueline Zollig, Anne Eschen, Susan Merillat, Christina Rocke, Sarah F. Schoch, Lutz Jäncke, & Mike Martin. 2015. "Multi-domain Training in Healthy Old Age: Hotel Plastisse as an iPad-based Serious Game to Systematically Compare Multi-domain and Single-domain Training." *Frontiers in Aging Neuroscience* 7.

Boos, Michael, Matthias Kobi, Stefan Elmer, & Lutz Jancke. 2022. "Tracking Lexical Access and Code Switching in Multilingual Participants with Different Degrees of Simultaneous Interpretation Expertise." *European Journal of Neuroscience* 56 (6): 4869–4888.

Button, Katherine S., John P.A. Ioannidis, Claire Mokrysz, Brian A. Nosek, Jonathan Flint, Emma S.J. Robinson, & Marcus R. Munafó. 2013. "Power Failure: Why Small Sample Size Undermines the Reliability of Neuroscience." *Nature Reviews Neuroscience* 14 (6): 365–376.

Christoffels, Ingrid K., Annette M.B. de Groot, & Judith F. Kroll. 2006. "Memory and Language Skills in Simultaneous Interpreters: The Role of Expertise and Language Proficiency." *Journal of Memory and Language* 54 (3): 324–345.

Colcombe, Stanley J., Kirk I. Erickson, Paige E. Scalf, Jenny S. Kim, Ruchika Prakash, Edward McAuley, Steriani Elavsky, David X. Marquez, Liang Hu, Arthur F. Kramer. 2006. "Aerobic Exercise Training Increases Brain Volume in Aging Humans." *Journals of Gerontology Series a-Biological Sciences and Medical Sciences* 61 (11): 1166–1170.

Dong, Yanping, & Fei Zhong. 2017. "Interpreting Experience Enhances Early Attentional Processing, Conflict Monitoring and Interference Suppression Along the Time Course of Processing." *Neuropsychologia* 95: 193–203.

Dottori, Martin, Eugenia Hesse, Micaela Santilli, Martina G. Vilas, Miguel Martorell Caro, Daniel Fraiman, Lucas Sedeño, Agustín Ibáñez, Adolfo M. García. 2020. "Task-specific Signatures in the Expert Brain: Differential Correlates of Translation and Reading in Professional Interpreters." *Neuroimage* 1 (209): 116519.

Elliott, Jane, Catharine R. Gale, Samantha Parsons, Diana Kuh, HALCyon Study Team. 2014. "Neighbourhood Cohesion and Mental Wellbeing Among Older Adults: A Mixed Methods Approach." *Social Science & Medicine* 107: 44–51.

Elmer, Stefan. 2012. "The Investigation of Simultaneous Interpreters as an Alternative Approach to Address the Signature of Multilingual Speech Processing." *Zeitschrift für Neuropsychologie* 23 (2): 105–116.

Elmer, Stefan, Jürgen Hänggi, & Lutz Jancke. 2014. "Processing Demands upon Cognitive, Linguistic, and Articulatory Functions Promote Gray Matter Plasticity in the Adult Multilingual Brain: Insights from Simultaneous Interpreters." *Cortex* 54: 179–189.

Elmer, S., Martin Meyer, & Lutz Jancke. 2010. "Simultaneous Interpreters as a Model for Neuronal Adaptation in the Domain of Language Processing." *Brain Research* 1317: 147–156.

Elmer, Stefan, Martin Meyer, Lucas Marrama, & Lutz Jancke. 2011. "Intensive Language Training and Attention Modulate the Involvement of Fronto-parietal Regions During a Non-verbal Auditory Discrimination Task." *European Journal of Neuroscience* 34 (1): 165–175.

doi Erickson, Kirk I., Michelle W. Voss, Ruchika Shaurya Prakash, Chandramallika Basak, Amanda Szabo, Laura Chaddock, Jennifer S. Kim, Susie Heo, Heloisa Alves, Siobhan M. White, Thomas R. Wojcicki, Emily Mailey, Victoria J. Vieira, Stephen A. Martin, Brandt D. Pence, Jeffrey A. Woods, Edward McAuley, & Arthur F. Kramer. 2011. "Exercise Training Increases Size of Hippocampus and Improves Memory." *Proceedings of the National Academy of Sciences of the United States of America* 108 (7): 3017–3022.

doi Fabbro, F., Bruno Gran, & Laura Gran. 1991. "Hemispheric-Specialization for Semantic and Syntactic Components of Language in Simultaneous Interpreters." *Brain and Language* 41 (1): 1–42.

doi Ferreira, A., John W. Schwieter, & Julia Festman. 2020. "Cognitive and Neurocognitive Effects from the Unique Bilingual Experiences of Interpreters." *Frontiers in Psychology*, 11.

doi Fjell, Anders M., Kristine B. Walhovd, Christine Fennema-Notestine, Linda K. McEvoy, Donald J. Hagler, Dominic Holland, James B. Brewer, & Anders M. Dale. 2009. "One-Year Brain Atrophy Evident in Healthy Aging." *Journal of Neuroscience* 29 (48): 15223–15231.

doi Fjell, A. M., Lars T. Westlye, Håkon Grydeland, Inge Amlien, Thomas Espeseth, Ivar Reinvang, Naftali Raz, Dominic Holland, Anders M. Dale, Kristine B. Walhovd, Alzheimer Disease Neuroimaging Initiative. 2013. "Critical Ages in the Life Course of the Adult Brain: Nonlinear Subcortical Aging." *Neurobiology of Aging* 34 (10): 2239–2247.

doi Foubert-Samier, A., Gwenaelle Catheline, Hélène Amieva, Bixente Dilharreguy, Catherine Helmer, Michèle Allard, & Jean-François Dartigues. 2012. "Education, Occupation, Leisure Activities, and Brain Reserve: a Population-based Study." *Neurobiology of Aging* 33 (2): 423.e15–423.e25.

doi Garcia, A. M., Edinson Munoz, & Boris Kogan. 2020. "Taxing the Bilingual Mind: Effects of Simultaneous Interpreting Experience on Verbal and Executive Mechanisms." *Bilingualism-Language and Cognition* 23 (4): 729–739.

doi Ghiselli, Serena. 2022. "Working Memory Tasks in Interpreting Studies: A Meta-analysis." *Translation, Cognition & Behavior* 5 (1): 50–83.

doi Giorgio, A., K. E. Watkins, M. Chadwick, S. James, L. Winmill, G. Douaud, N. De Stefano, P. M. Matthews, S. M. Smith, H. Johansen-Berg, & A. C. James. 2010. "Longitudinal Changes in Gray and White Matter During Adolescence." *Neuroimage* 49 (1): 94–103.

doi Giroud, N., Sarah Hirsiger, Raphaela Muri, Andrea Kegel, Norbert Dillier, & Martin Meyer. 2018. "Neuroanatomical and Resting State EEG Power Correlates of Central Hearing Loss in Older Adults." *Brain Structure & Function* 223 (1): 145–163.

doi Giroud, Natalie, Matthias Keller, & Martin Meyer. 2021. "Interacting Effects of Frontal Lobe Neuroanatomy and Working Memory Capacity to Older Listeners' Speech Recognition in Noise." *Neuropsychologia* 158.

doi Giroud, Natalie, Ulrike Lemke, Philip Reich, Katarina L. Matthes, & Martin Meyer. 2017. "Longitudinal Auditory Learning Facilitates Auditory Cognition as Revealed by Microstate Analysis." *Biological Psychology* 123: 25–36.

Gogtay, Nitin, Jay N. Giedd, Leslie Lusk, Kiralee M. Hayashi, Deanna Greenstein, A. Catherine Vaituzis, Tom F. Nugent, David H. Herman, Liv S. Clasen, Arthur W. Toga, & Judith L. Rapoport. 2004. "Dynamic Mapping of Human Cortical Development During Childhood through Early Adulthood." *Proceedings of the National Academy of Sciences of the United States of America* 101 (21): 8174–8179.

Gullifer, Jason W., Shanna Kousaie, Annie C. Gilbert, Angela Grant, Nathalie Giroud, Kristina Coulter, Denise Klein, Shari Baum, Natalie Phillips & Debra Titone. 2021. "Bilingual Language Experience as a Multidimensional Spectrum: Associations with Objective and Subjective Language Proficiency." *Applied Psycholinguistics* 42 (2): 245–278.

Harada, Caroline N., Marissa C. Natelson Love, & Kristen L. Triebel. 2013. "Normal Cognitive Aging." *Clinics in Geriatric Medicine* 29 (4): 737–752.

Hedden, Trey, & John D. E. Gabrieli. 2004. "Insights into the Ageing Mind: A View from Cognitive Neuroscience." *Nature Reviews Neuroscience* 5 (2): 87–96.

Alexis Hervais-Adelman, & Laura Babcock. 2020. "The Neurobiology of Simultaneous Interpreting: Where Extreme Language Control and Cognitive Control Intersect." *Bilingualism-Language and Cognition* 23 (4): 740–751.

Hervais-Adelman, Alexis, Barbara Moser-Mercer, & Narly Golestani. 2015. "Brain Functional Plasticity Associated with the Emergence of Expertise in Extreme Language Control." *Neuroimage* 114: 264–274.

Hervais-Adelman, Alexis, Barbara Moser-Mercer, Cristoph M. Michel, & Narly Golestani, N. 2015. "fMRI of Simultaneous Interpretation Reveals the Neural Basis of Extreme Language Control." *Cerebral Cortex* 25 (12): 4727–4739.

Hervais-Adelman, Alexis, Barbara Moser-Mercer, Micah M. Murray, & Narly Golestani. 2017. "Cortical Thickness Increases after Simultaneous Interpretation Training." *Neuropsychologia* 98: 212–219.

Hervais-Adelman, Alexis George, Barbara Moser-Mercer, & Narly Golestani. 2011. "Executive Control of Language in the Bilingual Brain: Integrating the Evidence from Neuroimaging to Neuropsychology." *Frontiers in Psychology* 2.

Injoque-Ricle, Irene, Juan Pablo Barreyro, Jesica Formoso, & Virginia I. Jaichenco. 2015. "Expertise, Working Memory and Articulatory Suppression Effect: Their Relation with Simultaneous Interpreting Performance." *Advances in Cognitive Psychology* 11 (2): 56–63.

Jaeggi, Susanne M., Martin Buschkuehl, John Jonides, & Priti Shah. 2011. "Short- and Long-term Benefits of Cognitive Training." *Proceedings of the National Academy of Sciences of the United States of America* 108 (25): 10081–10086.

Kopke, Barbara, & Teresa M. Signorelli. 2012. "Methodological Aspects of Working Memory Assessment in Simultaneous Interpreters." *International Journal of Bilingualism* 16 (2): 183–197.

Kramer, Arthur F., Louis Bherer, Stanley J. Colcombe, Willie Dong, & William T. Greenough. 2004. "Environmental Influences on Cognitive and Brain Plasticity During Aging." *Journals of Gerontology Series a-Biological Sciences and Medical Sciences* 59 (9): 940–957.

Lehtonen, M., A. Soveri, A. Laine, J. Jarvenpaa, A. de Bruin, & J. Antfolk. 2018. "Is Bilingualism Associated with Enhanced Executive Functioning in Adults? A Meta-Analytic Review." *Psychological Bulletin* 144 (4): 394–425.

Ping, Li, & Hyengjeong Jeong. 2020. "The Social Brain of Language: Grounding Second Language Learning in Social Interaction." *Npj Science of Learning* 5 (1).

doi Li, Ping, Jennifer Legault, & Kaitlyn A. Litcofsky. 2014. "Neuroplasticity as a Function of Second Language Learning: Anatomical Changes in the Human Brain." *Cortex* 58: 301–324.

doi Liu, Minhua, Ingrid Kurz, Barbara Moser-Mercer, & Miriam Shlesinger. 2020. "A Unique Story of Multilingual Cognitive Decline?" *Translation, Cognition & Behavior* 3 (2): 287–310.

doi Livingston, Gill, Jonathan Huntley, Andrew Sommerlad, David Ames, Clive Ballard, Sube Banerjee, Carol Brayne, Alistair Burns, Jiska Cohen-Mansfield, Claudia Cooper, Sergi G. Costafreda, Amit Dias, Nick Fox, Laura N. Gitlin, Robert Howard, Helen C. Kales, Mika Kivimäki, Eric B. Larson, Adesola Ogunniyi, Vasiliki Orgeta, Karen Ritchie, Kenneth Rockwood, Elizabeth L. Sampson, Quincy Samus, Lon S. Schneider, Geir Selbæk, Linda Teri, & Naaheed Mukadam. 2020. "Dementia Prevention, Intervention, and Care: 2020 Report of the Lancet Commission." *Lancet* 396 (10248): 413–446.

doi Livingston, Gill, Andrew Sommerlad, Vasiliki Orgeta, Sergi G. Costafreda, Jonathan Huntley, David Ames, Clive Ballard, Sube Banerjee, Alistair Burns, Jiska Cohen-Mansfield, Claudia Cooper, Nick Fox, Laura N. Gitlin, Robert Howard, Helen C. Kales, Eric B. Larson, Karen Ritchie, Kenneth Rockwood, Elizabeth L. Sampson, Quincy Samus, Lon S. Schneider, Geir Selbæk, Linda Teri, & Naaheed Mukadam. 2017. "Dementia Prevention, Intervention, and Care." *Lancet* 390 (10113): 2673–2734.

doi Mellinger, Christopher D., & Thomas A. Hanson. 2019. "Meta-analyses of Simultaneous Interpreting and Working Memory." *Interpreting* 21 (2): 165–195.

doi Morales, Julia, Francisca Padilla, Carlos J. Gomez-Ariza, & M. Teresa Bajo. 2015. "Simultaneous Interpretation Selectively Influences Working Memory and Attentional Networks." *Acta Psychologica* 155: 82–91.

doi Moser-Mercer, Barbara. 2000. "Simultaneous Interpreting: Cognitive Potential and Limitations." *Interpreting* 5 (2): 83–94.

doi Nour, Sourdabeh, Eslu Struys, & Helene Stengers. 2020. "Adaptive Control in Interpreters: Assessing the Impact of Training and Experience on Working Memory." *Bilingualism-Language and Cognition* 23 (4): 772–779.

doi Nour, Sourdabeh, Eslu Struys, Evy Woumans, Ily Hollebeke, & Helène Stengers. 2020. "An Interpreter Advantage in Executive Functions? A Systematic Review." *Interpreting* 22 (2): 163–186.

doi Orben, Amy, Livia Tomova, & Sarah-Jayne Blakemore. 2020. "The Effects of Social Deprivation on Adolescent Development and Mental Health." *Lancet Child & Adolescent Health* 4 (8): 634–640.

doi Paap, Kenneth R., & Zachary I. Greenberg. 2013. "There Is No Coherent Evidence for a Bilingual Advantage in Executive Processing." *Cognitive Psychology* 66 (2): 232–258.

doi Paap, Keneth R., Hunter A. Johnson, & Oliver Sawi. 2015. "Bilingual Advantages in Executive Functioning Either Do Not Exist or Are Restricted to Very Specific and Undetermined Circumstances." *Cortex* 69: 265–278.

doi Park, Denise C., Jennifer Lodi-Smith, Linda Drew, Sara Haber, Andrew Hebrank, Gérard N. Bischof, & Whitley Aamodt. 2014. "The Impact of Sustained Engagement on Cognitive Function in Older Adults: The Synapse Project." *Psychological Science* 25 (1): 103–112.

Paus, Tomáš. 2005. "Mapping Brain Maturation and Cognitive Development During Adolescence." *Trends in Cognitive Sciences* 9 (2): 60–68.

Perani, Daniela, Jubin Abutalebi, Eraldo Paulesu, Simona Brambati, Paola Scifo, Stefano F. Cappa, & Ferruccio Fazio. 2003. "The Role of Age of Acquisition and Language Usage in Early, High-proficient Bilinguals: An fMRI Study During Verbal Fluency." *Human Brain Mapping* 19 (3): 170–182.

Perani, Daniela, E. Paulesu, N. S. Galles, E. Dupoux, S. Dehaene, V. Bettinardi, S. F. Cappa, F. Fazio, J. Mehler. 1998. "The Bilingual Brain – Proficiency and Age of Acquisition of the Second Language." *Brain* 121: 1841–1852.

Pliatsikas, Christos. 2020. "Understanding Structural Plasticity in the Bilingual Brain: The Dynamic Restructuring Model." *Bilingualism-Language and Cognition* 23 (2): 459–471.

Porat, Shai, Naira Goukasian, Kristy S. Hwang, Theodore Zanto, Triet Do, Jonathan Pierce, Shantanu Joshi, Ellen Woo, & Liana G. Apostolova. 2016. "Dance Experience and Associations with Cortical Gray Matter Thickness in the Aging Population." *Dementia Geriatric Cognitive Disorders Extra* 6 (3): 508–517.

Proverbio, Alice Mado, Giuliana Leoni, & Alberto Zani. 2004. "Language Switching Mechanisms in Simultaneous Interpreters: An ERP Study." *Neuropsychologia* 42 (12): 1636–1656.

Raz, Naftalí, Ulman Lindenberger, Karen M. Rodrigue, Kristen M. Kennedy, Denise Head, Adrienne Williamson, Cheryl Dahle, Denis Gerstorf, & James D. Acker. 2005. "Regional Brain Changes in Aging Healthy Adults: General Trends, Individual Differences and Modifiers." *Cerebral Cortex* 15 (11): 1676–1689.

Rehfeld, Kathrin, Angie Lüders, Anita Hökelmann, Volkmar Lessmann, Joern Kaufmann, Tanja Brigadski, Patrick Müller, & Notger G. Müller. 2018. "Dance Training Is Superior to Repetitive Physical Exercise in Inducing Brain Plasticity in the Elderly." *Plos One* 13 (7).

Resnick, Susan M., Dzung L. Pham, Michael A. Kraut, Alan B. Zonderman, & Christos Davatzikos. 2003. "Longitudinal Magnetic Resonance Imaging Studies of Older Adults: A Shrinking Brain." *Journal of Neuroscience* 23 (8): 3295–3301.

Rinne, J. O., J. Tommola, M. Laine, B. J. Krause, D. Schmidt, V. Kaasinen, M. Teräs, H. Sipilä, & M. Sunnari. 2000. "The Translating Brain: Cerebral Activation Patterns During Simultaneous Interpreting." *Neuroscience Letters* 294 (2): 85–88.

Ripolles, Pablo, Laura Ferreri, Ernest Mas-Herrero, Helena Alicart, Alba Gómez-Andrés, Josep Marco-Pallares, Rosa Maria Antonijoan, Toemme Noesselt, Marta Valle, Jordi Riba, & Antoni Rodriguez-Fornells. 2018. "Intrinsically Regulated Learning Is Modulated By Synaptic Dopamine Signaling." *Elife* 7.

Ripolles, Pablo, Josep Marco-Pallarés, Helena Alicart, Claus Tempelmann, Antoni Rodríguez-Fornells & Toemme Noesselt. 2016. "Intrinsic Monitoring of Learning Success Facilitates Memory Encoding Via the Activation of the SN/VTA-Hippocampal Loop." *Elife* 5.

Roca, Javier, Cándida Castro, María Fernanda López-Ramón, & Juan Lupiáñez. 2011. "Measuring Vigilance while Assessing the Functioning of the Three Attentional Networks: The ANTI-Vigilance Task." *Journal of Neuroscience Methods* 198 (2): 312–324.

Rodrigue, Karen M., & Naftali Raz. 2004. "Shrinkage of the Entorhinal Cortex over Five Years Predicts Memory Performance in Healthy Adults." *Journal of Neuroscience* 24 (4): 956–963.

Rogenmoser, Lars, Julius Kernbach, Gottfried Schlaug, & Christian Gaser. 2018. "Keeping Brains Young with Making Music." *Brain Structure & Function* 223 (1): 297–305.

Salthouse, T.A. 2019. "Trajectories of Normal Cognitive Aging." *Psychology and Aging* 34 (1): 17–24.

Santilli, Micaela, Martina G. Vilas, Ezequiel Mikulan, Miguel Martorell Caro, Edinson Muñoz, Lucas Sedeño, Agustín Ibáñez, & Adolfo M. García. 2019. "Bilingual Memory, to the Extreme: Lexical Processing in Simultaneous Interpreters." *Bilingualism-Language and Cognition* 22 (2): 331–348.

Schmitt, Raffael, Martin Meyer, & Nathalie Giroud. 2023. "Training-based Improvements in a Naturalistic Speech-in-noise Task in Older Adults with Hearing Impairment." *Npj Science of Learning* 8 (32).

Sidarus, Nura, & Patrick Haggard. 2016. "Difficult Action Decisions Reduce the Sense of Agency: A Study Using the Eriksen Flanker Task." *Acta Psychologica* 166: 1–11.

Signorelli, Teresa M., Henk J. Haarmann, & Loraine K. Obler. 2012. "Working Memory in Simultaneous Interpreters: Effects of Task and Age." *International Journal of Bilingualism* 16 (2): 198–212.

Stavrakaki, Stravoula, Kalliopi Megari, Mary H. Kosmidis, Maria Apostolidou, & Eleni Takou. 2012. "Working Memory and Verbal Fluency in Simultaneous Interpreters." *Journal of Clinical and Experimental Neuropsychology* 34 (6): 624–633.

Sutcliffe, Ryan, Kangning Du, & Ted Ruffman. 2020. "Music Making and Neuropsychological Aging: A Review." *Neuroscience and Biobehavioral Reviews* 113: 479–491.

Van de Putte, Eowyn, Wouter De Baene, Lorna García-Pentón, Evy Woumans, Aster Dijkgraaf, & Wouter Duyck. 2018. "Anatomical and Functional Changes in the Brain After Simultaneous Interpreting Training: A Longitudinal Study." *Cortex* 99: 243–257.

van der Linden, Lize, Eowyn Van de Putte, Evy Woumans, Wouter Duyck, & Arnaud Szmalec. 2018. "Does Extreme Language Control Training Improve Cognitive Control? Comparison of Professional Interpreters, L2 Teachers and Monolinguals." *Frontiers in Psychology* 9.

Rob H. J. Van der Lubbe, & Rolf Verleger. 2002. "Aging and the Simon Task." *Psychophysiology* 39 (1): 100–110.

van der Meer, Dennis & Tobias Kaufmann. 2022. "Mapping the Genetic Architecture of Cortical Morphology through Neuroimaging: Progress and Perspectives." *Translational Psychiatry* 12 (447).

von Bastian, Claudia C. & Klaus Oberauer. 2014. "Effects and Mechanisms of Working Memory Training: A Review." *Psychological Research-Psychologische Forschung* 78 (6): 803–820.

Wen, Hao & Yanping Dong. 2019. "How Does Interpreting Experience Enhance Working Memory and Short-term Memory: A Meta-analysis." *Journal of Cognitive Psychology* 31 (8): 769–784.

White-Schwoch, Travis, Kali Woodruff Carr, Samira Anderson, Dana L. Strait, & Nina Kraus. 2013. "Older Adults Benefit from Music Training Early in Life: Biological Evidence for Long-Term Training-Driven Plasticity." *Journal of Neuroscience* 33 (45): 17667–17674.

Wimo, Anders, Linus Jönsson, John Bond, Martin Prince, Bengt Winblad, & Alzheimer Disease International. 2013. "The Worldwide Economic Impact of Dementia 2010." *Alzheimers & Dementia* 9 (1): 1–11.

Yagura, Haruko, Hiroki Tanaka, Taiki Kinoshita, Hiroki Watanabe, Shunnosuke Motomura, Katsuhito Sudoh, & Satoshi Nakamura. 2020. "Analysis of Selective Attention Processing on Experienced Simultaneous Interpreters Using EEG Phase Synchronization." *42nd Annual International Conferences of the Ieee Engineering in Medicine and Biology Society: Enabling Innovative Technologies for Global Healthcare Embc'20* 66–69.

Yagura, Haruko, Hiroki Tanaka, Taiki Kinoshita, Hiroki Watanabe, Shunnosuke Motomura, Katsuhito Sudoh, & Satoshi Nakamura. 2021. "Selective Attention Measurement of Experienced Simultaneous Interpreters Using EEG Phase-Locked Response." *Frontiers in Human Neuroscience* 15.

Yudes, Carolina, Pedro Macizo, & Teresa Bajo. 2011. "The Influence of Expertise in Simultaneous Interpreting on Non-verbal Executive Processes." *Frontiers in Psychology* 2: 309.

Zatorre, Robert J., R. Douglas Fields, & Heidi Johansen-Berg. 2012. "Plasticity in Gray and White: Neuroimaging Changes in Brain Structure During Learning." *Nature Neuroscience* 15 (4): 528–536.

Zhang, Haoyun, Yan Jing Wu, & Guillaume Thierry. 2020. "Bilingualism and Aging: A Focused Neuroscientific Review." *Journal of Neurolinguistics* 54.

Ziegler, Gabriel, Robert Dahnke, Lutz Jäncke, Rachel Aine Yotter, Arne May, & Christian Gaser. 2012. "Brain Structural Trajectories Over the Adult Lifespan." *Human Brain Mapping* 33 (10): 2377–2389.

Zilles, Karl, Axel Schleicher, & Hans-Joachim Kretschmann. 1988. "The Human Pattern of Gyrification in the Cerebral-Cortex." *Anatomy and Embryology* 179 (2): 173–179.

Address for correspondence

Stefan Elmer
Department of Computational Linguistics
Computational Neuroscience of Speech & Hearing
Competence center Language & Medicine
University of Zurich
Andreasstrasse 15
8050 Zurich
Switzerland

stefan.elmer@uzh.ch

Biographical notes

Stefan Elmer is a neuroscientist and senior researcher at the lab of "Computational Neuroscience of Speech & Hearing" and interested, among other topics, in better understanding the brain mechanisms underlying language learning, language expertise and simultaneous interpretation. Using electroencephalography and brain imaging techniques, he fundamentally contributed to elucidate the functional and anatomical correlates of simultaneous language translation.

https://orcid.org/0000-0003-1721-450X

Nathalie Giroud is a neuropsychologist and Assistant professor at the University of Zurich. She heads the "Computational Neuroscience of Speech & Hearing" research group where she and her team study the neural and cognitive underpinnings of speech and language with a focus on clinical populations who have difficulties to process and understand spoken language (e.g., due to hearing loss, aging, dementia). She develops interventions against speech communication difficulties using state-of-the-art technology and develops diagnostic tools for different speech communication disorders using neurophysiology.

https://orcid.org/0000-0002-9632-5795

Publication history

Date received: 20 June 2023
Date accepted: 12 September 2023