# Does A Bilingual Experience Enhance Cognitive Flexibility in Older Adults? Behavioural and Neurophysiological Indications

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Master Thesis, Applied Cognitive Neuroscience

S4059328

February, 2022

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# Abstract

This study investigated changes in cognitive flexibility in older adults after complex skill learning, specifically learning to speak a new language. Aging brings neuroanatomical and physiological changes that cause cognitive functions such as executive functions to fade. Cognitive flexibility is the ability to alternate between different mental tasks and it is considered to be one of the main elements of executive functions. The coordination of executive functions underpins high-level thought, at which older adults seem to face age-related deficits, resulting in daily challenges. In order to moderate this issue, complex skill learning such as language learning has been proposed to enhance cognitive flexibility. Cognitive flexibility can be indicated in switching costs: the tendency to perform worse when switching between tasks, compared to repeating the same task. The goal of the current study, on a behavioural level, was to examine whether cognitive flexibility, was improved after language learning. On a neurophysiological level, the aim was to inspect any differences in event related potentials before and after the interventions, measured using electroencephalogram during the switching task. Specifically, the N2 and P3 neural components were inspected, as these are often observed during switching tasks and are often related to cognitive flexibility. This study was part of the FlexLang project, in which older adults participated in one of the three interventions: language, music or social-art learning, all lasting three months. Cognitive flexibility was assessed using a colour-shape switching task before and after the intervention. The results are ambiguous. Switching costs in accuracy, but not reaction time, were lower after the intervention compared to before, with no difference between the three interventions. No differences were found in the N2 and P3 between the two measurement points. Results suggest that the interventions or practice improved cognitive flexibility in older adults. However, further research needs to be done to explore the neurophysiological background that supports this process.

**Keywords.** Cognitive flexibility, switching costs, bilingualism, event related potentials, N2, P3

# DOES A BILINGUAL EXPERIENCE ENHANCE COGNITIVE FLEXIBILITY IN OLDER ADULTS? BEHAVIOURAL AND NEUROPSYSIOLOGICAL INDICATIONS

One of the impressive abilities of human behaviour is the reconfiguration of the mind. Quite easily, almost effortlessly, humans can switch between different mental tasks. This so called procedure of *cognitive flexibility*, is often a fast process; most of the times individuals do not even realize when or how it happened (Braem & Egner, 2018). Diamond (2013) proposes cognitive flexibility, inhibition, and working memory as the main components of executive functions (EFs). Due to the coordination of multiple EFs individuals can process and mentally digest ideas that come up in mind, analyse them before making decisions, accept changes, and react to challenges (Diamond, 2013). EFs are therefore responsible for high level thought, multi-tasking, and sustained attention. Cognitive flexibility here holds a special position. It is the ability to reconfigure the mind, or specifically, to mentally switch between different tasks or thoughts. Cognitive flexibility entails the creative or “out of the box” thinking, the quick and flexible adjustment to different scenarios and circumstances, adjustment to new demands, priorities’ checking, and exploitation of unforeseen events and opportunities (Diamond, 2013). Essentially, it comes down to the ability to change perspectives. Developmentally, cognitive flexibility is attained after the acquisition and establishment of the other two main executive functions of inhibition and working memory (Davidson et al., 2006; Garon et al., 2008). To alter our perspective and thus to employ cognitive flexibility, we first need to inhibit our previous perspective and activate the new one into working memory. According to this pattern, inhibition and working memory are both necessary to provoke cognitive flexibility and make individuals able to adjust to new demands.

Experimentally, cognitive flexibility is often measured using task-switching and set-shifting tasks. Commonly used paradigms are the Wisconsin Card Sorting Task (Stuss & Alexander, 2000), the Simon task (Simon & Rudell, 1967), the flanker task (Eriksen & Eriksen, 1974), the Stroop task (Stroop, 1935), and versions of switching tasks (Prior & Macwhinney, 2010). Task switching includes set of stimuli, presenting series of trials. The tasks can include either the same elements and so the participant needs to repeat the task, or different elements, where the participant needs to switch (Diamond, 2013; Miyake et al., 2000). The cognitive task in switch trials differs from the previously executed tasks, while in the case of repeat trials the previously task is simply re-executed (Kopp et al., 2020). A prominent behavioural observation during the switching task is the phenomenon of *Switching Cost (SC)*: a cost observed when switching compared to repeating in switch trials relative to repeat ones, represented by a less accurate (low percentage of correct responses) and slower performance (longer RTs) (Meiran, 1996; Rogers & Monsell, 1995; G. Wylie & Allport, 2000). SC then, represents the time needed to change from a stimulus-response mapping rule necessary for the execution of one task, to a different stimulus-response mapping rule fitting the needs of the new task. This idea has been associated with the term of task-set reconfiguration (Monsell, 2003; Rogers & Monsell, 1995). This asks for a combination of cognitive procedures like retrieval of working memory, activation and inhibition of irrelevant task sets, important features that contribute to cognitive flexibility (Gajewski & Falkenstein, 2012; Kiesel et al., 2010).

Importantly, cognitive flexibility changes throughout life: it improves during child development and then decreases again during aging. Broad age-related deficits are commonly observed in several mental processes such as working or episodic memory, spatial and reasoning abilities, and processing speed (Salthouse et al., 1996; Wasylyshyn et al., 2011). Additionally, cognitive flexibility has been shown to decline with increasing age (Boone et al., 1993; Wecker et al., 2005). Most of the difficulties arise when older adults need to perform tasks at the same time or in inhibiting one response and need to produce another one (Richard's et al., 2021). The decrease in cognitive flexibility with age can cause problems in adaptation to new situations and environments in older adults (Cepeda et al., 2001; Kray, 2006; Stern et al., 2014). Cognitive flexibility has been found to be a better predictor of performance in activities that are instrumental to the daily life of older adults than are other cognitive functions (Bell-McGinty et al., 2002; Vaughan & Giovanello, 2010). This is problematic because the number of older adults in the EU aged 85 years and over is expected to double to more than 26.8 million people in 2050 (Ageing Europe - Statistics on Population Developments - Statistics Explained, 2021). Society therefore, expects older adults to remain active in the labour market for longer. Consequently, these trends demand from older adults to remain cognitively, physically, socially and emotionally functional for longer in life. The arising challenge that occurs here is to find ways and practices to help older adults maintain or enhance their personal performance at all levels.

## Bilingualism to improve cognitive flexibility

Recently, attention has been drawn to how speaking multiple languages could help to maintain or improve cognitive flexibility. Individuals who speak multiple languages need to manage two or more languages in one mind, calling upon cognitive flexibility (Green, 1998; Grosjean, 1989; Rodriguez-Fornells et al., 2005). Bilinguals need to check which language they should use, update the relevant information of the “correct” language under specific circumstances, and switch between languages when needed according to the environment and conditions. To do so, they also have to suppress the non-relevant language codes (Abutalebi & Green, 2007; Costa et al., 2009; Festman & Münte, 2012). Thus, the coordination of the executive functions and especially the one of cognitive flexibility appear prominent in bilingualism.

In general, being able to speak more than two languages can enhance a person's social skills and promotes communicational opportunities. Paradoxically, the only disadvantage of bilingualism seems to concern a linguistic characteristic: smaller vocabularies for each language and difficulties with lexical access-retrieval for bilinguals compared to monolinguals (Michael E. & Gollan T., 2005; Bialystok & Craik, 2010). In addition to the social benefits, people who learn or speak multiple languages seem to have cognitive advantages. Cognitive functions, especially executive functions such as inhibition, working memory and cognitive flexibility, are found to be enhanced when speaking multiple languages compared to speaking just one language (Bialystok & Martin, 2004b; Kroll & Bialystok, 2013). Bilinguals have often been found to outperform monolinguals as shown by studies involving different age groups, assessing for example non-verbal conflict resolution (Bialystok et al., 2005; Costa et al., 2009), inhibitory control (Colzato et al., 2008; Lee Salvatierra & Rosselli, 2011), and task switching (Prior & Gollan, 2011; Prior & Macwhinney, 2010). Specifically for switching tasks, studies found that bilinguals showed smaller switching costs than monolinguals (Prior & Gollan, 2011), indicating a better switching performance by bilinguals. These studies support the so-called *bilingual advantage*, a hypothesis that claims that bilingualism enhances executive control abilities (Pot et al., 2019).

It must be noted however that many studies dispute the claim for a bilingual advantage and suggest that this advantage occurs only under specific methodological practices like uncontrolled non-linguistic factors, such as individual differences (de Bruin et al., 2015;

Dunabeitia et al., 2014; Gathercole et al., 2014; Paap et al., 2016; Paap & Greenberg, 2013) or incorrectly matched samples (Costa et al., 2009; Kousaie & Phillips, 2012). Other studies have observed the bilingual advantage but only in specific age groups, such as children under school age (Bialystok & Martin, 2004a), in middle childhood (Garraffa et al., 2015), young adults (Pelham & Abrams, 2014) and in older adults (Bialystok et al., 2006, 2014). These studies support the similarity and not an unequivocal difference in EFs between bilinguals and monolinguals, as no big differences have been observed between these two groups.

Studies with older adults have showed that, bilingualism can be beneficial in attenuating certain age-related conditions and frailties (Bak et al., 2014; Craik et al., 2016; Wilson et al., 2018). Bilingualism could for example potentially delay the onset of dementia symptoms (Craik et al., 2016; Mortimer et al., 2014), or contribute to the offset of age-related losses in executive processes in older adulthood (Costumero et al., 2020; Dash et al., 2019). Since normal aging involves some degree of decline in memory, executive functions and attention, it is thought that learning a new language or active bilingualism in older adulthood may act as a shield in order to preserve these cognitive functions (Antoniou, 2019; Antoniou & Wright, 2017; Chan et al., 2020). So far, few studies have been performed investigating this hypothesis, although some are currently conducted (Nijmeijer et al., 2021). The studies that have been done are inconclusive to date. Some studies show that language learning in older adults results in minor changes in global cognition and brain structure (Bubbico et al., 2019; Pot et al., 2019), while others have found no changes in switching abilities (Ramos et al., 2017). However, there are researchers that do not exclude the possibility of a bilingual advantage and acknowledge its existence in later stages in life (Antón et al., 2016). Although older adults show lower cognitive flexibility in switching tasks than younger adults, (Roldán-Tapia et al., 2017; Wilson et al., 2018) bilingual older adults perform better in switching tasks and cognitive flexibility than monolinguals older adults (Gold et al., 2013). Additionally, studies have shown that bilinguals older adults who could not complete the colour-shape task, exhibited larger switching costs than matched bilinguals who completed the task(Weissberger et al., 2012). This seems to support the theory that bilingualism may contribute to the enhancement of cognitive flexibility in elderly.

### Neural underpinnings of cognitive flexibility

Cognitive flexibility requires the coordination of multiple executive functions, making it difficult to isolate cognitive flexibility at the neural level (Dajani & Uddin, 2019). Therefore, specific regions that are found to be involved in cognitive flexibility are not necessarily involved solely in this particular process. Neuroimaging data from non-linguistic cognitive control studies suggest that brain areas which are mainly involved in cognitive flexibility involve frontal and parietal regions (Brass & Von Cramon, 2004; Kim et al., 2012). Specifically, the dorsolateral prefrontal cortex (dlPFC) is thought to be involved in the representation of task-set rules during the task (Crone et al., 2006; Cutini et al., 2008). The left superior frontal gyrus (sFG) is suggested to be engaged in interference detection and suppression (Jamadar et al., 2010; Langenecker et al., 2004). The inferior frontal junction (IFJ) is believed to play a critical role in updating the task rules representations or the inhibition of previous response sets (Armbruster et al., 2012). The left ventrolateral prefrontal cortex (v1PFC) is suggested to resolve proactive interference from the previous task set (Badre & Wagner, 2006) and the right (vlPFC) is thought to be involved in selecting the most effective response (Dippel & Beste, 2015). The parietal regions have been found to be involved in task-set reconfiguration and rule representation (Crone et al., 2006) and in general attentional mechanisms, needed for the switching purposes (Smith et al., 2004; Wager et al., 2004).

In order to further distinguish the neural subprocesses underlying cognitive flexibility, it is important to study not only the spatial regions, but also temporal aspects. Electroencephalogram (EEG) has a good temporal resolution and examines event-related potential components (ERPs). These are specific neural responses related with specific cognitive, sensory and motor events (Luck, 2014). With other words they are electrical potentials associated with specific events such as stimulus or response onset.

Neurophysiological studies with ERPs have repeatedly shown two electrophysiological components associated with cognitive flexibility and task-switching processes: the N2 and the P3. The N2 is a negative wave and appears around 200-400ms after stimulus presentation mainly at fronto-central cortical areas (Folstein & Van Petten, 2008; Van Veen & Carter, 2002; Yeung & Cohen, 2006). Specifically during task switching, researchers have observed an enhanced negativity response, represented by a larger (more negative) N2 amplitude in switch trials compared to non-switch trials (Capizzi et al., 2016; Cutini et al., 2021). A larger N2 has been proposed to reflect response selection when switching is needed and it seems to play a role in the detection of conflict and in stimulus-response mapping processes (Gajewski et al., 2018; Liu & Zhang, 2020). In general, it seems that smaller (less negative) amplitudes of N2 are associated with enhanced performance, better cognitive control and cognitive flexibility processes (Barceló et al., 2000; Finke et al., 2012; Gaál & Czigler, 2018; Gajewski et al., 2010; Goffaux et al., 2008; Jackson et al., 2004; Jost et al., 2008; Karayanidis et al., 2003, 2011; Kieffaber & Hetrick, 2005; Kotchoubey, 2006; Lavric et al., 2008). Studies with older adults show that N2 amplitudes are larger (more negative) with aging (Gajewski et al., 2018), perhaps as a result of the attenuation of cognitive control processes.

The P3 is a positive deflection that appears around 300ms post stimulus, mainly in parietal regions. A smaller in amplitude (less positive) positive ERP response has been observed in switch trials compared to non-switch trials (Cutini et al., 2021; Karayanidis, Jamadar, 2013; Kopp et al., 2014; Li et al., 2012; Miniussi et al., 2005; Nicholson et al., 2005) and is linked to updating, organizing and implementing the new task-set (Barceló et al., 2000; Gajewski et al., 2010; Jamadar et al., 2010; Jost et al., 2008; Karayanidis et al., 2003; Kieffaber & Hetrick, 2005; Lorist et al., 2000; Petruo et al., 2016; Poulsen et al., 2005). P3 amplitudes seem to be smaller when the task is more demanding (Kok, 2001).

The N2 and the P3 thus seem to be appearing in switching activities: a larger N2 and a smaller P3 during switching compared to repeating  (Hsieh & Cheng, 2006; Kieffaber & Hetrick, 2005; Lavric et al., 2008; Poulsen et al., 2005; Wylie et al., 2003). These ERPS therefore might be correlated with more complex, demanding, and time-consuming tasks, assuming that switch tasks are more difficult and require more time. Together these components reflect the involvement of decision or response control processes that are involved in order to solve the interference occurring in the most challenging (switch) trials (Capizzi et al., 2016).

So far, relatively few studies have examined cognitive flexibility related ERPs in older adults. Studies show a larger N2 and a smaller P3 for switch compared to repeat trials with increasing age (Gajewski et al., 2018; Karayanidis et al., 2011; Kropotov et al., 2016; Travers & West, 2008). Another effect of aging that has been found across different tasks is a latency delay of the N2 and the P3 (Bertoli et al., 2005; Czigler et al., 1996; Gajewski & Falkenstein, 2014; Lucci et al., 2013).

### ***N2-P3 in switching task in bilinguals***

Similarly, only few neurophysiological studies have inspected the N2 and P3 components in bilinguals and monolinguals during switching tasks. The findings are contradictory. Only one study has found a larger N2 for bilinguals in switch tasks (Timmer et al., 2017). Studies that measured conflict detection using the flanker task showed that bilinguals exhibited a larger N2 and smaller P3 components compared to their monolingual counterparts, suggesting enhanced monitoring processes and reduced categorisation effort (Markiewicz et al., 2021). However, when measuring executive control and response inhibition using the Go/no Go task, researchers observed larger P3 amplitudes together with better behavioural performance for bilingual than monolingual children (Barac et al., 2016).

If enhanced cognitive flexibility and its related neural ERP components are indeed related to speaking multiple languages, the question arises whether learning to speak a new, additional language can improve cognitive flexibility in older adults. Potentially, a language training can decrease the aging effect. However, whether such a bilingual experience for older adults can attenuate switching cost and their related ERP components has not been studied before.

## Aim-Question/ Hypothesis

The current study focuses on whether cognitive flexibility in elderly improves after a bilingual experience. This is done by examining whether older adults perform better on a switching task after a three months' period of foreign language training. Given the behavioural evidence from the bilingual advantage, that proposes better cognitive flexibility for bilinguals, better cognitive flexibility is expected for older adults after the language training, compared to before. Increases in cognitive flexibility are expressed by lower switching costs, both in accuracy and reaction time.

On a neurophysiological level, the study examines the N2 and P3 ERP components, focusing on response selection and updating processes respectively. Given that bilinguals older adults show lower switching costs than monolinguals, less negative (smaller) N2 and more positive (larger) P3 are expected in older adults after the language training compared to before, in switch versus repeat trials. This indicates a more efficient conflict detection/monitoring processing and response inhibition after the language learning and enhanced cognitive flexibility ability in general.

# Methods

This study is part of the FlexLang study (Nijmeijer et al., 2021), which was funded by the University of Groningen and the University of Medical Center Groningen(UMCG) and approved by the medical ethical committee of the UMCG (registration number METC 2018.375; NL65233.042.18). The trial was registered at the Netherlands Trial Register(NTR), protocol number NTR7336.

## Study Design

The study included four phases: a selection procedure for eligibility, a baseline cognitive and neuropsychological examination (T0), the intervention that lasted for three months, a post-intervention cognitive and neuropsychological examination (T1), and a six-month follow up examination (T2). The current study will focus on the baseline and post-intervention examinations. In both examinations, brain activity was measured using electroencephalography (EEG), during the colour-shape switching task. The intervention of interest was the language intervention where the purpose was to learn a new language. Two control interventions included a music intervention, aimed at learning to play a musical instrument as a cognitive control condition, and a social-art intervention with no focus on learning but to control for social skills activation.

## Participants

Overall, 122 older adults were included in the FlexLang study, ranging from 65 to 85 years old (M= 69.98, SD = 3.83), all having the Dutch nationality. All elderly included in the study experienced subjective cognitive decline, which is a risk factor for further cognitive decline and late-life depression (Xu et al., 2021). Other, inclusion criteria were functional monolingualism, English knowledge maximum at A2 level, music abstention for at least 20 years, basic computer experience and access, and an IQ higher than 85(M = 116, SD= 15.33). Exclusion criteria were the presence of objective cognitive decline with score higher than 23 on Montreal Cognitive Assessment (MoCA), presence of a major DSM-IV disorder, diagnosed neurological problems (dementia, Mild Cognitive Impairment, epilepsy, etc.), daily use of benzodiazepines or antidepressants, presence of self-reported vision and/or hearing problems that cannot be corrected by vision/hearing aids.

Participants were recruited via primary and specialised health care institutions: general practitioners and memory clinics, organizations for senior citizens, participant platforms (hersenonderzoek.nl), public media (regional newspapers) and social media. The recruitment procedure lasted from November 2018 till December 2020. All subjects provided informed written consent, according to the principles expressed in the Declaration of Helsinki and each participant received a gift card of 25 euros for their participation.

## Groups

The participants were randomly allocated to one of the three interventions: language learning, music learning and social-art intervention. The randomization procedure was conducted using a computer-generated randomization list in Microsoft Excel. The experimental group received language training in the English language. This specific language was selected since a pilot work within the Bilingualism and Aging Lab at the University of Groningen showed that the elderly had a higher motivation to learn English compared to other languages such as Spanish or Italian. The language intervention included self-study of the participants in online language activities, where they had to send homework assignments for at least 45 minutes a day, five times a week. In-person 90 minute meetings took place every two weeks at the University of Groningen with the rest of the class, accompanied by an English language instructor. The class meetings included group exercises and short presentations.

The control groups received either a musical training, with guitar lessons (high-level active control) or a social-art intervention with creative workshops (low-level active control). The music intervention followed the set-up and format of the language intervention: 45 minutes per day for five days per week of online learning activities at home, combined with in-person meetings with a music instructor for 90 minutes every fortnight. For the social intervention, the participants had to meet only every other week for 90 minutes. Creativity workshops such as painting and woodcrafts were offered during these meetings. No home assignments or online training was involved for the social intervention. The social interaction level was aimed to have the same level of social interaction as in the other training interventions (language and music), but only a minimum complex skill learning was aimed. The duration of all the interventions was three months.

## Materials

### *Stimuli, task and procedure*

A modified version of the colour-shape switching task was used to measure cognitive flexibility, based on the task of Prior & MacWhinney (2010). The general goal of the task was for participants to respond as quickly as possible to the appearance of coloured-shaped targets. Stimuli were presented on a screen at a resolution of 1024 * 768 pixels. Participants were seated in a chair at a distance of approximately 60 cm from the screen in a dimly lit and shielded room. The monitor's height was 20 cm and the vertical resolution of the monitor 76 cm. Participants were instructed to rest the index and middle fingers of the right and left hand on the ‘d’, ‘f’ and ‘j’, ‘k’ keys of the keyboard throughout the whole experiment, except for the breaks. The task lasted approximately 20-25 minutes.

The task consisted of three blocks reflecting single tasks, shape and colour block and switched cue tasks, mixed block (see Appendix). A sandwich design was used for the blocks’ sequence: the repetition of the single-task blocks after completing the mixed-task blocks allowed avoidance of influence of order effects on mixed block performance. Four different versions of the task were used to counterbalance the order of the task blocks and the hand participants used to respond when pressing the keys.

During the colour block, a coloured figure (circle or square in red or green) appeared at the centre of the screen and participants had to respond to the colour of the figure (red or green). During the shape block, again a coloured figure appeared at the centre of the screen but participants had to respond to the shape of the figure (circle or square). In the colour block, participants had to press a key with their index finger when a red target appeared and with their middle finger for a green figure. In the shape block, they had to press a key with their middle finger when the figure was a square, and with their index finger when it was a circle. During the mixed block, the two single-tasks were combined, maintaining the assignment of task to hand and finger. In the mixed block, a cue appeared to indicate the task of the trial. If a colour-wheel cue appeared on the screen, the participants should respond to the colour of the figure. If the cue that appeared was a pair of black shapes, participants should respond to the shape of the figure. This cue (colour-wheel or pair of black shapes) was depicted on the upper centre side of the screen before the stimuli appeared and it remained visible on the screen for the whole trial. Indications of which keys should be pressed under which conditions were presented in the top corners of the screen during the whole procedure to help subjects remember the instructions.

Each trial began with a blank screen that lasted for 850ms (jittered in 100ms to reduce temporal predictability of the next trial), followed by a fixation dot at the centre of the screen for 350ms and again a blank screen for 150ms. In the single trial blocks, next the target appeared on the screen and stayed there until the participant had responded or for maximum of 4000ms. In the mixed task blocks, the 150ms blank screen was followed by a cue that appeared on the screen for 250ms, followed by the target. Together cue and target remained on the screen until the participant responded or for a maximum duration of 4000ms.

In the first part of the task, participants performed a colour task and a shape task block (order was counterbalanced across participants). Each block included 8 practice trials, followed by a sequence of 36 experimental trials. In the second part, participants performed three mixed trial blocks consisting of 48 experimental trials each and once 16 practice trials at the beginning. In the third part, participants again performed two single-task blocks presented in the opposite order from the first part, but with the same number of trials.

Accuracy and reaction time per trial were measured. Averages for accuracy (percentage of correct responses) and reaction time (in milliseconds) were calculated for each block. Switching costs were defined as the difference in performance on switch trials in the mixed block (changes in colour-shape indications and vice versa), comparing to non-switch trials in the mixed block. This difference occurs by subtracting the repeat from the switch values. A positive outcome will indicate that participants were better (or faster) in switch rather than repeat and a negative outcome will mean the opposite.

The colour-shape switching task was designed and conducted in OpenSesame version 3.1.9 (Mathôt et al., 2012).

## Behavioural analysis

Statistical analyses were performed using R statistical software version 4.0.2 (R Core Team, 2020). Two repeated measures (RM)-ANOVAs, one for accuracy one for reaction time, were conducted to assess whether the switching costs, as an indicator of cognitive flexibility, significantly differed for the two measurements (pre- and post-intervention) and for intervention method. The calculated switching costs scores were used as dependent variable, time as within and intervention as between variable. All assumptions were met for this analysis. Bonferroni was used to correct p-values.

## EEG

### *EEG apparatus-recordings*

During the colour-shape switching task, EEG was continuously recorded using 34 Ag|AgCl electrodes connected on a textile cap (EasyCap, Herrsching, Germany). The electrodes' position was arranged according to the international 10/20 system. An ANT Neuro amplifier system was used (Advanced Neuro Technologies B.V., Enschede, the Netherlands) at a sampling frequency of 512 Hz and the electrode impedances were kept below 7 kΩ. Two electrodes AFz, FCz were used as ground and reference electrodes and two extra electrodes were placed at both mastoids for re-referencing the EEG signal offline. Horizontal and vertical eye movements (EOG) were measured using, electrodes that were placed above and below the left eye and laterally at the sides of both eyes. The electrode positions used in the current study were: Fp1, Fp2, F7, F3, Fz, F4, F8, Ft7, Fc3, Fcz, Fc4, Ft3, T7, C3, Cz, C4, T8, Tp7, Cp3, Cpz, Cp4, Tp8, P7, P3, Pz, P4, P8, Po7, Po1, Po2, Po8, O1, Oz, O2.

### ***EEG (pre)processing***

EEG Data was analysed by MATLAB (Version 2020a, MathWorks, Natick, MA, USA). Processing and analysis of the EEG data was performed using the EEGLAB toolbox (Delorme & Makeig, 2004) and ERPLAB toolbox (Lopez- Calderon & Luck, 2014). Custom MATLAB scripts were used for offline processing of EEG signal, with functions from the EEGLAB environment.

First, the EEG graph plots from all the subjects (46) were inspected one by one to check for noisy data/subjects. After the visual inspection together with the artefact detection, only 20 subjects (10 from language,7 from musical and 3 from social-art) were selected to be analysed (26 participants were excluded). Because of the small sample size for each group, no group comparisons were conducted. The analysis continued as a whole group, compare differences between pre and post measurements over all interventions. Another 5 subjects were excluded from the final analysis because after computing the ERPs, these subjects showed flattened lines, meaning no good recorded signal. The final ERP sample thus consisted of 15 participants.

For each participant, the following steps were taken. For the pre-processing, a high band-pass filter was applied at 0.1 Hz to attenuate low frequencies and suppress noise (Luck, 2014). Data were re-referenced to the average of electrodes A1 and A2. The data was segmented into epochs starting 500 ms before the stimulus onset (target appearance) and ending 1000 ms after it. The epochs of the data were time-locked to a task condition. The focus of this study was on the condition with switch trials from the mixed block (switch condition), and the condition with repeat trials from the mixed block (repeat condition). Both correct and incorrect trials were included. The baseline correction was set by averaging the pre-stimulus voltage of all the set of epochs divided by the number of segments. The data was cleaned using stepwise artefact detection to remove eye blinks and eye movements. Artefacts above 50Hz within the time-windows of interest were removed. Participants average ERPs were calculated for switch and repeat conditions. Next, a grand average ERP was calculated over all participants by averaging all participant average ERPs. This resulted in a grand average ERP for both conditions (switch and repeat). A low-pass filter at 30 Hz was applied to the grand average ERPs to reduce noise. This study focused on the N2 on fronto-central site within the time window of 200-400ms and on the P3 on centro-parietal site within 230-350ms. For the N2 component, the mean amplitude was calculated for the fronto-central FC electrode site over the 200-300ms time window. For the P3 component, the mean amplitude was calculated for the parietal electrode site Pz over the 300-400ms time window. The N2 and P3 mean amplitudes were calculated both for t1 and t2, for the switch and repeat conditions.

### ***EEG statistical analysis***

Statistical analyses on the mean amplitudes were performed using R statistical software version 4.0.2 (R Core Team, 2020). A two-way Repeated Measures ANOVA was used with time (2 levels: pre-post) and condition (2 levels: switch- repeat) as within variables and mean N2 amplitude on electrode site FC as dependent variable. The same analysis was performed with mean amplitude for the P3 component as dependent variable on electrode site Pz. As literature indicates a higher activity in fronto-central regions for N2 and in parietal regions for P3, the central electrode sites of these regions (Fc and Pz) were selected for analyses.

# Results

## Behavioural Data

The results for accuracy and reaction time (RTs) for the repeat and switch condition of the colour-shape switching task for all three interventions are presented in Table 1.

**Table 1**

*Means of Accuracy and Reaction Times per Task Switching Condition, Time, and Intervention*

| Intervention | | Repeat | | Switch | |
|---|---|---|---|---|---|
| | | Pre Mean (SD) | Post Mean (SD) | Pre Mean (SD) | Post Mean (SD) |
| Language (N = 15) | Accuracy % | 91.4(16.65) | 96.06(4.9) | 90.16(16.85) | 96.64(4.5) |
| | RTs | 1103.81(166.56) | 1029.84(198.15) | 1270.89(211.26) | 1192.69(177.34) |
| Music (N = 15) | Accuracy % | 92.63(14.13) | 95.20(5.4) | 91.51(15.69) | 94.62(4.25) |
| | RTs | 1122.29(217.05) | 1066.07(233.11) | 1275.95(209.58) | 1261.96(288.55) |
| Art-Social (N = 16) | Accuracy % | 93.3(9.23) | 96.12(3.7) | 91.24(11.27) | 96.5(2.9) |
| | RTs | 1024.37(222.2) | 994.2(189.22) | 1220.81(263.47) | 1195.89(175.56) |
| Total (N = 46) | Accuracy % | 92.46(13.32) | 95.8(4.6) | 90.98(14.41) | 95.93(3.9) |
| | RTs | 1082.6(202.77) | 1029.25(204.8) | 1255.12(226.57) | 1216.39(216.78) |

*Note.* Accuracy is measured by percentages of correct responses and reaction times in milliseconds

As depicted in Table 1, total accuracies over all interventions for both task conditions were higher after the intervention compared to before for both the repeat condition (post: M = 95.8, SD = 4.6 and pre: M = 92.46, SD = 13.32) and the switch condition (post: M = 95.93, SD = 3.9 and pre: M = 90.98, SD = 14.41). A similar pattern was observed for reaction time. Reaction times were smaller (thus faster) over all interventions at post-measurements compared to pre-measurement in both repeat (pre: M = 1082.6, SD = 202.77 and post: M = 1029.25, SD = 204.8) and switch condition (pre: M = 1216.39, SD = 216.78 and post: M=

1255.12, SD = 226.57). Furthermore, the average scores for accuracy and reaction time in Table 1 show that on average, participants needed less time (lower RTs) for repeat trials than for switching, and they performed slightly more accurate (0.68 %) in the repeat condition compared to switching.

**Table 2**

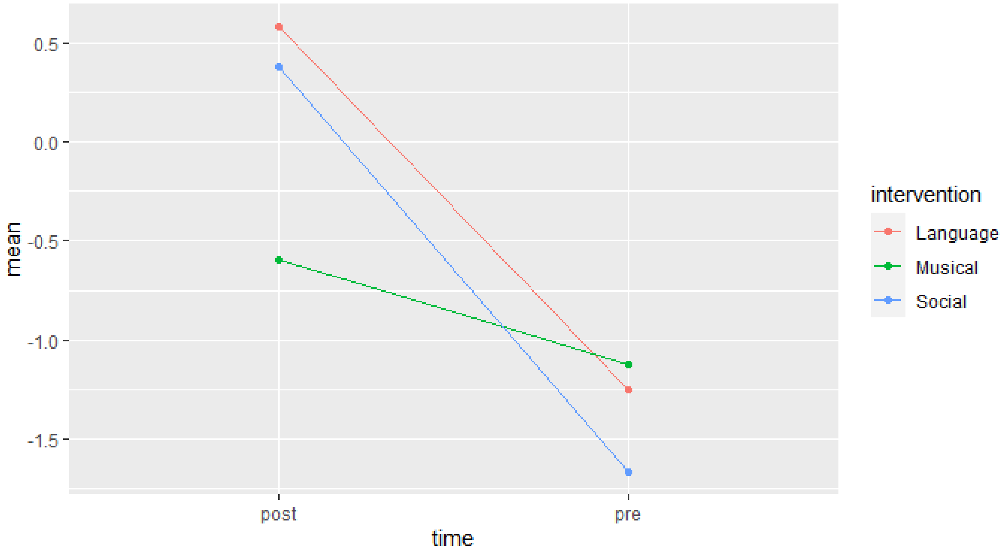
Means and SDs of Switching Costs in Accuracy and RTs

| Intervention | | Time | |
|---|---|---|---|
| | | Pre<br>Mean (SD) | Post<br>Mean (SD) |
| Language (N = 15) | Accuracy % | -1.249(2.938) | .582(2.618) |
| | RTs | 167.084(110.227) | 160.907(86.094) |
| Music (N = 15) | Accuracy % | -1.12(2.696) | -0.593(3.787) |
| | RTs | 152.438(108.817) | 195.899(102.113) |
| Art-Social (N = 16) | Accuracy % | -1.665(2.992) | .38(3.591) |
| | RTs | 196.448(124.905) | 201.676(78.233) |

*Note*. Switching costs are the difference between switch and repeat trials (switch- repeat)

**Figure 1**

*Switching Costs in Accuracy before and after the three Interventions*



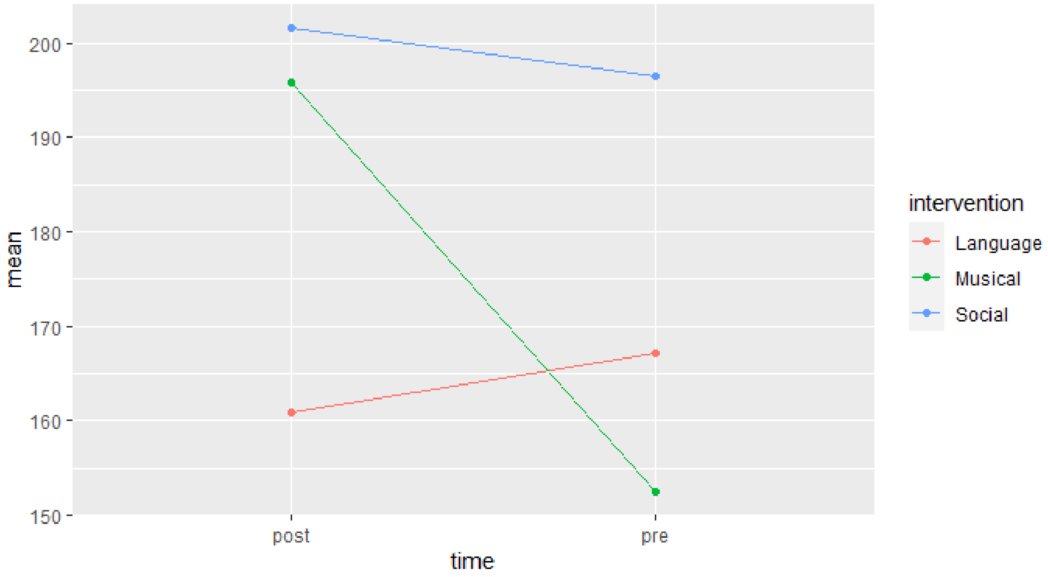
*Note.* Switching costs reflect the difference subtracting the mean accuracy for the repeat condition from the mean accuracy for the switch condition in the mixed block. A positive outcome for switching costs accuracy indicates higher accuracy (better performance) for switch trials rather than repeat trials. A negative outcome means the opposite.

The one-way RM-ANOVA with switching costs in accuracy as dependent variable showed a statistically significant effect of time [F (1,43) = 5.89, *p* = .019, ges = .055], indicating that participants differed in accuracy of switching costs before and after the intervention. No statistically significant effect on interaction of time and intervention was found, indicating no differences between the language, music and social learning and time. This difference can be seen also in the figure 1, where it is illustrated that before the intervention all the groups had negative switching costs in accuracy, which means participants were more accurate in repeat trials. However, the post measurements illustrate a change, turning the switching costs in positive values, for the language and musical learning intervention.

As depicted in Figure 2, only the language intervention seems to tend to react faster after the intervention, comparing to the two experimental groups and especially the social one.  However, switching costs in RTs, had no significant effects for either time nor intervention. Participants' reaction speed did not change after the intervention and neither of the three groups was faster than the other.

**Figure 2**

*Switching Costs in Reaction Times before and after the three Interventions*



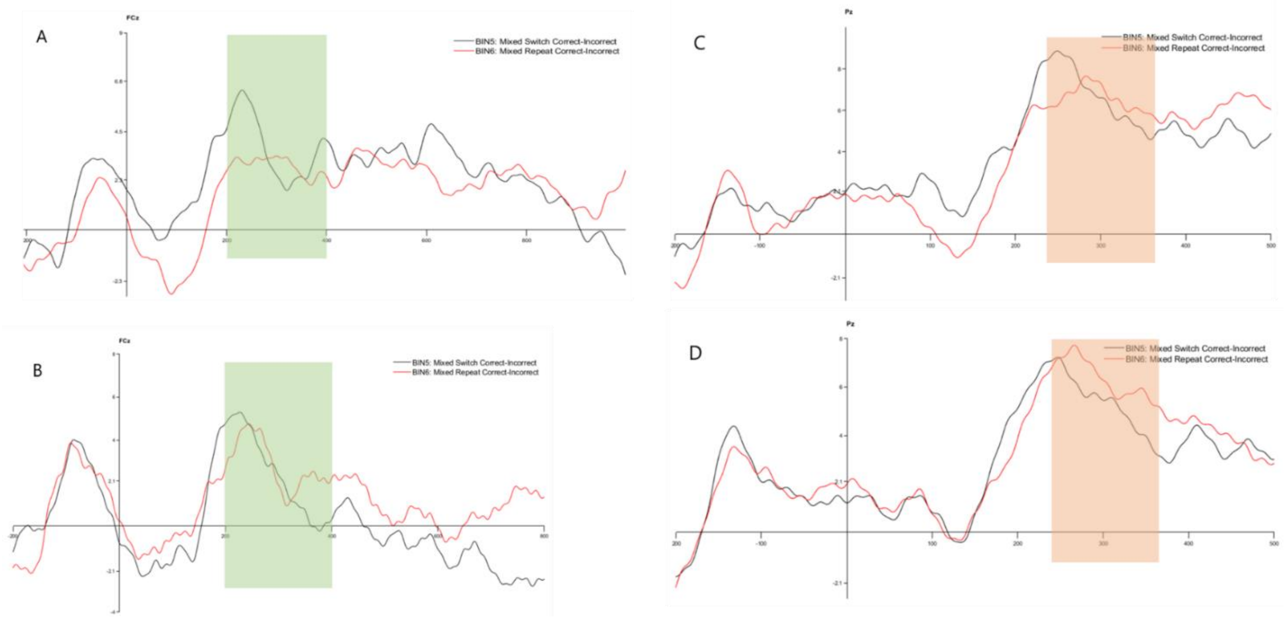
## ERP results

### *Grand average: pre –post*

Figure 3 displays the grand average ERPs for N2 and P3 during switch-repeat conditions, separately before and after the intervention.

**Figure 3**

*Grand Average ERP set*



*Note.* This figure demonstrates the Grand Averages of Event-related potential (ERP) for the N2 and P3 component at fronto-central(FC) and parietal site(Pz) accordingly, in switch-repeat condition during the two measurements points (Pre: A and C and Post: B and D). The vertical line corresponds to the target onset. The black line reflects switching, while red line reflects repeating condition. Time-window of interest with green colour at 200-400ms for N2 and at 250-350ms with orange colour for P3.

### *N2 and P3 Summary Statistics*

Table 3 below, depicts the average N2 and P3 mean amplitudes for both task conditions (switch and repeat) and time (pre and post), for each electrode site separately. Lower amplitudes are observed in the repeat condition for both pre (M = 5.152, SD = 5.28) and post (M = 4.701, SD = 4.16) compared to the switch condition (M= 7.182, SD = 3.69) and (M =

5.357, SD = 4.17), respectively. Comparing time points, N2 amplitudes was found to be lower after the intervention than before.

Comparing conditions, P3 amplitudes at Pz were observed to be higher in repeat trials for both pre (M = 5.644, SD = 4.94) and post (M = 5.192, SD = 4.52) measurements, compared to switch trials pre (M = 5.371, SD = 3.87) and post (M = 4.219, SD = 4.86). Furthermore, P3 mean amplitude values were lower at post- compared to pre-measurements.

**Table 3**

*Means of Mean Amplitudes of N2 and P3 per Condition, Electrode Site and Time point*

| Electrode site | | Repeat | | Switch | |
|---|---|---|---|---|---|
| Time | | Pre<br>Mean(SD) | Post<br>Mean(SD) | Pre<br>Mean(SD) | Post<br>Mean(SD) |
| FC(N2) | µV | 5.152(5.28) | 4.701(4.16) | 7.182(3.69) | 5.357(4.17) |
| Pz(P3) | µV | 5.644(4.94) | 5.192(4.52) | 5.371(3.87) | 4.219(4.86) |

*Note.* FC = Fronto-central, Pz = Parietal

In order to evaluate the effect of task condition and time on N2 amplitudes, a two-way repeated measures ANOVA was performed. No statistically significant effects were found neither in time or condition, meaning the N2 amplitudes did not differ before and after the intervention, or between the switch and repeat condition at FC electrode site. Similarly, in order to evaluate the effect of task condition over time on P3 amplitudes, a two-way repeated measures ANOVA was performed on Pz electrode site. No statistically significant effect was found for neither condition or time, meaning the P3 amplitudes did not differ between switch or repeat conditions and no differences found before and after the intervention.

# Discussion

The current study aimed to examine whether the acquisition of a new language could benefit older adults' cognitive flexibility ability. This was done by focusing on the switching costs in a colour-shape switching task and its underlying ERPs. Switching costs, which reflect the difference in performance between the switch and repeat condition of the switching task, are a direct indication of cognitive flexibility. As stated above, a better performance in cognitive flexibility, expressed by lower switching costs in accuracy and reaction times, was expected, after a three months' language intervention, compared to before.

From a behavioural aspect the results are ambiguous. Switching costs in accuracy differed significantly with respect to time, but there was no effect of intervention and time. This suggests that either the interventions contributed to older adult's better accuracy, or a practice effect has occurred. This is in line with findings suggesting that learning processes can guide cognitive control (Braem & Egner, 2018; Crump & Logan, 2010; Farooqui & Manly, 2015). The interventions did not differ from each other. Although the same trend was observed for the switching costs in reaction times, with participants being faster after the interventions, this finding was not significant. Thus, no clear interpretation can be made for the impact of the three intervention styles and most importantly the language learning, on participants' reaction times.

In general, the findings contradict previous studies which show that bilingualism has impact on older adults' reaction speed, when measuring in the colour shape switching task (Gold et al., 2013). However, in the study of Gold and colleagues, bilingualism is considered to be a life-long outcome and not an intervention at a later stage of life, as in this study.

Maybe a longer than three months' language intervention would have shown more transparent results also in reaction times. However, the current results are encouraging given that even in this somewhat brief period of language training (compared to lifelong bilingualism) older adults increased their accuracy levels.

A potential explanation for this tendency of increased accuracy is that older adults prefer to spend more time on a task, aiming to respond correctly, sacrificing their speed (Forstmann et al., 2011). This idea is in line with the assumption that when being in a switching situation, older adults tend to update task sets on each trial to determine whether updating is necessary as in switch trials, or not, as in repeat trials. This means that they take more time to react, in order to maintain their accuracy in high levels (Eppinger et al., 2007; Friedman et al., 2008; Karayanidis et al., 2011). Interestingly, the language and musical intervention performed better in switching than repeating trials after the interventions. Considering practice effects, participants might have focused more on switching, the most challenging trials, during the second measurement time point, where they knew how the task will be like. Another thought might be that the task was modified in a simpler way to fit to the needs of older adults and so indications on the rules of which keys to press were always on the screen. Because of this, older adults might have needed more time in order to first look at these rules and then react. However, an advantage of this format was the minimisation of working memory because participants do not need to recall the rules. This allows for more clean measure of cognitive flexibility, with less interference of working memory processes.

No effect of intervention was found for either accuracy or RTs. It was expected that the language learning intervention would have a greater impact compared to the two control groups in lowering the switching costs. It can therefore be concluded that the interventions in general did not influence switching costs in reaction time and no conclusion can be made in terms of the different intervention styles. As many researchers support, it is possible that interventions and especially language learning, did not have an effect on cognitive flexibility (Paap & Greenberg, 2013). However, the findings also partially contradict findings supporting no actual bilingual benefit in older adults' cognitive flexibility in either accuracy or reaction times (Ramos et al., 2017), since there is some proof of lowered switching costs in accuracy. However, any effect on cognitive flexibility might not be specifically for language learning.

### ERPs

Because of the absence of significant intervention effects in the behavioural data and the high number of participants who got excluded because of noisy data, the three interventions were combined into one group for the ERP analysis. The aim was to find differences over time and between task conditions, no differences between the three groups were analysed.

The ERP results focused on N2 and P3 components, since ample of studies have supported the relation of these components with cognitive flexibility (Capizzi et al., 2016; Karayanidis, Jamadar, 2013; Kopp et al., 2014; Miniussi et al., 2005; Nicholson et al., 2005). Smaller (less negative) N2 amplitudes and larger (more positive) P3 amplitudes were expected post compared to pre intervention in switch than repeat trials. This would suggest a more efficient conflict detection processing and response inhibition learning and thus strong indications for better cognitive control and cognitive flexibility. In general, no significant differences were found in either N2 or P3 amplitude for either condition or for time in the electrode sites of interest. One explanation why the expected differences were not found might be that as P3 temporally follows the N2 there might be a partial overlap of N2 and P3 waves on switch-repeat trials, leading to no clear distinct differences (Gajewski et al., 2018).

Although no significant effects were found, the expected trends were observed: post measurements showed smaller N2 amplitudes and larger P3 amplitudes in switch compared to repeat conditions. This supports previous findings relating N2 and P3 component's tendencies with task-driven interference (Capizzi et al., 2016) and with response execution (Kieffaber & Hetrick, 2005; Lavric et al., 2008), respectively. Specifically, smaller N2 amplitudes have been associated with smaller switching costs, proposing that as the frontal activity grows, the coping of the interference becomes better. In the same vein, larger P3 amplitudes have been linked to a more efficient task set reconfiguration, resulting in lower switching costs (Cutini et al., 2021). When switching, participants may first need to detect the change and suppress the existed knowledge-rule (Cutini et al., 2021; Jamadar et al., 2010), leading to a more switching cost prone behaviour. It is believed that interventions like language learning can help lowering the switching costs and improving cognitive control processes, confirming the smaller N2 and larger P3 amplitudes. With respect to findings with older adults, these tendencies on N2 and P3 might also reflect on deficits in interference processing when older adults need to select the right response (Kray et al., 2005; Eppinger et al., 2007), as well as highlight an additional effort to implement the task (Karayanidis et al., 2011).

The study had several limitations. Firstly, the number of participants who completed the behavioural and EEG measures at pre-measurement and post-measurement was smaller than initially planned, which resulted in low power to detect an effect of intervention. Especially since quite a lot of participants were excluded for the ERP analysis, this was done for only a very small sample. Power analysis showed that the study was underpowered. This also changed the initial research question for the neural underpinnings of cognitive flexibility because no comparison could be made between the three interventions. Another limitation that is related to the general set-up of the study is that a longer duration of the interventions could potentially establish bigger learning and produce bigger effects. Also, in this study no mixing costs were inspected and tested, although N2 differences appear to be stronger related to mixing cots (Gajewski & Falkestein, 2012, 2015; Kray et al., 2005; Karayanidis et al., 2011). Latencies of the components was also not inspected, while this could have illustrated a broader image of the task switching process. Something worth mentioning is that more data were collected after the completion of this study, and analysing them could support current findings or provide a clearer picture of the results of this study.

In general, the findings are ambiguous and more research using task switching needs to be done to inspect the neural components that underlie the processes of cognitive flexibility in older adults. More paradigms, except for the colour-shape task could confirm or lead to new results. Studies could also inspect language with other learning settings or maybe also switching tasks but with linguistic background, to exclusively test the procedure of cognitive flexibility on language settings.

## Conclusion

Finding practical ways to enhance older adults' functionality is of great importance. Physical and cognitive training can play a vital role in older adults' performance in executive functions tasks, and most importantly in daily life challenges. Bilingualism is a promising intervention to ameliorate older adults' cognitive control and maybe to slow down age-related frailties. Switching task is a good measuring tool to start investigating the cognitive processes that get activated in cognitive flexibility and together with the event related potentials which zoom in the temporal aspects, behavioural and neurophysiological findings will contribute to the understanding, and form conclusions about the process of cognitive flexibility. Although this study showed some indications, no clear conclusions can be drawn for the impact of language learning on participants’ performance on cognitive flexibility. The observed differences may indicate that either practice effects for subjects or that indeed all interventions were effective, in the sense that any new activity can boost cognitive flexibility. Findings in event related potentials were also ambiguous, giving no significant results. Future research can highlight possible alternations to the practices implemented in this study, suggest new interventions and practices to enhance cognitive flexibility and enlighten how bilingualism actually help older adults in a behavioural and neurophysiological way.

# References

Abutalebi, J., & Green, D. (2007). Bilingual language production: The neurocognition of language representation and control. In *Journal of Neurolinguistics* (Vol. 20, Issue 3). https://doi.org/10.1016/j.jneuroling.2006.10.003

*Ageing Europe - statistics on population developments - Statistics Explained*. Retrieved January 5, 2022, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Ageing_Europe_-_statistics_on_population_developments

Antón, E., Fernández García, Y., Carreiras, M., & Duñabeitia, J. A. (2016). Does bilingualism shape inhibitory control in the elderly? *Journal of Memory and Language*, *90*, 147–160. https://doi.org/10.1016/j.jml.2016.04.007

Antoniou, M. (2019). The Advantages of Bilingualism Debate. *Annual Review of Linguistics*, *5*(June 2018), 395–415. https://doi.org/10.1146/annurev-linguistics-011718-011820

Antoniou, M., & Wright, S. M. (2017). Uncovering the mechanisms responsible for why language learning may promote healthy cognitive aging. *Frontiers in Psychology*, *8*(DEC), 1–12. https://doi.org/10.3389/fpsyg.2017.02217

Armbruster, D. J. N., Ueltzhöffer, K., Basten, U., & Fiebach, C. J. (2012). Prefrontal cortical mechanisms underlying individual differences in cognitive flexibility and stability. *Journal of Cognitive Neuroscience*, *24*(12), 2385–2399. https://doi.org/10.1162/jocn_a_00286

Badre, D., & Wagner, A. D. (2006). Computational and neurobiological mechanisms underlying cognitive flexibility. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(18), 7186–7191. https://doi.org/10.1073/pnas.0509550103

Bak, T. H., Nissan, J. J., Allerhand, M. M., & Deary, I. J. (2014). Does bilingualism influence cognitive aging? *Annals of Neurology*, *75*(6), 959–963.

https://doi.org/10.1002/ana.24158

Barac, R., Moreno, S., & Bialystok, E. (2016). Behavioral and Electrophysiological Differences in Executive Control Between Monolingual and Bilingual Children. *Child Development*, *87*(4), 1277–1290. https://doi.org/10.1111/cdev.12538

Barceló, F., Muñoz-Céspedes, J. M., Pozo, M. A., & Rubia, F. J. (2000). Attentional set shifting modulates the target P3b response in the Wisconsin card sorting test. *Neuropsychologia*, *38*(10), 1342–1355. https://doi.org/10.1016/S0028-3932(00)00046-4

Bell-McGinty, S., Podell, K., Franzen, M., Baird, A. D., & Williams, M. J. (2002). Standard measures of executive function in predicting instrumental activities of daily living in older adults. *International Journal of Geriatric Psychiatry*, *17*(9), 828–834. https://doi.org/10.1002/GPS.646

Bertoli, S., Smurzynski, J., & Probst, R. (2005). Effects of age, age-related hearing loss, and contralateral cafeteria noise on the discrimination of small frequency changes: Psychoacoustic and electrophysiological measures. *JARO - Journal of the Association for Research in Otolaryngology*, *6*(3), 207–222. https://doi.org/10.1007/s10162-005-5029-6

Bialystok, E., & Craik, F. I. M. (2010). Cognitive and linguistic processing in the bilingual mind. *Current Directions in Psychological Science*, *19*(1), 19–23. https://doi.org/10.1177/0963721409358571

Bialystok, E., Craik, F. I. M., & Ryan, J. (2006). Executive control in a modified antisaccade task: Effects of aging and bilingualism. *Journal of Experimental Psychology: Learning Memory and Cognition*, *32*(6), 1341–1354. https://doi.org/10.1037/0278-7393.32.6.1341

Bialystok, E., & Martin, M. M. (2004a). *Bialystok_Martin_2004 ! .pdf*. *3*, 325–339.

Bialystok, E., & Martin, M. M. (2004b). Attention and inhibition in bilingual children: evidence from the dimensional change card sort task. *Undefined*, *7*(3), 325–339.

https://doi.org/10.1111/J.1467-7687.2004.00351.X

Bialystok, E., Martin, M. M., & Viswanathan, M. (2005). Bilingualism across the lifespan: The rise and fall of inhibitory control. *International Journal of Bilingualism*, *9*(1), 103–119. https://doi.org/10.1177/13670069050090010701

Bialystok, E., Poarch, G., Luo, L., & Craik, F. I. M. (2014). Effects of bilingualism and aging on executive function and working memory. *Psychology and Aging*, *29*(3), 696–705. https://doi.org/10.1037/A0037254

Boone, K. B., Miller, B. L., & Lesser, I. M. (1993). Frontal lobe cognitive functions in aging: Methodologic considerations. *Dementia*, *4*(3–4), 232–236. https://doi.org/10.1159/000107328

Braem, S., & Egner, T. (2018). Getting a Grip on Cognitive Flexibility. *Current Directions in Psychological Science*, *27*(6), 470–476. https://doi.org/10.1177/0963721418787475

Brass, M., & Von Cramon, D. Y. (2004). Decomposing components of task preparation with functional magnetic resonance imaging. *Journal of Cognitive Neuroscience*, *16*(4), 609–620. https://doi.org/10.1162/089892904323057335

Bubbico, G., Chiacchiaretta, P., Parenti, M., Di Marco, M., Panara, V., Sepede, G., Ferretti, A., & Perrucci, M. G. (2019). Effects of second language learning on the plastic aging brain: Functional connectivity, cognitive decline, and reorganization. *Frontiers in Neuroscience*, *13*(MAY), 1–13. https://doi.org/10.3389/fnins.2019.00423

Capizzi, M., Ambrosini, E., Arbula, S., Mazzonetto, I., & Vallesi, A. (2016). Electrophysiological evidence for domain-general processes in task-switching. *Frontiers in Human Neuroscience*, *10*(MAR2016), 1–14. https://doi.org/10.3389/fnhum.2016.00124

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. C. (2001). Changes in executive control across the life span: examination of task-switching performance. *Developmental*

*Psychology*, *37*(5), 715–730. https://doi.org/10.1037/0012-1649.37.5.715

Chan, C. G. H., Yow, W. Q., & Oei, A. (2020). Active bilingualism in aging: Balanced bilingualism usage and less frequent language switching relate to better conflict monitoring and goal maintenance ability. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, *75*(9), E231–E241. https://doi.org/10.1093/geronb/gbaa058

Colzato, L. S., Bajo, M. T., van den Wildenberg, W., Paolieri, D., Nieuwenhuis, S., Heij, W. La, & Hommel, B. (2008). How Does Bilingualism Improve Executive Control? A Comparison of Active and Reactive Inhibition Mechanisms. *Journal of Experimental Psychology: Learning Memory and Cognition*, *34*(2), 302–312. https://doi.org/10.1037/0278-7393.34.2.302

Costa, A., Hernández, M., Costa-Faidella, J., & Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don’t. *Cognition*, *113*(2), 135–149. https://doi.org/10.1016/j.cognition.2009.08.001

Costumero, V., Marin-Marin, L., Calabria, M., Belloch, V., Escudero, J., Baquero, M., Hernandez, M., Ruiz De Miras, J., Costa, A., Parcet, M. A., & Ávila, C. (2020). A cross-sectional and longitudinal study on the protective effect of bilingualism against dementia using brain atrophy and cognitive measures. *Alzheimer’s Research and Therapy*, *12*(1), 1–11. https://doi.org/10.1186/s13195-020-0581-1

Craik, F. I. M., Bialystok, E., & Freedman, M. (2016). Delaying the onset of alzheimer’s disease: Bilingualism as a form of cognitive reserve. *Memory, Attention, and Aging: Selected Works of Fergus I. M. Craik*, 312–317. https://doi.org/10.4324/9781315440446

Crone, E. A., Wendelken, C., Donohue, S., Van Leijenhorst, L., & Bunge, S. A. (2006). Neurocognitive development of the ability to manipulate information in working memory. *Proceedings of the National Academy of Sciences of the United States of*

*America*, *103*(24), 9315–9320. https://doi.org/10.1073/pnas.0510088103

Crump, M. J. C., & Logan, G. D. (2010). Hierarchical Control and Skilled Typing: Evidence for Word-Level Control Over the Execution of Individual Keystrokes. *Journal of Experimental Psychology: Learning Memory and Cognition*, *36*(6), 1369–1380. https://doi.org/10.1037/A0020696

Cutini, S., Duma, G. M., & Mento, G. (2021). How time shapes cognitive control: A high-density EEG study of task-switching. *Biological Psychology*, *160*(January), 108030. https://doi.org/10.1016/j.biopsycho.2021.108030

Cutini, S., Scatturin, P., Menon, E., Bisiacchi, P. S., Gamberini, L., Zorzi, M., & Dell'Acqua, R. (2008). Selective activation of the superior frontal gyrus in task-switching: An event-related fNIRS study. *NeuroImage*, *42*(2), 945–955. https://doi.org/10.1016/j.neuroimage.2008.05.013

Czigler, I., Csibra, G., & Ambró, Á. (1996). Aging, stimulus identification and the effect of probability: An event-related potential study. *Biological Psychology*, *43*(1), 27–40. https://doi.org/10.1016/0301-0511(95)05173-2

Dajani, D. R., & Uddin, L. Q. (2019). Writing with purpose. *Basics Advertising 01: Copywriting*, *38*(9), 10–25. https://doi.org/10.5040/9781350152892.ch-001

Dash, T., Berroir, P., Joanette, Y., & Ansaldo, A. I. (2019). Alerting, orienting, and executive control: The effect of bilingualism and age on the subcomponents of attention. *Frontiers in Neurology*, *10*(OCT), 1–12. https://doi.org/10.3389/fneur.2019.01122

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, *44*(11), 2037. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2006.02.006

de Bruin, A., Treccani, B., & Della Sala, S. (2015). Cognitive Advantage in Bilingualism: An

Example of Publication Bias? *Psychological Science, 26*(1), 99–107. https://doi.org/10.1177/0956797614557866

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Dippel, G., & Beste, C. (2015). A causal role of the right inferior frontal cortex in implementing strategies for multi-component behaviour. *Nature Communications, 6*, 1–10. https://doi.org/10.1038/ncomms7587

Dunabeitia, J. A., Hernandez, J. A., Anton, E., Macizo, P., Estevez, A., Fuentes, L. J., & Carreiras, M. (n.d.). *The Inhibitory Advantage in Bilingual Children Revisited: Myth or reality? | Experimental Psychology | Vol 61, No 3*. https://econtent.hogrefe.com/doi/abs/10.1027/1618-3169/a000243?journalCode=zea

Eppinger, B., Kray, J., Mecklinger, A., & John, O. (2007). Age differences in task switching and response monitoring: Evidence from ERPs. *Biological Psychology, 75*(1), 52–67. https://doi.org/10.1016/J.BIOPSYCHO.2006.12.001

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics 1974 16:1, 16*(1), 143–149. https://doi.org/10.3758/BF03203267

Farooqui, A. A., & Manly, T. (2015). Anticipatory Control Through Associative Learning of Subliminal Relations: Invisible May Be Better Than Visible. *Psychological Science, 26*(3), 325–334. https://doi.org/10.1177/0956797614564191

Festman, J., & Münte, T. F. (2012). Cognitive control in Russian-German bilinguals. *Frontiers in Psychology, 3*(APR). https://doi.org/10.3389/fpsyg.2012.00115

Finke, M., Escera, C., & Barceló, F. (2012). *The Effects of Foreknowledge and Task-Set Shifting as Mirrored in Cue-and Target-Locked Event-Related Potentials*. https://doi.org/10.1371/journal.pone.0049486

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, *45*(1), 152–170. https://doi.org/10.1111/j.1469-8986.2007.00602.x

Forstmann, B. U., Tittgemeyer, M., Wagenmakers, E. J., Derrfuss, J., Imperati, D., & Brown, S. (2011). The Speed-Accuracy Tradeoff in the Elderly Brain: A Structural Model-Based Approach. *Journal of Neuroscience*, *31*(47), 17242–17249. https://doi.org/10.1523/JNEUROSCI.0309-11.2011

Friedman, N. P., Miyake, A., Young, S. E., DeFries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology. General*, *137*(2), 201–225. https://doi.org/10.1037/0096-3445.137.2.201

Gaál, Z. A., & Czigler, I. (2018). Task-Switching Training and Transfer: Age-Related Effects on Late ERP Components. *Journal of Psychophysiology*, *32*(3), 106–130. https://doi.org/10.1027/0269-8803/A000189

Gajewski, P. D., & Falkenstein, M. (2012). Training-induced improvement of response selection and error detection in aging assessed by task switching: Effects of cognitive, physical, and relaxation training. *Frontiers in Human Neuroscience*, *6*(MAY 2012), 1–18. https://doi.org/10.3389/fnhum.2012.00130

Gajewski, P. D., & Falkenstein, M. (2014). Age-Related Effects on ERP and Oscillatory EEG-Dynamics in a 2-Back Task. *Journal of Psychophysiology*, *28*(3), 162–177. https://doi.org/10.1027/0269-8803/a000123

Gajewski, P. D., Ferdinand, N. K., Kray, J., & Falkenstein, M. (2018). Understanding sources of adult age differences in task switching: Evidence from behavioral and ERP studies. *Neuroscience & Biobehavioral Reviews*, *92*, 255–275. https://doi.org/10.1016/J.NEUBIOREV.2018.05.029

Gajewski, P. D., Wild-Wall, N., Schapkin, S. A., Erdmann, U., Freude, G., & Falkenstein, M. (2010). Effects of aging and job demands on cognitive flexibility assessed by task switching. *Biological Psychology*, *85*(2), 187–199. https://doi.org/10.1016/j.biopsycho.2010.06.009

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive Function in Preschoolers: A Review Using an Integrative Framework. *Psychological Bulletin*, *134*(1), 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Garraffa, M., Beveridge, M., & Sorace, A. (2015). Linguistic and cognitive skills in Sardinian-Italian bilingual children. *Frontiers in Psychology*, *6*(DEC), 1–15. https://doi.org/10.3389/fpsyg.2015.01898

Gathercole, V. C. M., Thomas, E. M., Kennedy, I., Prys, C., Young, N., Guasch, N. V., Roberts, E. J., Hughes, E. K., & Jones, L. (2014). Does language dominance affect cognitive performance in bilinguals? Lifespan evidence from preschoolers through older adults on card sorting, Simon, and metalinguistic tasks. *Frontiers in Psychology*, *5*(FEB), 1–14. https://doi.org/10.3389/fpsyg.2014.00011

Goffaux, P., Phillips, N. A., Sinai, M., & Pushkar, D. (2008). Neurophysiological Measures of Task-Set Switching: Effects of Working Memory and Aging. *The Journals of Gerontology: Series B*, *63*(2), P57–P66. https://doi.org/10.1093/GERONB/63.2.P57

Gold, B. T., Kim, C., Johnson, N. F., Kryscio, R. J., & Smith, C. D. (2013). Lifelong bilingualism maintains neural efficiency for cognitive control in aging. *Journal of Neuroscience*, *33*(2), 387–396. https://doi.org/10.1523/JNEUROSCI.3837-12.2013

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition*, *1*(2), 67–81. https://doi.org/10.1017/s1366728998000133

Grosjean, F. (1989). Neurolinguists, beware! The bilingual is not two monolinguals in one person. *Brain and Language*, *36*(1), 3–15. https://doi.org/10.1016/0093-

934X(89)90048-5

Hsieh, S., & Cheng, P. (2006). Task reconfiguration and carryover in task switching: An event-related potential study. *Brain Research*, *1084*(1), 132–145. https://doi.org/10.1016/j.brainres.2006.02.060

Jackson, G. M., Swainson, R., Mullin, A., Cunnington, R., & Jackson, S. R. (2004). ERP correlates of a receptive language-switching task. *THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY*, *57*(2), 223–240. https://doi.org/10.1080/02724980343000198

Jamadar, S., Michie, P. T., & Karayanidis, F. (2010). Sequence effects in cued task switching modulate response preparedness and repetition priming processes. *Psychophysiology*, *47*(2), 365–386. https://doi.org/10.1111/j.1469-8986.2009.00932.x

Jost, K., Mayr, U., & Rösler, F. (2008). Is task switching nothing but cue priming? Evidence from ERPs. *Cognitive, Affective and Behavioral Neuroscience*, *8*(1), 74–84. https://doi.org/10.3758/CABN.8.1.74

Karayanidis, Jamadar, 2014. (2013). Chambers, RT. *Etica e Politica*, *15*(1), 583–605. https://doi.org/10.1093/acprof

Karayanidis, F., Coltheart, M., Michie, P. T., & Murphy, K. (2003). Electrophysiological correlates of anticipatory and poststimulus components of task switching. *Psychophysiology*, *40*(3), 329–348. https://doi.org/10.1111/1469-8986.00037

Karayanidis, F., Whitson, L. R., Heathcote, A., & Michie, P. T. (2011). Variability in proactive and reactive cognitive control processes across the adult lifespan. *Frontiers in Psychology*, *2*(NOV), 318. https://doi.org/10.3389/FPSYG.2011.00318/BIBTEX

Kieffaber, P. D., & Hetrick, W. P. (2005). Event-related potential correlates of task switching and switch costs. *Psychophysiology*, *42*(1), 56–71. https://doi.org/10.1111/j.1469-8986.2005.00262.x

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching-a review. *Psychological Bulletin*, *136*(5), 849–874. https://doi.org/10.1037/a0019842

Kim, P., Jenkins, S. E., Connolly, M. E., Deveney, C. M., Fromm, S. J., Brotman, M. A., Nelson, E. E., Pine, D. S., & Leibenluft, E. (2012). Neural correlates of cognitive flexibility in children at risk for bipolar disorder. *Journal of Psychiatric Research*, *46*(1), 22–30. https://doi.org/10.1016/j.jpsychires.2011.09.015

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, *38*(3), 557–577. https://doi.org/10.1017/S0048577201990559

Kopp, B., Lange, F., Howe, J., & Wessel, K. (2014). Age-related changes in neural recruitment for cognitive control. *Brain and Cognition*, *85*(1), 209–219. https://doi.org/10.1016/j.bandc.2013.12.008

Kopp, B., Steinke, A., & Visalli, A. (2020). Cognitive flexibility and N2/P3 event-related brain potentials. *Scientific Reports*, *10*(1), 1–17. https://doi.org/10.1038/s41598-020-66781-5

Kotchoubey, B. (n.d.). *Event-related potentials, cognition, and behavior: A biological approach*. https://doi.org/10.1016/j.neubiorev.2005.04.002

Kousaie, S., & Phillips, N. A. (2012). Ageing and bilingualism: Absence of a “bilingual advantage” in Stroop interference in a nonimmigrant sample. *Quarterly Journal of Experimental Psychology*, *65*(2), 356–369. https://doi.org/10.1080/17470218.2011.604788

Kray, J. (2006). Task-set switching under cue-based versus memory-based switching conditions in younger and older adults. *Brain Research*, *1105*(1), 83–92. https://doi.org/10.1016/j.brainres.2005.11.016

Kroll, J. F., & Bialystok, E. (2013). Understanding the Consequences of Bilingualism for

Language Processing and Cognition. *Journal of Cognitive Psychology (Hove, England), 25*(5), 497–514. https://doi.org/10.1080/20445911.2013.799170

Kropotov, J., Ponomarev, V., Tereshchenko, E. P., Müller, A., & Jäncke, L. (2016). Effect of aging on ERP components of cognitive control. *Frontiers in Aging Neuroscience, 8*(APR), 1–15. https://doi.org/10.3389/fnagi.2016.00069

Langenecker, S. A., Nielson, K. A., & Rao, S. M. (2004). fMRI of healthy older adults during Stroop interference. *NeuroImage*, *21*(1), 192–200. https://doi.org/10.1016/j.neuroimage.2003.08.027

Lavric, A., Mizon, G. A., & Monsell, S. (2008). Neurophysiological signature of effective anticipatory task-set control: A task-switching investigation. *European Journal of Neuroscience*, *28*(5), 1016–1029. https://doi.org/10.1111/j.1460-9568.2008.06372.x

Lee Salvatierra, J., & Rosselli, M. (2011). The effect of bilingualism and age on inhibitory control. *International Journal of Bilingualism*, *15*(1), 26–37. https://doi.org/10.1177/1367006910371021

Li, J., Wang, Y., Zhang, L., & Jung, T. P. (2012). Combining ERPs and EEG spectral features for decoding intended movement direction. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*, 1769–1772. https://doi.org/10.1109/EMBC.2012.6346292

Liu, H., & Zhang, Q. (2020). Neural correlates of the mechanism underlying negative response repetition effects in task-switching. *Brain and Cognition, 145*(105), 105627. https://doi.org/10.1016/j.bandc.2020.105627

Lorist, M. M., Klein, M., Nieuwenhuis, S., De Jong, R., Mulder, G., & Meijman, T. F. (2000). Mental fatigue and task control: Planning and preparation. *Psychophysiology*, *37*(5), 614–625. https://doi.org/10.1017/S004857720099005X

Lucci, G., Berchicci, M., Spinelli, D., Taddei, F., & Di Russo, F. (2013). The Effects of

Aging on Conflict Detection. *PLoS ONE*, *8*(2). https://doi.org/10.1371/journal.pone.0056566

Luck, S. (n.d.). *An Introduction to the Event-Related Potential Technique, Second Edition | The MIT Press*. Retrieved January 5, 2022, from https://mitpress.mit.edu/books/introduction-event-related-potential-technique-second-edition

Markiewicz, R., Mazaheri, A., & Krott, A. (2021). Bilingual speakers' enhanced monitoring can slow them down. *BioRxiv*, 2021.05.12.443807. https://doi.org/10.1101/2021.05.12.443807

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning Memory and Cognition*, *22*(6), 1423–1442. https://doi.org/10.1037/0278-7393.22.6.1423

Miniussi, C., Marzi, C. A., & Nobre, A. C. (2005). Modulation of brain activity by selective task sets observed using event-related potentials. *Neuropsychologia*, *43*(10), 1514–1528. https://doi.org/10.1016/j.neuropsychologia.2004.12.014

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. *Cognitive Psychology*, *41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, *7*(3), 134–140. https://doi.org/10.1016/S1364-6613(03)00028-7

Mortimer, J. A., Alladi, S., Bak, T. H., Russ, T. C., Shailaja, M., & Duggirala, V. (2014). Bilingualism delays age at onset of dementia, independent of education and immigration status. *Neurology*, *82*(21), 1936. https://doi.org/10.1212/WNL.0000000000000400

Nicholson, R., Karayanidis, F., Poboka, D., Heathcote, A., & Michie, P. T. (2005).

Electrophysiological correlates of anticipatory task-switching processes. *Psychophysiology*, *42*(5), 540–554. https://doi.org/10.1111/j.1469-8986.2005.00350.x

Nijmeijer, S. E., van Tol, M. J., Aleman, A., & Keijzer, M. (2021). Foreign Language Learning as Cognitive Training to Prevent Old Age Disorders? Protocol of a Randomized Controlled Trial of Language Training vs. Musical Training and Social Interaction in Elderly With Subjective Cognitive Decline. *Frontiers in Aging Neuroscience*, *13*(April), 1–14. https://doi.org/10.3389/fnagi.2021.550180

Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology*, *66*(2), 232–258. https://doi.org/10.1016/j.cogpsych.2012.12.002

Paap, K. R., Johnson, H. A., & Sawi, O. (2016). Should the search for bilingual advantages in executive functioning continue? *Cortex*, *74*, 305–314. https://doi.org/10.1016/j.cortex.2015.09.010

Pelham, S. D., & Abrams, L. (2014). Cognitive advantages and disadvantages in early and late bilinguals. *Journal of Experimental Psychology: Learning Memory and Cognition*, *40*(2), 313–325. https://doi.org/10.1037/a0035224

Petruo, V. A., Stock, A. K., Münchau, A., & Beste, C. (2016). A systems neurophysiology approach to voluntary event coding. In *NeuroImage* (Vol. 135). Elsevier B.V. https://doi.org/10.1016/j.neuroimage.2016.05.007

Pot, A., Porkert, J., & Keijzer, M. (2019). The bidirectional in bilingual: Cognitive, social and linguistic effects of and on third-age language learning. *Behavioral Sciences*, *9*(9). https://doi.org/10.3390/bs9090098

Poulsen, C., Luu, P., Davey, C., & Tucker, D. M. (2005). Dynamics of task sets: Evidence from dense-array event-related potentials. *Cognitive Brain Research*, *24*(1), 133–154. https://doi.org/10.1016/j.cogbrainres.2005.01.008

Prior, A., & Macwhinney, B. (2010). A bilingual advantage in task switching. *Bilingualism*, *13*(2), 253–262. https://doi.org/10.1017/S1366728909990526

Ramos, S., Fernández García, Y., Antón, E., Casaponsa, A., & Duñabeitia, J. A. (2017). Does learning a language in the elderly enhance switching ability? *Journal of Neurolinguistics*, *43*, 39–48. https://doi.org/10.1016/j.jneuroling.2016.09.001

Richard's, M. M., Krzemien, D., Valentina, V., Vernucci, S., Zamora, E. V., Comesaña, A., García Coni, A., & Introzzi, I. (2021). Cognitive flexibility in adulthood and advanced age: Evidence of internal and external validity. *Applied Neuropsychology:Adult*, *28*(4), 464–478. https://doi.org/10.1080/23279095.2019.1652176

Rodriguez-Fornells, A., Van Der Lugt, A., Rotte, M., Britti, B., Heinze, H. J., & Münte, T. F. (2005). Second language interferes with word production in fluent bilinguals: Brain potential and functional imaging evidence. *Journal of Cognitive Neuroscience*, *17*(3), 422–433. https://doi.org/10.1162/0898929053279559

Rogers, R. D., & Monsell, S. (1995). Costs of a predictible switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*(2), 207–231. https://doi.org/10.1037//0096-3445.124.2.207

Roldán-Tapia, M. D., Cánovas, R., León, I., & García-Garcia, J. (2017). Cognitive vulnerability in aging may be modulated by education and reserve in healthy people. *Frontiers in Aging Neuroscience*, *9*(OCT), 1–8. https://doi.org/10.3389/fnagi.2017.00340

Salthouse, T. A., Fristoe, N., & Rhee, S. H. (1996). How localized are age-related effects on neuropsychological measures? *Neuropsychology*, *10*(2), 272–285. https://doi.org/10.1037/0894-4105.10.2.272

Simon, J. R., & Rudell, A. P. (1967). Auditory S-R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology*, *51*(3), 300–304.

https://doi.org/10.1037/h0020586

Smith, A. B., Taylor, E., Brammer, M., & Rubia, K. (2004). Neural Correlates of Switching Set as Measured in Fast, Event-Related Functional Magnetic Resonance Imaging. *Human Brain Mapping*, *21*(4), 247–256. https://doi.org/10.1002/hbm.20007

Stern, P., Hines, P. J., & Travis, J. (2014). THE AGING brain. In *Science* (Third Edit, Vol. 346, Issue 6209). Elsevier. https://doi.org/10.1126/science.346.6209.566

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643–662. https://doi.org/10.1037/h0054651

Stuss, D. T., & Alexander, M. P. (2000). Executive functions and the frontal lobes: A conceptual view. *Psychological Research*, *63*(3–4), 289–298. https://doi.org/10.1007/s004269900007

Timmer, K., Grundy, J. G., & Bialystok, E. (2017). Earlier and more distributed neural networks for bilinguals than monolinguals during switching. *Neuropsychologia*, *106*(April), 245–260. https://doi.org/10.1016/j.neuropsychologia.2017.09.017

Travers, S., & West, R. (2008). Neural correlates of cue retrieval, task set reconfiguration, and rule mapping in the explicit cue task switching paradigm. *Psychophysiology*, *45*(4), 588–601. https://doi.org/10.1111/J.1469-8986.2008.00658.X

Van Veen, V., & Carter, C. S. (2002). The anterior cingulate as a conflict monitor: FMRI and ERP studies. *Physiology and Behavior*, *77*(4–5), 477–482. https://doi.org/10.1016/S0031-9384(02)00930-7

Vaughan, L., & Giovanello, K. (2010). Executive function in daily life: Age-related influences of executive processes on instrumental activities of daily living. *Psychology and Aging*, *25*(2), 343–355. https://doi.org/10.1037/a0017729

Wager, T. D., Jonides, J., & Reading, S. (2004). Neuroimaging studies of shifting attention: A meta-analysis. *NeuroImage*, *22*(4), 1679–1693.

https://doi.org/10.1016/j.neuroimage.2004.03.052

Wasylyshyn, C., Verhaeghen, P., & Sliwinski, M. J. (2011). Aging and Task Switching: A Meta-Analysis. *Psychology and Aging*, *26*(1), 15–20. https://doi.org/10.1037/a0020912

Wecker, N. S., Kramer, J. H., Hallam, B. J., & Delis, D. C. (2005). Mental flexibility: Age effects on switching. *Neuropsychology*, *19*(3), 345–352. https://doi.org/10.1037/0894-4105.19.3.345

Weissberger, G. H., Wierenga, C. E., Bondi, M. W., & Gollan, T. H. (2012). Partially overlapping mechanisms of language and task control in young and older bilinguals. *Psychology and Aging*, *27*(4), 959–974. https://doi.org/10.1037/A0028281

Wilson, C. G., Nusbaum, A. T., Whitney, P., & Hinson, J. M. (2018). Age-differences in cognitive flexibility when overcoming a preexisting bias through feedback. *Journal of Clinical and Experimental Neuropsychology*, *40*(6), 586–594. https://doi.org/10.1080/13803395.2017.1398311

Wylie, G., & Allport, A. (2000). Task switching and the measurement of “switch costs.” *Psychological Research*, *63*(3–4), 212–233. https://doi.org/10.1007/s004269900003

Wylie, G. R., Javitt, D. C., & Foxe, J. J. (2003). Task switching: A high-density electrical mapping study. *NeuroImage*, *20*(4), 2322–2342. https://doi.org/10.1016/j.neuroimage.2003.08.010

Xu, W. Q., Lin, L. H., Ding, K. R., Ke, Y. F., Huang, J. H., Hou, C. L., Jia, F. J., & Wang, S. Bin. (2021). The role of depression and anxiety in the relationship between poor sleep quality and subjective cognitive decline in Chinese elderly: Exploring parallel, serial, and moderated mediation. *Journal of Affective Disorders*, *294*, 464–471. https://doi.org/10.1016/J.JAD.2021.07.063

Yeung, N., & Cohen, J. D. (2006). The Impact of Cognitive Deficits on Conflict Monitoring. *Psychological Science*, *17*(2), 164–171.

http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=19473526&site=ehost-live

# Appendix

*Task Switching Paradigm*