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Does Bilingualism Enhance Cognitive Reserve and thus Protect Against Dementia?

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Fraudepreventie

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Abstract

The present bachelor's thesis aims to research and summarize the current literature on the possible effects of bilingualism on cognitive decline in healthy older adults and on the age at symptom onset and/or diagnosis in dementia patients. Bilinguals' supposed constant need to inhibit one language to avoid interference on the communicatively relevant language (Green, 1998; Meuter & Allport, 1999) is hypothesized to enhance cognitive reserve (CR; e.g., Bialystok, Craik, Klein, & Viswanathan, 2004). Numerous studies have reported a bilingual advantage in CR in the form of reduced cognitive decline (e.g., Bialystok, Poarch, Luo, & Craik, 2014; Gold, 2015) or protection against dementia (e.g., Alladi et al., 2013; Chertkow et al., 2010; Woumans et al., 2014). However, overall, findings of such a bilingual advantage have been inconsistent, as will be discussed in this bachelor's thesis. Potential confounding variables (e.g., immigration and education), methodological differences, and a possible publication bias (De Bruin, Treccani, & Della Sala, 2015b) will subsequently be addressed.

Contents

0. Introduction

Bilingualism and its effects have been studied for decades. Until Peal and Lambert (1962) reported higher verbal and non-verbal intelligence scores for bilingual relative to monolingual children, bilinguals were commonly thought to be at a disadvantage regarding language proficiency and overall intellectual function. However, over the past few decades, research has shifted its focus to the possible existence of an advantage rather than a disadvantage for bilinguals.

Numerous publications propose that bilingualism may boost cognitive reserve (CR; Bak, Nissan, Allerhand, & Deary, 2014; Bialystok, Craik, Klein, & Viswanathan, 2004; Craik, Bialystok, & Freedman, 2010; Gold, Kim, Johnson, Kryscio, & Smith, 2013b; Grant, Dennis, & Li, 2014; Kavé, Eyal, Shorek, & Cohen-Mansfield, 2008). The brain is adaptable and flexible (Pinto & Tandel, 2016) and intellectual, social, and physical stimulation may boost CR (Valenzuela & Sachdev, 2006a). CR would account for differences between individuals concerning the severity of age-related cognitive decline (Pinto & Tandel, 2016) and dementia-related neurodegeneration (Schweizer, Ware, Fischer, Craik, & Bialystok, 2012). Due to "individual differences in the cognitive processes or neural networks underlying task performance" (Stern, 2009), individuals would vary in their ability to cope with cognitive decline or brain pathology caused by dementia (Stern, 2009). All in all, the hypothesis proposes that CR may attenuate cognitive decline (Valenzuela & Sachdev, 2006a; Valenzuela & Sachdev, 2006b).

This supposed link between bilingualism and superior CR has also been investigated in conjunction with dementias, including Alzheimer's disease (AD), vascular dementia (VaD), frontotemporal dementia (FTD), dementia with Lewy bodies (DLB), the preclinical stages of dementia ("cognitive impairment no dementia"; CIND), and so forth. Bilingualism has been found to cause a delay in dementia symptom onset (e.g., Alladi et al., 2013; Bialystok, Craik, & Freedman, 2007; Ossher, Bialystok, Craik, Murphy, & Troyer, 2013; Woumans et al., 2014) and/or a delay in age at diagnosis (e.g., Chertkow et al., 2010; Craik et al., 2010; Gollan, Salmon, Montoya, & Galasko, 2011; Woumans et al., 2014).

1. The origin of a bilingual advantage

1.1. Inhibition

According to Kroll & Bialystok (2013) and De Groot (2013), bilinguals use executive control in the form of inhibition to reduce the activation of the language that is irrelevant in a particular situation. Executive control or executive function refers to the cognitive functions that are engaged in "deliberate control of thought, emotion[,] and action" (Brocki, 2007). Executive function allows for decision-making (Logan, 1985), exerting self-control, paying selective attention, and so forth (Diamond, 2013).

Bilinguals rely on this executive control to inhibit items from the non-target language or to inhibit this language altogether in order to avoid interference from this irrelevant language on the relevant language (Green, 1998; Meuter & Allport, 1999). Bialystok, Craik, and Luk (2008a) argue that this constant need to suppress one language or the lexicon of that language may magnify a bilingual's ability to ignore irrelevant stimuli in many tasks beyond the selection of a language in a particular communicative situation.

Due to this supposed constant need to inhibit one language and due to the repeated switching between languages (e.g., activating Dutch and inhibiting English in one context and inhibiting Dutch and activating English in another), bilinguals may demonstrate improved skills in the fields of cognitive and attentional control (Bialystok, 2001; Bialystok et al., 2004; Bialystok, Craik, & Ruocco, 2006a). Thus, bilinguals' constant practice in switching languages could potentially yield an advantage beyond linguistic tasks (Hilchey & Klein, 2011). The hypothesis is that bilinguals would also enjoy cognitive benefits in non-linguistic tasks that assess conflict resolution and could, hence, suffer from interference from the irrelevant information (Hilchey & Klein, 2011). A bilingual advantage would entail smaller interference effects for bilinguals than for monolinguals in such tasks (Hilchey & Klein, 2011).

Support for superior inhibitory control in bilinguals has been found in a number of tasks that require inhibition, e.g., the Simon task (e.g., Bialystok et al., 2004; Salvatierra & Rosselli, 2010; Schroeder & Marian, 2012), in which a stimulus is presented left or right on a computer screen and a button has to be pressed to indicate the color of the stimulus. Conflict arises when the stimulus is presented on a different side than the corresponding response button (Bialystok et al., 2004). Inhibitory mechanisms should suppress the location of the stimulus, since this is irrelevant for the task.

Bilinguals have also outperformed monolinguals in the Stroop task (e.g., Bialystok et al., 2008a; Bialystok, Craik, & Luk, 2008b; Bialystok, Poarch, Luo, & Craik, 2014; Zied et al., 2004). The Stroop task includes color names printed in an incongruent color (e.g., the color name "red" written in green). The color of the ink, not the color name that is written, has to be provided (Dijkstra, Grainger, & Van Heuven, 1999; Luk, Bialystok, Craik, & Grady, 2011; Meuter & Allport, 1999).

Another task of inhibitory control that has yielded better scores for bilinguals relative to monolinguals is the task-switching paradigm (Gold et al., 2013b; Prior & Gollan, 2011; Prior & MacWhinney, 2010). Switch costs refer to longer reaction times (RTs) for switch than for repeat trials. On a repeat trial, the participant is faced with the same task from the previous trial, e.g., a color decision, which may include three colors, one of which matches the color (but not necessarily the shape) of the shape at the bottom of the screen (Calabria, Hernández, Branzi, & Costa, 2012). On a switch trial, the participant has to respond to a different task than on the trial prior to the current trial, e.g., a shape decision task, which asks participants to match the shape at the bottom with one of the three shapes presented at the top (Calabria et al., 2012), instead of the color decision task of the previous trial. Both tasks make use of the same stimuli, but a different characteristic (color or shape) has to be responded to. The reduced task-switching costs that have been observed for bilinguals are considered to be indicative of improved inhibitory control. The Simon task, the Stroop task, and the task-switching paradigm all depend on inhibition and can hence also be seen as tasks in executive control (Martin, Wiggs, Lalonde, & Mack, 1994).

In lexical decision and go/no-go tasks, bilinguals are instructed to only respond in one particular language. Bilinguals' performance in these tasks further supports the view that bilinguals need to inhibit one language or the lexicon of a language at all times. For instance, in Dijkstra, Van Heuven, and Grainger's (1998) L2 lexical decision task, Dutch-English bilinguals yielded slower reaction times (RTs) and higher error rates to interlingual homographs (e.g., *list*) than to frequency- and length-matched monolingual words. These observations suggest that bilinguals were unable to suppress their L1 before lexical representations in both their L1 and their L2 became activated and that the participants therefore encountered a decision conflict when facing an item that exists in both of their languages, as is the case with interlingual homographs.

These results were echoed by Van Heuven, Schriefers, Dijkstra, and Hagoort (2008), who noted slower RTs for bilinguals in their L2 lexical decision task for interlingual homographs compared to control words. Their monolingual control group did not display such an inhibition effect. Dijkstra, Timmermans, and Schriefers (2000) also found a substantial inhibition effect for bilinguals in their go/no-go task.

1.2. Executive control

At any time in life, the brain adapts to (language) experience (Bialystok & Poarch, 2014). Bilingualism has been suggested to specifically enhance executive function because of a bilingual's constant need to suppress the irrelevant language, which requires cognitive and attentional control (Bialystok, 2001). Executive control may be boosted by bilingualism throughout life, since the effect of bilingualism increases "with increased experience" (Bialystok & Barac, 2012; Poarch & Van Hell, 2012). This is consistent with Green's (1998) view concerning the role of control in bilingualism, as he states: "Control of more than one language requires control, which may strengthen [executive control] circuits" (Green, 1998).

Furthermore, Gold (2015) observed greater metabolic activity in executive control (EC) circuits for bilinguals than for monolinguals. This greater metabolic activity originates from an increase in myelin, which insulates the white matter of the brain (Raine, 1984) and therefore allows for improved neuronal communication (Bradi & Lassmann, 2010; Gyllensten & Malmfors, 1963; Rosselli, Ardila, Matute, & Vélez-Uribe, 2014). This increase in neuronal communication may enhance angiogenesis (Gold, 2015), which is the process in which "new blood and lymphatic vessels form" (Nishida, Yano, Nishida, Kamura, & Kojiro, 2006). Angiogenesis may contribute to a bilingual's CR, since it seems to have a protective effect on frontostratial circuits (Gold, 2015), which are the circuits that generally appear to be particularly affected by "age-related small vessel disease" (Gold, 2015). Thus, bilingualism is considered to be an experience that can yield beneficial effects for bilinguals and boost CR effects through an increase of metabolic activity in EC circuits (Gold, 2015).

1.3. Cognitive reserve

Improved executive function, i.e., greater control of thought, action, and emotion (Brocki, 2007) may provide CR at old age (Bialystok et al., 2004; Grant et al., 2014) so that individuals with enhanced CR can cope better with cognitive decline (Stern, 2009). Furthermore, Gold's (2015) observation of an increase of metabolic activity in bilinguals' EC circuits may be indicative of greater CR in bilinguals compared to monolinguals. Nevertheless, it is not clear to what extent CR and executive function overlap (Miyake & Friedman, 2012; Valian, 2015).

Valenzuela and Sachdev (2006a) distinguish between brain reserve and cognitive reserve. Brain reserve originates from brain features, i.e., a larger total brain volume or a greater dendric or synaptic density (Crane et al., 2010; Valenzuela & Sachdev, 2006a). In contrast, cognitive reserve does not depend on brain characteristics, but rather on intellectual, social, and physical stimulation (Valenzuela & Sachdev, 2006a). It appears that activities and merits including aerobic exercise (Erickson et al., 2011; Guiney & Machado, 2013; Kramer et al., 1999), music training (Bialystok & DePape, 2009; Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Moreno et al., 2011), higher educational attainment (Crane et al., 2010; Valenzuela & Sachdev, 2006a; Zahodne, Schofield, Farrell, Stern, & Manly, 2014), a mentally challenging occupation (Crane et al., 2010; Staff, Murray, Deary, & Whalley, 2004), and other factors can augment CR. In addition, a number of studies have found an improvement in CR as a result of bilingualism (e.g., Gold, 2015; Guzmán-Vélez & Tranel, 2015; Stern, 2002).

CR is hypothesized to bridge the gap between cognitive decline and cognitive function (Gold, 2015). Therefore, neurodegeneration in healthy older adults or pathological burden in dementia patients may be counteracted by an increase in CR. This CR "compensate[s] for pathology by recruiting alternate brain networks" (Stern, 2002) and both brain reserve and cognitive reserve are thought to postpone the effects of neurodegeneration in AD patients (Crane et al., 2010). Thus, according to the reserve hypothesis (Crane et al., 2009; Fratiglioni, Paillard-Borg, & Winblad, 2004; Perquin et al., 2013; Staff et al., 2004), enhanced CR accounts for the absence of signs of cognitive impairment in many Alzheimer's disease patients (Schweizer et al., 2012).

In brief, bilinguals are hypothesized to continuously inhibit one of their two languages in their everyday lives, which is believed to contribute to their executive control. Their greater executive control boosts their CR (Gold, 2015), which potentially accounts for the bilingual advantage in CR that has been observed in a multitude of tasks. Furthermore, enhanced CR may offer protection against dementia and postpone symptom onset and/or the age of diagnosis (Crane et al., 2010; Gold, 2015; Schweizer et al., 2012; Stern, 2002).

2. Bilingual advantage

2.1. Bilingual advantage in healthy older adults

Aging affects the brain in multiple manners. Cognitive processes such as the ability to inhibit, control attention, and shift between tasks "show the first evidence of decline in aging" (Bialystok & Craik, 2010). A decline in language performance commonly arises after the age of 70 in healthy adults (Manchon et al., Annoni, 2014). In addition, episodic memory degenerates in normal aging (Craik, 1994). Episodic memory refers to people's ability to remember events that they have experienced themselves (Tulving, 1983). This includes experiences from multiple decades ago and those from the past few minutes or hours (Tulving, 1983). A decline in the ability to recall these events may, to some extent, be caused by reduced executive functioning in the elderly (Schroeder & Marian, 2012). Furthermore, older individuals have repeatedly demonstrated a reduced ability to ignore distracting and irrelevant information in language tasks (e.g., the location of a blue rectangle in a color condition in which the color blue has to be identified by a left button press) and in general cognitive processing in comparison with younger adults (Connelly, Hasher, & Zacks, 1991; Hasher & Zacks, 1988; Logan & Balota, 2003; Zacks & Hasher, 1994). Inhibitory capacity (Hasher, Zacks, & May, 1999) also decreases in aging.

However, older bilinguals have shown different patterns in cognitive aging than older monolinguals. For instance, Bialystok et al. (2014) argue that bilingualism can counteract the aforementioned degeneration of executive function (Schroeder & Marian, 2012). Moreover, although Connelly, Hasher, and Zacks (1991), Hasher and Zacks (1988), Logan and Balota (2003), and Zacks and Hasher (1994) reported an increased difficulty for older adults in handling distracting stimuli, older bilinguals may be better at ignoring such irrelevant information than monolinguals (Bialystok et al., 2008a). Older bilinguals and monolinguals were matched on age and compared to younger monolinguals and bilinguals, since age may affect performance. For instance, in Bialystok et al.'s (2008a) study, older participants (68 years) yielded longer RTs overall and outperformed the younger adults (20 years) in picture naming.

2.1.1. The Simon task

In a vast array of studies, older bilinguals have demonstrated a supposed bilingual advantage. A notable example of a bilingual advantage is a smaller Simon effect. Simon tasks are used to assess inhibitory control and make use of stimuli that are presented on the left- or the right-hand side of a computer screen. Different stimuli can be used, e.g., arrows (Bialystok, 2006; De Bruin, Bak, & Della Sala, 2015a), letters (Paap & Greenberg, 2013), or colored squares (Salvatierra & Rosselli, 2010). If colored shapes are used, participants have to press a button to indicate the color of the stimulus. On congruent trials, the location of the stimulus corresponds with that of the key for the color, e.g., a red square on the left side of the screen when the response key for "red" is situated on the left side of the keyboard. On incongruent trials, the location of the stimulus does not coincide with that of the corresponding response button (Bialystok et al., 2004), e.g., a red square on the left side of the screen when the correct response key is on the right side of the keyboard. Inhibitory mechanisms should suppress the irrelevant information, i.e., the location of the stimulus (Colzato et al., 2008). All in all, this type of task appears to examine conflict resolution through inhibitory control (Hilchey & Klein, 2011), i.e., the irrelevant stimulus characteristic must be inhibited as an irrelevant source for response determination. The Simon effect refers to the longer reaction time that participants need to respond to incongruent items in comparison with the time needed to respond to congruent trials (Bialystok et al., 2014).

Van der Lubbe and Verleger (2002) obtained a larger Simon effect for older than for younger adults "even after correcting for the general slowing associated with aging" (Bialystok et al., 2004). Thus, Simon effects appear to increase with age (Bialystok et al., 2004; Schroeder & Marian, 2012; Van der Lubbe & Verleger, 2002).

Older bilinguals have repeatedly yielded a reduced Simon effect in comparison with monolinguals of similar age (Bialystok et al., 2004; Bialystok et al., 2008a; Salvatierra & Rosselli, 2010). In Bialystok et al.'s (2004) study, the Simon effect was notably smaller among young adults and bilinguals. The age-related increase in the Simon effect was attenuated by the bilingual condition relative to the monolingual condition. This implies that the habit of managing two languages reduces “the age-related decline of inhibitory processing” (Bialystok et al., 2004).

Salvatierra and Rosselli (2010) reported a significantly reduced Simon effect in the simple condition of their task for old bilinguals relative to old monolinguals. Nonetheless, the younger bilinguals’ performance was comparable to that of the younger monolinguals. Furthermore, this distinction between the two older language groups regarding the Simon effect was absent in the complex condition, which comprised 4 differently colored squares that were positioned either to the left or to the right of a monitor (blue or yellow squares were on the left on congruent trials; purple or white ones on the right) instead of only 2 (green and red). From these results, they inferred that bilingualism boosts selective attention “when working memory demands are low” (Salvatierra & Rosselli, 2010), since the bilingual advantage was limited to the condition in which only 2 colors had to be associated with their respective button. The complex condition included 4 stimuli and therefore also assessed working memory ability (Salvatierra & Rosselli, 2010) instead of merely testing inhibitory control as was the case in the simple condition. Due to this increased “working memory load” (Salvatierra & Rosselli, 2010) in the complex condition, RTs to congruent trials increased to a greater extent than those to incongruent trials, which attenuated the Simon effect and accounted for the lack of a bilingual advantage in this complex condition (Salvatierra & Rosselli, 2010).

Other researchers have argued that the reduced Simon effect reported by Bialystok et al. (2004) is hard to replicate (Colzato et al., 2008). Bialystok, Martin, and Viswanathan (2005b) and Bialystok (2006) were unable to detect a bilingual advantage in their Simon tasks. Likewise, Paap and Greenberg (2013) failed to note a bilingual advantage in reaction times in either one of their three Simon tasks. In fact, they reported a small but significant disadvantage for bilinguals in one Simon task (Paap & Greenberg, 2013).

De Bruin et al. (2015a) studied Gaelic-English bilinguals and English monolinguals. They divided their bilingual population into “active bilinguals” (individuals who used both Gaelic and English in everyday life) and “inactive bilinguals” (individuals who mostly used English). The participants of their study were matched on a large number of variables including immigrant status. The three groups yielded comparable RTs in the Simon arrow task. This suggests that bilinguals do not benefit from enhanced executive control and that another explanation should be sought for bilinguals' advantages in this task (De Bruin et al., 2015a).

2.1.2. Task- and language-switching

De Bruin et al. (2015a) and Paap and Greenberg (2013) did not only fail to observe a smaller Simon effect in their bilingual populations, they were also unable to find a bilingual advantage in their non-verbal task-switching paradigm in overall reaction times and proportional switching costs. The absence of a bilingual advantage in De Bruin et al.'s (2015a) and Paap and Greenberg's (2013) Simon tasks and task-switching paradigms is consistent with Hilchey and Klein's (2011) conclusion that there "is only limited evidence for a bilingual advantage on local inhibitory control processes".

In task-switching, longer RTs for switch than for repeat trials are referred to as switch costs. Non-verbal task-switching skills are tested in mixed blocks in which two distinct decisions occur, e.g., color and shape decisions (Timmer, Grundy, & Bialystok, 2017). Repeat trials present the same task as that of the previous trial, e.g., a color decision task follows another color decision task, whereas switch trials present a different task, e.g., a shape decision task instead of the color decision task of the previous trial. Even though these two tasks use the same stimuli (e.g., a red rectangle), the participant is asked to respond to a different characteristic in the color decision task (the color "red") than in the shape decision task (the shape "rectangle"). Older adults commonly yield greater switch costs than younger adults (Gold et al., 2013b). Nonetheless, bilingualism may offset this divergence and may even give rise to a bilingual advantage (Gold et al., 2013b).

Neuroimaging studies have yielded disparate patterns between bilinguals and monolinguals in relation to task-switching. In Timmer et al.'s (2017) study, the N2 (a negative-going wave that demonstrates "greater negativity for repeat than switch trials"; Timmer et al., 2017) peaked in the 225-275 ms time window. As evinced by a deflection in this N2 waveform, bilinguals exhibit faster attentional cue processing, which entails that they are quicker at identifying whether a trial is a repeat or a switch trial on the basis of a cue in comparison with the monolinguals (Timmer et al., 2017). Moreover, bilinguals activate a more distributed network than monolinguals (Timmer et al., 2017). This earlier stimulus processing in bilinguals is thought be attributable to their "lifelong experience with paying attention to contextual cues informing them about the language to be used" (Timmer et al., 2017).

Moreover, several other studies have reported a bilingual advantage on switching trials (De Bruin et al., 2015a), among which Prior and MacWhinney (2010) and Gold et al. (2013b). In Gold et al.'s (2013b) study, switch costs were smaller for older adult bilinguals than for older adult monolinguals, as was visible in several brain regions located in the left dorsolateral prefrontal cortex (DLPFC), the left ventrolateral prefrontal cortex (VLPFC), and the anterior cingulate cortex (ACC). Nevertheless, these observations and those of Prior and MacWhinney (2010) only applied to the immigrant populations, not to the individuals who were native to the US, of their studies (De Bruin et al., 2015a).

Even within the same (non-linguistic) task-switching paradigm, different groups of bilinguals have not yielded identical results. Spanish-English bilinguals have demonstrated significantly reduced switching costs in comparison with monolinguals and Mandarin-English bilinguals in both language-switching and in non-linguistic task-switching (Prior & Gollan, 2011). The Spanish-English bilinguals of this study reported more frequent switching between their two languages than the Mandarin-English bilinguals. The discrepancy between the two bilingual populations remained apparent after matching on L2 language proficiency, which suggests that regularly switching between languages in daily life may be responsible for a bilingual advantage in task-switching (Prior & Gollan, 2011).

Gollan, Kleinman, and Wierenga (2014) propose that "bilingual" advantages may ensue from task settings rather than from bilingualism. Their experiment compared cued and voluntary language-switching and non-verbal task-switching, in the form of a read-add task (in which participants alternated between reading numbers and adding them), in bilinguals and used a monolingual control group. Bilinguals named pictures (in Spanish or English, with a total of 8 switches in the cued-switch picture naming block that included 32 pictures) and performed the read-add task (Gollan et al., 2014). Monolinguals performed the size-parity task (in which participants either formed numbers using eight digits in the parity task or had to identify digits as "smaller" if they were under 5 or "bigger" if it was above 5 in the size task) and the read-add task. Both tasks included a condition in which participants could freely switch. The data of participants who did not sufficiently switch between these tasks was excluded (Gollan et al., 2014).

In the voluntary condition, monolinguals who were considered in the further analyses switched on 31% of the size-parity trials and on 32% of the read-add trials (Gollan et al., 2014). These percentages were higher than those in the cued switching condition (25%). A voluntary advantage arose for the monolinguals, as they yielded shorter RTs in the voluntary than in the cued condition in both the read-add and the size-parity task. Likewise, bilinguals yielded faster RTs on both repeat and switch trials in the voluntary switching condition than in the cued switching condition, in particular in non-linguistic switching (Gollan et al., 2014). In a second experiment with the same bilingual participants, stimuli were repeated, which elicited even faster RTs in the voluntary relative to the cued condition in the picture naming task as well as in task-switching, most notably on switch trials (Gollan et al., 2014). Overall, participants were quicker in the voluntary than in the cued switching condition, which supports the view that switching in cued experimental tasks may not be representative of a bilingual's language-switching in everyday life (Blanco-Elorrieta & Pylkkänen, 2017; Gollan et al., 2014).

Additional corroboration of a discrepancy between cued and voluntary switching was found by Blanco-Elorrieta and Pylkkänen (2017). Their study revealed that less executive control was required to switch languages in more natural circumstances in comparison with stimulus-induced switching. Whereas this cued switching elicited an increase in activity "in prefrontal and anterior cingulate control networks" (Blanco-Elorrieta & Pylkkänen, 2017), no such activation was found in spontaneous language-switching (Blanco-Elorrieta & Pylkkänen, 2017).

Blanco-Elorrieta and Pylkkänen (2017) used a switching paradigm to research the effect of a language-switch from English to Arabic and the other way around. Switching could occur “at the level of a single word, phrase, clause, sentence, or third-person speech quotation” (Blanco-Elorrieta & Pylkkänen, 2017). In the cued condition, a color cue was displayed and participants had to indicate through a button press whether a picture that followed matched the word from the audio recording that they had just heard. In the more natural condition, participants heard snippets of a recorded and natural conversation in which the interlocutors switched at their own volition. Participants were asked to indicate whether the picture matched the recording (Blanco-Elorrieta & Pylkkänen, 2017).

In the cued condition, the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC) were engaged, but “the understanding of natural switches within a conversation only engaged the auditory cortex” (Blanco-Elorrieta & Pylkkänen, 2017). The DLPFC (Carter et al., 2000) and the ACC (Forbes et al., 2014) have been associated with executive control (Carter et al., 2000; Forbes et al., 2014). Blanco-Elorrieta & Pylkkänen (2017) compared the bilinguals of their study to English monolinguals. Whereas the auditory cortex activity of bilinguals rose regardless of the direction in which the switch occurred, the monolinguals’ auditory cortex activity was only affected by a switch from Arabic to English, since the monolinguals were not capable of decoding the boundary types in Arabic (Blanco-Elorietta & Pylkkänen, 2017). The bilinguals yielded smaller switch effects when the discourse boundaries were larger (e.g., when a switch occurred after a monolingual sentence and the following sentence was entirely in the other language), which suggests that their left auditory cortex may have been “tracking the predictability of the switch” (Blanco-Elorrieta & Pylkkänen, 2017). The monolinguals were not able to track this predictability due to their unfamiliarity with Arabic.

Blanco-Elorrieta & Pylkkänen (2017) concluded that the two language groups differed from one another in terms of their auditory cortex activity. Contrary to the monolinguals, the bilinguals may have been able to predict a switch using their left auditory cortex (Blanco-Elorrieta & Pylkkänen, 2017). In addition, in the cued condition, the bilinguals relied on areas that supposedly underlie executive control (Blanco-

Elorrieta & Pylkkänen, 2017; Carter et al., 2000; Forbes et al., 2014), but these areas were not engaged in the natural condition (Blanco-Elorrieta & Pylkkänen, 2017). The observations of their study support the hypothesis that cued switches in tasks are dissimilar from bilingual switches in more natural settings, as the two conditions differed from one another in terms of the engagement of brain regions that are thought to govern executive control (Blanco-Elorrieta & Pylkkänen, 2017).

2.1.3. The Stroop color-naming task

In Stroop tasks, color names are written in an incongruent color (e.g., the color name "red" printed in green). Participants are commonly asked to name the color of the ink in which the word is printed, not the actual color name that is written (Dijkstra, Grainger, & Van Heuven, 1999; Luk, Bialystok, Craik, & Grady, 2011; Meuter & Allport, 1999). Stroop color-naming tasks measure cognitive control, since participants should ignore one of the features (word or color) and react to the other (Bialystok et al., 2008a). A Stroop effect describes the difference between RTs for incongruent and congruent trials (Kousaie & Phillips, 2012). If bilinguals do indeed have superior executive control, as has been suggested (e.g., Bialystok, 2001), they will yield smaller Stroop effects than monolinguals (Bialystok et al., 2008a; Calabria et al., 2012).

Bialystok et al.'s (2008a) study demonstrated a reduced Stroop effect for bilingual relative to monolingual adults in both the younger and the older participant group. The findings of smaller Stroop interference for older bilingual adults has been echoed by numerous publications (e.g., Bialystok et al., 2008b; Bialystok et al., 2014; Zied et al., 2004).

Nevertheless, bilinguals do not always outperform monolinguals in Stroop color-naming tasks. One electrophysiological study revealed no distinctions between younger bilinguals and younger monolinguals who performed a Simon, a Stroop, and a flanker task (Kousaie & Phillips, 2012). Stroop effects may become smaller, and therefore less noticeable, for bilingual participants as age increases (Bialystok et al., 2008a).

2.2. Bilingual advantage in dementia patients

2.2.1. Bilingualism may protect against dementia

The supposed beneficial effects of bilingualism have not merely been reported for healthy older adults, but also for individuals with dementia. These bilingual advantages come in the form of a delay in symptom onset (Alladi et al., 2013; Bialystok et al., 2007; Ossher et al., 2013; Woumans et al., 2014) or an older age of diagnosis (Chertkow et al., 2010; Craik et al., 2010; Gollan et al., 2011; Woumans et al., 2014).

In their review, Valenzuela and Sachdev (2006a) established links between several variables and dementia incident rates. Their review did not address bilingualism but instead focused on factors including educational and occupational background and "mentally stimulating leisure activities" (Valenzuela & Sachdev, 2006a). The overall odds ratio[1] across 15 studies indicated a 47% decrease in the risk of incident dementia for highly educated participants (Valenzuela & Sachdev, 2006a). Similarly, a high occupational status or history thereof was associated with a reduction by 44% regarding the same risk and a 42% decrease for participants with a high premorbid IQ relative to those with a lower IQ (Valenzuela & Sachdev, 2006a).

All these findings propose that complex and demanding mental activity can lower the odds of dementia conversion (Valenzuela & Sachdev, 2006a). What these variables have in common is that they are intellectually demanding activities. According to Valenzuela and Sachdev (2006a), such mental stimulation provides CR.

Bilingualism is thought to enhance CR in the same way that intellectual, social, and physical stimulation (Valenzuela & Sachdev, 2006a) can (e.g., Gold, 2015; Guzmán-Vélez & Tranel, 2015; Stern, 2002). Likewise, bilingualism has been shown to provide older adults with protection against dementia (e.g., Craik et al., 2010), but the reports of such an effect have not been unambiguous. After all, numerous studies have failed to demonstrate a link between bilingualism and protection against dementia (e.g., Crane et

[1] The odds ratio "compare[s] the relative odds of the occurrence" (Szumilas, 2010) of dementia in the presence of a particular variable (Szumilas, 2010), e.g., a higher educational level, "to the odds of the outcome occurring in the absence" (Szumilas, 2010) of this variable.

al., 2009; Lawton, Gasquoine, & Weimer, 2015; Ljungberg, Hansson, Adolfsson, & Nilsson, 2016; Zahodne et al., 2014).

2.2.1.1. Cognitive impairment no dementia (CIND)

"Cognitive impairment no dementia" (CIND; Perquin et al., 2013) refers to the preclinical stages of dementia and includes reduced cognitive abilities or memory function. Even in these stages prior to dementia symptom manifestation, an effect of multilingualism has been noted (Perquin et al., 2013). In their study, Perquin et al. (2013) compared bilingual to multilingual participants. With the bilinguals as a reference group, multilinguals were three times less likely to suffer from CIND. Nevertheless, relative to trilinguals, those who spoke 4 languages did not benefit from additional protection. The same applied for the older adults who were proficient in more than 4 languages in comparison with those who indicated proficiency in 4 languages (Perquin et al., 2013).

For every year a bilingual postponed learning a third language (and thus becoming multilingual), the risk of CIND increased by 1.022. Monolinguals who learned two languages at once yielded a risk of CIND that was 13 times reduced relative to that of bilinguals. Bilinguals who acquired one additional language were 7 times more likely to be shielded from CIND than bilinguals who remained bilingual (Perquin et al., 2013).

The observations of Perquin et al.'s (2013) study were in line with those of Kavé et al. (2008), who reported enhanced cognitive function in healthy older adults based on the number of languages they were proficient in. Additionally, Kavé et al. (2008) found that, regardless of education level, cognitive function improved for older non-demented participants "in function of the number of languages spoken (2, 3, or more)" (Kavé et al., 2008).

However, in Perquin et al.'s (2013) study, variables other than bilingualism may have confounded the link between bilingualism and protection against CIND. This protective effect may have (partially) arisen on the basis of differences between individuals, since the CIND and the CIND-free adults differed from one another in terms of their engagement in leisure and sociocultural activities. Participants without CIND reported higher activity levels than those who were suffering from CIND (Perquin et al., 2013).

Further potential caveats in studies will be addressed in chapter 4, which focuses on caveats in task design and variables that may confound a study's outcomes.

2.2.1.2. Amnestic mild cognitive impairment (aMCI)

Ossher et al. (2013) researched amnestic mild cognitive impairment (aMCI), which refers to a memory deficit that is "not severe enough to warrant a diagnosis of dementia" (Ossher et al., 2013). Single-domain aMCI patients only experience memory problems, whereas those with multiple-domain aMCI can also be affected in their "executive functions, language, or visuospatial ability" (Ossher et al., 2013) and these individuals are "further along in the progression toward dementia and more at risk of conversion to [AD]" (Alexopoulos, Grimmer, Perneczky, Domes, & Kurz, 2006; Busse, Hensel, Gühne, Angermeyer, & Riedel-Heller, 2006; Rasquin, Lodder, Visser, Lousberg, & Verhey, 2005).

Bilingual patients with single-domain aMCI were on average 4.5 years older at the time of their diagnosis than monolingual patients with the same type of aMCI (Ossher et al., 2013). The outcomes of Ossher et al.'s (2013) study indicated protection only against single-domain aMCI, not against multiple-domain aMCI. Ossher et al. (2013) suggest that the bilinguals may have benefited from their bilingualism in the sense that other brain systems were able to compensate for their cognitive impairment. It is conceivable that this compensation originates from improved frontal systems, which are responsible for executive functions and attentional control (Ossher et al., 2013). Multiple-domain aMCI yields more frontal lobe pathology than single-domain aMCI (Bell-McGinty et al., 2005). Thus, bilingual multiple-domain aMCI patients may have "lost a frontally based compensatory mechanism" (Ossher et al., 2013), since their impairment is located in the network that has been boosted by their bilingual status (Ossher et al., 2013).

2.2.1.3. (Probable) Alzheimer's disease (AD)

One of the most remarkable bilingual advantages was found by Bialystok et al. (2007). These researchers reported a 4.1-year delay in dementia symptom onset for their bilingual relative to their monolingual population. This delayed onset was significant for bilinguals who had been diagnosed with probable AD and those who suffered from other dementias. Additionally, the bilinguals were on average 3.2 years older at their first clinic appointment than the monolinguals. Due to their cultural backgrounds, bilinguals could have avoided seeking medical attention for a longer period than monolinguals, but the opposite was discovered to be true (Bialystok et al., 2007).

Chertkow et al. (2010) also reported a significant delay in AD diagnosis for bilingual patients. On average, the bilinguals of their study received their diagnosis 5 years after their monolingual counterparts. This effect was even more pronounced among participants who were proficient in three languages, since they were diagnosed 6.4 years later than the monolinguals. For individuals who reported fluency in four or more languages, diagnosis was postponed by 9.5 years relative to the monolingual group. Nonetheless, the bilingual effect was limited to immigrants (Chertkow et al., 2010).

However, both among immigrants and native Canadians, a significant protective effect was noted for individuals who spoke three or more languages (Chertkow et al., 2010). Multilingualism is therefore “associated with a significant delay in the onset of symptoms of AD” (Schweizer et al., 2012). Schweizer et al. (2012) further propose that bilingualism offers additional CR and therefore “modulates the behavioral expression of the underlying neuropathology associated with AD”.

Similar outcomes have been reported for a Belgian population (Woumans et al., 2014). Bilingualism was found to delay dementia symptom onset by 4.6 years. Bilingual participants also yielded a 4.8-year delay in their age of diagnosis in comparison with the monolingual group (Woumans et al., 2014).

2.2.1.4. Multiple dementia types

Alladi et al.’s (2013) study further underlined the hypothesis that bilingualism has a protective effect against dementia. Their study comprised 648 dementia patients (of which 424 were men) of various dementia types (AD=340, VaD=189, FTD=116, DLB=55[2]). In total, 391 participants were bilingual. Whereas monolinguals experienced their initial dementia symptoms at an average of 61.1 years, symptom onset was around

[2] Alzheimer’s disease (AD), vascular dementia (VaD), frontotemporal dementia (FTD), and dementia with Lewy bodies (DLB), respectively.

65.6 years old for bilinguals. Bilingual AD patients benefited from a delay in symptom onset of 3.2 years relative to monolingual AD patients, bilingual frontotemporal dementia (FTD) patients' symptoms were delayed by 6.0 years, and individuals with vascular dementia (VaD) experienced symptoms 3.7 years later than monolinguals with the same dementia type (Alladi et al., 2013).

2.2.2. Bilingualism may not protect against dementia

Numerous other articles have failed to report a bilingual advantage. For example, Ljungberg et al. (2016) did not note a protective effect of bilingualism in their study on native Swedish speakers. At the first session of their study, their participants were 60 years or older. In total, 112 participants developed dementia whereas 706 did not develop dementia symptoms. At baseline, monolinguals who did not develop dementia were significantly older, had fewer years of education, and were in fewer cases carriers of the Apolipoprotein E (APOE) ε4 allele relative to the bilinguals who remained free of dementia (Ljungberg et al., 2016). The APOE ε4 allele is a protein that transports "cholesterol and other lipids between cellular structures" (Rawle et al., 2018). It has been found to be "an established risk factor for dementia" (Corder et al., 1993) and being a carrier of one ε4 allele triples or quadruples the risk of AD (Ljungberg et al., 2016). In Ljungberg et al.'s (2016) study, this allele was "the overall strongest predictor for developing dementia" (Ljungberg et al., 2016). Individually, bilingualism did not lower the risk of dementia (Ljungberg et al., 2016). Ljungberg et al. (2016) hypothesized that the absence of immigrants (Kousaie & Phillips, 2012) in their study may have affected the outcomes, since the bilingual participants may not have used their L2 as frequently as immigrants and therefore may not have benefited from the same cognitive advantages as immigrants might (Ljungberg et al., 2016).

Likewise, Crane et al. (2009) failed to find a protective effect of being able to write Japanese. Their study comprised adults who reported speaking and/or writing skills in Japanese, including *Kibei* participants, which referred to individuals who had spent part of their childhood in Japan for educational purposes (Crane et al., 2009). There was hardly any difference in dementia odds ratios between including and excluding the 335 *Kibei* individuals in the analyses. All in all, proficiency in Japanese, regardless of where it had been learned, did not have a significant effect on the findings (Crane et al., 2009).

Zahodne et al.'s (2014) 23-year-long study did not reveal a protective effect for bilinguals, either. Cognitive decline and dementia conversion rates did not significantly differ between bilinguals and monolinguals. From the 1.067 individuals who developed AD during the experiment, the bilinguals did yield "better memory and executive function at baseline" (Calvo, García, Manoiloff, & Ibáñez, 2016), as was evinced by their higher memory scores in the Selective Reminding Test (SRT; Buschke & Fuld, 1974) and their superior performance in tests of executive function. In the SRT (Buschke & Fuld, 1974), participants were given six trials to recall 12 words that they had learned. After every trial, the words that they had not recalled were repeated. Their "[t]otal learning" (Zahodne et al., 2014) was measured in terms of the number of words that they had successfully recalled across the six trials (Zahodne et al., 2014).

Furthermore, bilinguals demonstrated better executive function in the Similarities subtest of the Wechsler Adults Intelligence Scale – Revised (WAIS-R; Wechsler, 1981), the Identities and Oddities subtest of the Mattis Dementia Rating Scale (Mattis, 1976), and a letter fluency task, in which participants were given three trials of 60 seconds each to generate words starting with a P, S, or V (Zahodne et al., 2014). In the Similarities subtest of the Wechsler Adult Intelligence Scale – Revised (WAIS-R; Wechsler, 1981) participants had to "articulate similarities in a set of items" (Siedlecki et al., 2010). In the first eight trials of Mattis' (1976) Identities and Oddities subtest, participants were asked to choose which two out of three items were alike. In the eight trials that follow, the same items were used and participants had to select the item that was different from the others (Siedlecki et al., 2010).

In Lawton et al.'s (2015) study, the bilingual Hispanic Americans (both US-natives and immigrants) were not diagnosed at an older age than the monolinguals. As a matter of fact, monolinguals were 1.8 years older than bilinguals when they received their dementia diagnosis. The monolinguals had a lower education (4.99 years) than bilinguals (7.70 years), which, according to Beydoun et al. (2014), would normally be correlated with an increased risk of developing Alzheimer's disease.

3. Neuroimaging data

3.1. Differences between the monolingual and the bilingual brain

In order to further investigate the potential link between bilingualism and cognitive reserve, various neuroimaging studies have compared the brains of bilinguals to those of monolinguals. For bilinguals, greater brain atrophy (Bialystok & Barac, 2012), strengthened EC circuits (Gold, 2015), and a greater decline in white matter volume (WMV; Gold, Johnson, & Powell, 2013a) has been found in comparison with monolinguals. Bilinguals have demonstrated enhanced anterior to posterior functional connectivity in comparison with monolinguals (Abutalebi et al., 2014; Luk et al., 2011). This strengthened functional connectivity can supposedly compensate for higher levels of brain atrophy (Perani et al., 2017) and for reduced white matter integrity (Gold et al., 2013a) in bilinguals relative to monolinguals who are impaired to a similar extent (Guzmán-Vélez & Tranel, 2015; Watson, Manly, & Zahodne, 2016). However, contrary to Gold et al. (2013a), two studies revealed better preserved white matter in bilinguals than in monolinguals (Anderson et al., 2018; Luk et al., 2011).

Neuroimaging studies have also revealed distinctions between the brains of bilingual and monolingual dementia patients. Even when they are matched to monolingual AD patients with comparable overall cognitive and memory performance as well as YOE, bilinguals with AD present greater amounts of brain atrophy in brain areas that are linked to disease pathology (Schweizer et al., 2012). Among bilinguals, cerebral atrophy is more prominent and it is mostly located in regions that are used to discern between AD patients and normal controls (Schweizer et al., 2012).

3.2. The Posterior-Anterior Shift in Aging (PASA) hypothesis

Older bilinguals may benefit from improved anterior to posterior functional connectivity (Abutalebi et al., 2014; Luk et al., 2011), as is proposed by the Posterior-Anterior Shift in Aging (PASA) hypothesis. According to this hypothesis, older adults increasingly rely on frontal rather than on posterior cortical brain regions in order to maintain their cognitive function (Grant et al., 2014). Moreover, even though both bilinguals and monolinguals demonstrate PASA, the posterior regions of older bilingual adults do not display the same deterioration as those of monolinguals of comparable age and therefore their shift is not as pronounced as that of individuals who only speak one language (Grant et al., 2014). PASA is thought to function as a compensatory mechanism in aging, since cognitive performance of older adults can be upheld by engaging frontal rather than posterior cortical regions (Grant et al., 2014). It has been suggested that older bilinguals may engage in similar PASA patterns as younger adults in cognitive tasks (Grant et al., 2014). Whereas the shift in older adults entails increased activity in the left dorsolateral prefrontal cortex (DLPFC) and reduced activity in the left visual cortex, younger adults yield the exact opposite pattern. Younger adults exhibit greater levels of activity in the left visual cortex than in the DLPFC (Grant et al., 2014). As a result of their bilingual status, older bilinguals may demonstrate this reversed pattern that has been observed in younger adults (Grant et al., 2014).

3.3. The basal ganglia

The finding that bilinguals tend to shift less from the posterior to the anterior cortical brain areas is in accordance with the boosted grey matter volume (GMV) that has been reported for bilinguals in the left anterior temporal lobe (ATL) and the inferior parietal lobule (IPL; Abutalebi et al., 2014). Stocco, Yamasaki, Natalenko, and Prat (2014) also observed an increase in WMV and GMV. The basal ganglia, "a set of interconnected gr[e]y matter nuclei located in the middle of the brain" (Stocco et al., 2014), appear to be involved in language selection (Abutalebi, Miozzo, & Cappa, 2000; Green & Abutalebi, 2013; Stocco et al., 2014) and have been shown to strengthen cortical connections (Grant et al., 2014). Normally, these specific connections would not have been engaged, as their resting activation is relatively low (Grant et al., 2014). Switching between languages supposedly "trains the brain" (Stocco et al., 2014), since bilinguals have to distinguish between two vocabularies and grammars (Stocco et al., 2014). As a result, bilinguals' control mechanism may be improved. The basal ganglia are engaged not only in language-switching, but also in task switching in general (Stocco et al., 2014). In conclusion, the basal ganglia appear to strengthen connections to "over-ride the currently most active connection" (Grant et al., 2014) in order to switch between languages or from one task to another (Grant et al., 2014).

4. Caveats in task design and confounding variables

4.1. No convergent validity

As has been discussed in this review, the reports of a bilingual advantage have been inconsistent across studies. There has been no convergent validity (Paap & Greenberg, 2013). For instance, some articles have noted a smaller Simon effect or reduced Stroop interference for bilinguals, whereas others found no difference between bilingual and monolingual participants (Paap & Greenberg, 2013).

4.2. Tasks may not assess what they are supposed to assess

Tasks are often represented as an assessment of one particular executive process (Paap & Greenberg, 2013). For example, the Simon task is often considered a measure of inhibitory control. Yet, as has been discussed in this article, these tasks have not elicited consistent effects. Similarly, other tasks that are believed to examine the same skill do not necessarily yield compatible outcomes (Paap & Greenberg, 2013). For example, the Simon and the flanker task are both commonly adopted to measure inhibitory skills, but in their study, Paap and Greenberg (2013) found a miniscule correlation between the two (r = -0.01). Therefore, it is highly likely that at least one of these tasks does not specifically measure inhibitory control or that the inhibitory skills that are tested in these tasks are "completely task dependent", and, hence, differ across tasks (Paap & Greenberg, 2013). At the same time, tasks generally merely assess a single component of executive function and measure processes that overlap only in part with executive control as a global construct (Valian, 2015). It is not surprising, then, that many studies reach different conclusions.

4.3. Direction of causality and assumptions

Moreover, the direction of causality may confound findings (Gold et al., 2013a; Li & Grant, 2015; Paap, Johnson, & Sawi, 2016; Schweizer et al., 2012). Highly educated bilinguals or bilinguals with an intellectually challenging occupation may outperform monolinguals in tasks (e.g., inhibition tasks) and they may demonstrate greater cognitive reserve, but that does not necessarily entail that these advantages stem from their bilingualism. Rather, these individuals may benefit from boosted CR because "their brains are genetically well endowed" (Schweizer et al., 2012), which allows them to do well in these fields, or because of their "heightened levels of intellectual and social engagement" (Schweizer et al., 2012).

In addition, "type of language experience" is generally taken as an independent variable (IV) and "level of executive function" as a dependent variable (DV; Li & Grant, 2015). Li and Grant (2015) argue for an examination of the "reverse IV-DV relationship" (Li & Grant, 2015). Moreover, it is possible that "the cognitive exercises involved in second language acquisition" (Klein, 2015) do not enhance executive control, but that, inversely, individuals with better executive control will demonstrate superior second language learning skills (Klein, 2015).

As far as neuroimaging is concerned, differences between bilinguals and monolinguals have repeatedly been interpreted as evidence of a bilingual advantage. Nevertheless, "reorganization to accommodate bilingualism does not logically need to result in more efficient performance" (Paap et al., 2016). Instead, performance may be similar for the two participant groups or poorer for bilinguals in comparison with monolinguals (Paap et al., 2016). Thus, discrepancies between the brains of these two language groups do not necessarily prove the existence of a bilingual advantage. In order to ascertain the validity of a bilingual advantage, neural distinctions between bilinguals and monolinguals should concur with behavioral differences between these two groups, which is not always the case (Hilchey & Klein, 2011; Paap et al., 2016).

For instance, Bialystok et al.'s (2005a) study reported an inconsistent pattern between performance in a Simon task and magneto-encephalography (MEG) data. Bialystok et al. (2005a) compared the performance of Cantonese-English, French-English bilinguals, and English-speaking monolinguals in a Simon task in the MEG. The Cantonese-English bilinguals yielded shorter RTs than the two other groups (Bialystok et al., 2005a). MEG imaging revealed a difference between monolinguals and bilinguals. For monolingual participants, shorter RTs were linked to greater activation in middle frontal regions, whereas for both Cantonese-English and French-English bilinguals, shorter RTs were associated with increased activity "in superior and middle temporal, cingulate, and superior and inferior frontal regions largely in the left hemisphere" (Bialystok et al., 2005a). There were no differences between the two bilingual groups in terms of the brain regions that were recruited (Bialystok et al., 2005a).

Thus, even though participants from both groups relied on the same brain regions to yield quick RTs, only the Cantonese-English bilinguals, not the French-English bilinguals, managed to outperform the monolinguals (Bialystok et al., 2005a). The Cantonese-English bilinguals' engagement of the aforementioned brain areas could not fully account for enhanced performance relative to monolinguals (Hilchey & Klein, 2011), since these bilinguals activated the same brain regions as the French-English bilinguals who did not outperform the monolingual group. Considering that the two bilingual groups yielded disparate results and that the French-English bilinguals did not outperform the monolinguals, a factor other than bilingualism appears to have given rise to the Cantonese-English bilinguals' superior performance (Hilchey & Klein, 2011).

4.4. Retrospective versus prospective studies

The nature of a study appears to influence its results, as well, since AD protection for bilinguals relative to monolinguals is commonly reported in retrospective but not in prospective studies (Calvo et al., 2016; Yeung, St. John, Menec, & Tyas, 2014; Zahodne et al., 2014). Not all individuals with symptoms of dementia seek help. Therefore, a "class problem" (Valian, 2015) or a "selection bias" (Watson et al., 2016) may manifest itself in retrospective studies, since the medical situation of these individuals is not studied and the individuals that are considered in studies on dementia may not be representative for all patients (Valian, 2015).

Furthermore, the age of symptom onset is commonly reported by the patient or by someone close to the patient, which is a subjective measure (Bialystok et al., 2007; Chertkow et al., 2010; Watson et al., 2016). Hinton, Franz, Yeo, and Levko (2005) found that "ethnic minority caregivers and those with less formal education" (Watson et al., 2016) would, in some cases, believe that the dementia-related symptoms were caused by "psychosocial stress or normal aging, rather than dementia" (Watson et al., 2016). In contrast, a prospective study objectively investigates the health of its participants across a period of multiple years. These individuals are not demented at baseline and the development of all participants is studied over time (Valian, 2015).

Additionally, as Calvo et al. (2016) note, retrospective studies commonly match participants to one another, which may result in unbalanced sample sizes (e.g., 50% more monolinguals than bilinguals, as was the case in the studies of Chertkow et al. (2010), Lawton et al. (2015), Sanders, Hall, Katz, & Lipton (2012), and Zahodne et al. (2014). The greater groups may yield more variance and may "be more representative of [their] respective population[s]" (Calvo et al., 2016) than the smaller groups.

Nevertheless, one prospective study did report an effect of multilingualism. Kavé et al.'s (2008) 12-year prospective study yielded significant differences between monolinguals and multilinguals, since test scores increased as the number of languages a participant spoke increased. In their random sample of Israelis, test performance was best for those who mastered 4 or more languages (Kavé et al., 2008).

4.5. Populations

Furthermore, the populations of bilinguals and monolinguals that are studied can also partially account for the varying patterns that studies have yielded. As Paap et al. (2016) argue, many studies have relied on small sample sizes (e.g., Chertkow et al., 2010; Craik et al., 2010; Gollan et al., 2011; Schweizer et al., 2012). Additionally, various studies have grouped together disparate dementia diagnoses, which prohibits researchers from investigating a possible correlation between bilingualism and one specific dementia type (e.g., AD) Chertkow et al., 2010).

In studies that include multiple monolingual groups, bilinguals sometimes only outperform one group of monolinguals (Kousaie & Taler, 2015). If a study comprises two or more groups of monolinguals, these groups tend to yield different results (Carlson & Choi, 2009; Kousaie, Sheppard, Lemieux, Monetta, & Taler 2014). Moreover, studies that observe enhanced CR for bilingual participants compare bilinguals and monolinguals that are "quite heterogeneous both between and within groups" (Baum & Titone, 2014). An illustration of this are the aforementioned differences that Prior and

Gollan (2011) noted between their group of Mandarin-English bilinguals and their Spanish-English bilinguals.

4.6. "Conflict adaptation" rather than inhibitory control

Some articles have concluded that, in the Simon task, bilinguals perform better on both congruent and incongruent trials in comparison with the monolingual control group (Paap et al., 2016). The finding of shorter RTs for bilinguals than for monolinguals on both congruent and incongruent trials of the Simon task does not necessarily imply a bilingual advantage in inhibitory control (Paap et al., 2016). Instead, Paap et al. (2016) argue that bilinguals may be better than their monolingual counterparts at focusing on task demands that are constantly shifting. Hilchey and Klein (2011) propose that bilinguals may be better at "conflict adaptation" (Hilchey & Klein, 2011), which entails that they are more skilled at diverting their attention (Schmidt, Notebaert, & Van Den Bussche, 2015) from irrelevant information (e.g., the information related to the previous trial). Furthermore, bilinguals may benefit from "a more widespread cognitive advantage" (Hilchey & Klein, 2011) that does not always manifest itself in non-linguistic tasks that require inhibitory skills (Hilchey & Klein, 2011).

4.7. General language skills

Iacono et al.'s (2009) study established a correlation between linguistic ability and cognitive decline, as (monolingual) individuals with higher linguistic scores (measured in terms of idea density[3] and grammar skills) were less likely to suffer from cognitive deficits than those with lower linguistic scores. Baum and Titone (2014) described bilingualism as "a type of advanced language ability" (Baum & Titone, 2014) and hypothesized on the basis of Iacono et al.'s (2009) findings that CR might be enhanced through greater language skills in general, not necessarily specifically through bilingualism (Baum & Titone, 2014). Thus, they proposed that the "bilingual" advantage may arise on the basis of superior overall linguistic abilities (Baum & Titone, 2014). This view is in line with Snowdon et al.'s (1996) observations, since they discovered an association between poorer overall (not necessarily bilingual) linguistic skills (that is,

[3] Idea density was established on the basis of "the average number of ideas expressed per 10 words" (Iacono et al., 2009) in written essays (Iacono et al., 2009).

the combination of idea density and grammatical complexity) at the age of 22 and greater cognitive decline 58 years later. Linguistic skills were also found to be a predictor of AD later in life (Snowdon et al., 1996).

4.8. Age

Another potential caveat is the inconsistency between age groups in the observation of a bilingual advantage. Some studies report improved executive control for older bilinguals but fail to note such an effect for younger bilinguals. For instance, Salvatierra and Rosselli's (2010) study did not reveal a distinction between their monolingual and bilingual participants with a mean age of 27. Nonetheless, in the same study, a smaller Simon effect was found for older bilinguals in comparison with their monolingual peers. The researchers believe the bilingual advantage to be age-dependent (Salvatierra & Rosselli, 2010). Moreover, it has been argued that a bilingual advantage may become more prominent "in cases where cognitive functioning is sub-optimal" (Kousaie & Taler, 2015). Thus, older bilinguals who experience age-related neurodegeneration may exhibit a bilingual advantage in their executive control whereas younger bilinguals may not, since the latter group is already "at the height of cognitive function" (Kousaie & Taler, 2015).

4.9. Confounding variables

Even if bilingual advantages are discovered for older adults, confounding variables may (partially) give rise to such advantages. For instance, and importantly, it is difficult to isolate socioeconomic status (SES; Valian, 2015) and immigration status (De Bruin et al., 2015a) from other factors that they can correlate with. Lifestyle and environment may also affect results (De Bruin et al., 2015a).

Immigration status may account for further distinctions between bilinguals and monolinguals, in particular if the bilingual group comprises a large number of immigrants and the monolingual group does not. Immigrants may differ from native inhabitants regarding their genetics, education, ethnical and cultural background, and so forth (De Bruin et al., 2015a). Immigration status usually reduces SES and heightens mental illness rates (Bhugra & Becker, 2005). In comparison with non-immigrants,

immigrants have displayed greater cognitive control and reduced cognitive decline (Hill, Angel, Balistreri, & Herrera, 2012; Kopec, Williams, To, & Austin, 2001). It is also possible that immigrants are "more practiced in adapting to new circumstances" (De Bruin et al., 2015a) and that this boosts their cognitive flexibility. Moreover, the healthy immigrant effect (Fuller-Thomson & Kuh, 2014; Fuller-Thomson, Nuru-Jeter, Richardson, Raza, & Minkler, 2013) proposes that healthy individuals may be more inclined to immigrate (and become bilingual after their immigration) than those with medical issues. This hypothesis was further supported by Fuller-Thomson et al.'s (2013) observation of a 26% "lower chance of functional limitations" for white Hispanic immigrants than for white non-immigrants in the United States. In addition, immigrants may have a higher IQ than individuals from their home country (Fuller-Thomson, & Kuh, 2014; Milne, Poulton, Caspi, & Moffitt, 2001).

Furthermore, researchers may not always have access to data. For example, Chertkow et al. (2010) did not have information on the participants' immigrant/native status at their disposal. Therefore, they considered every participant with English, French, or a Canadian aboriginal language as their L1 a native Canadian. These individuals were assumed to have been born and raised in Canada and/or to have received their primary or secondary education in that country. Chertkow et al. (2010) acknowledged that some individuals who were classified as natives could have been raised in another English- or French-speaking country and that native Canadians may have had a language other than English or French as their L1.

Moreover, the variable of education has yielded inconsistent findings in research on dementia. Multiple articles have reported an association between level of education and protection against dementia. Zahodne et al. (2014) noted reduced dementia conversion for higher years of education (YOE), but in other studies, an advantage was observed for lower, but not for higher educated adults.

For instance, highly educated dementia patients had been experiencing symptoms for 15 or 16 years on average at the time of Amieva et al.'s (2014) study, whereas this was 7 years for low-education patients. Gollan et al. (2011) reported a bilingual advantage in the age at which dementia was diagnosed for lower rather than for higher educated individuals. Therefore, bilingualism could boost CR but only in patients who "may not already have achieved their maximum potential as a result of other factors" (Baum & Titone, 2014).

Another problem is that the definition and assessment of bilingualism (or multilingualism) differs from study to study (Calvo et al., 2016), which may render it more difficult to compare the findings of one study to those of another. As Calvo et al. (2016) indicate, proficiency in a second language is generally established through interviews with dementia patients (e.g., Bialystok et al., 2007; Crane et al., 2010; Woumans et al., 2014) or with their caregivers (Alladi et al., 2013; Schweizer et al., 2012). Recall bias regarding language proficiency (and age of symptom onset) may affect such subjective measures (Crane et al., 2009; Fritsch et al., 2005; Fuller-Thomson & Kuh, 2014; Sanders et al., 2012).

A number of studies, e.g., Alladi et al. (2013), "confound bilingualism with plurilingualism" and do not distinguish between bilinguals and individuals who are proficient in three or more languages (Calvo et al., 2016). Moreover, many studies do not assess levels of proficiency in the second language (Watson et al., 2016). Furthermore, they do not take the age of acquisition (AoA) of this second language into account nor the frequency with which the bilinguals switch between languages (Watson et al., 2016). Some studies also fail to consider that age-induced neurodegeneration may affect a bilingual's abilities in one of the two languages before their abilities in the other (Watson et al., 2016). As far as the monolingual population is concerned, most studies forgo an assessment of monolingualism altogether, even though this could be relevant in order to ensure that they really differ from the bilingual population, since "pure monolingualism" may not exist (De Bot & Jaensch, 2015).

Alternatively, personal characteristics may play a role, since individuals who engage in potentially cognitively enriching activities are possibly "antecedently different" (Valian, 2015) from those who do not (Valian, 2015). There may be underlying differences that motivate people to take piano classes, to play video games, or to engage in aerobic exercise. It is possible that the mere motivation to seek cognitive enrichment can trump the cognition-boosting effects of the activity itself (Valian, 2015). Contrary to many activities that have been associated with enhanced cognitive function, bilingualism is often not a choice (Valian, 2015). In numerous countries, bilingualism is "imposed on community members as a whole" (Valian, 2015) rather than a personal choice of the bilingual or the bilingual's parents. Thus, whereas personal characteristics may account for a person's decision to learn to play an instrument or to engage in physical exercise, becoming bilingual is not always motivated by personality traits. Therefore, in contrast with individuals who engage in other cognitively enhancing activities and who may differ from those who choose not to, bilinguals are not necessarily "antecedently different" (Valian, 2015) from monolinguals.

In addition to bilingualism, a vast array of other factors have also been hypothesized to boost CR. These factors include intelligence, SES, exercise (Stern, 2002; Stern, 2009), occupational attainment (OCC; Staff et al., 2004; Valenzuela & Sachdev, 2006a), complex mental activity (Valenzuela & Sachdev, 2006a), genetics, gender, culture, immigration status, parental education (PED; Paap et al., 2016), stress resilience (Staudinger, Marsiske, & Baltes, 1993), aerobic exercise (Erickson et al., 2011), playing video games (Green, Sugarman, Medford, Klobusicky, & Bavelier, 2012), music training (Bialystok & De Pape, 2009; Bugos et al., 2007; Moreno et al., 2011), leisure activities in general (Scarmeas, Levy, Tang, Manly, & Stern, 2001), social engagement (Bennett, Schneider, Tang, Arnold, & Wilson, 2006; Fratiglioni et al., 2004; James, Wilson, Barnes, & Bennett, 2011; Paap et al., 2016; Verghese et al., 2003), and higher education level (Staff et al., 2004; Stern, 2002; Stern; 2009; Valenzuela & Sachdev, 2006a).

4.10. Publication bias

De Bruin, Treccani, and Della Sala (2015b) found a small but significant effect of bilingualism ($d = .30$) in their meta-analysis of articles on bilingualism and executive control. Nonetheless, this significant effect was established on the basis of studies that had been published and the meta-analysis itself indicated that the literature can be affected by a publication bias. This publication bias entails that studies that report positive outcomes have a greater chance of being published than those that yield null results or negative findings (De Bruin et al., 2015a) and this may (in part) account for the often-reported bilingual advantage (De Bruin et al., 2015b; Fratiglioni et al., 2014;

Fuller-Thomson, 2015; Paap et al., 2016). Overall, preliminary research supported the view that bilingualism can offer protection against dementia and have beneficial effects on the aging brain. However, a “decline effect” (De Bruin et al., 2015a) has emerged, which entails that more recent publications have challenged the findings and the existence of a bilingual advantage altogether (De Bruin et al., 2015a).

5. Conclusion

All in all, the everyday practice of inhibiting one or more languages while speaking the communicatively relevant language may provide bilinguals with greater executive function, which is thought to provide CR (Gold, 2015). Enhanced CR has been noted in numerous tasks. Older bilinguals are hypothesized to experience less cognitive decline than monolinguals as a result of this additional CR (e.g., Bialystok et al., 2014). These positive effects may extend to bilingual adults with dementia-induced neurodegeneration in the sense that their symptom onset and/or their diagnosis could be postponed (e.g., Bialystok et al., 2007; Craik et al., 2010; Crane et al., 2010; Gold, 2015; Gollan et al., 2011; Ossher et al., 2013; Schweizer et al., 2012; Stern, 2002). A few articles have even gone as far as to suggest a reduced risk of incident dementia for bilinguals (e.g., Valenzuela & Sachdev, 2006a) or have reported a decreased risk of CIND for multilinguals (Perquin et al., 2013).

In healthy older adults, inhibitory skills (Hasher et al., 1999) and executive function degenerate (Schroeder & Marian, 2012). Nonetheless, bilingual older adults may benefit from executive functions superior to those of monolinguals of the same age (Bialystok et al., 2014). Their improved executive functions may enhance their CR (Bialystok et al., 2004; Grant et al., 2014). Indeed, various tasks have evinced boosted CR for this group, e.g., Simon tasks (Bialystok et al., 2004; Bialystok et al., 2008a; Salvatierra & Rosselli, 2010), task-switching paradigms (Gold et al. 2013b; Prior & Gollan, 2011; Prior & MacWhinney; 2010), and Stroop color-naming tasks (Bialystok et al., 2008a; Bialystok et al., 2008b; Bialystok et al., 2014; Zied et al., 2004). However, even within studies, findings have not been unequivocal and other variables may have confounded the outcomes of the studies that reported a bilingual advantage in CR.

In adults with dementia, pathological burden appears to be reduced for bilinguals relative to monolinguals. Bilinguals may also be less likely to develop CIND, which is characterized by poorer cognitive skills or memory function in the preclinical stages of dementia (Perquin et al., 2013). In addition, studies have reported a 4.1-year delay in dementia symptom onset for bilinguals (Bialystok et al., 2007) and a 9.5-year delay in diagnosis for individuals with knowledge of 4 or more languages, though this effect is limited to immigrants (Chertkow et al., 2010).

Similarly, other factors may have contributed to bilingual advantages. Immigration has been shown to affect findings (e.g., De Bruin et al., 2015a) and immigrants may differ from native inhabitants in numerous manners, e.g., in terms of cognitive control and cognitive decline (Hill et al., 2012; Kopec et al., 2001). Other noteworthy variables that may confound the outcomes are education level (Amieva et al., 2014; Gollan et al., 2011; Sanders et al., 2012; Zahodne et al., 2014), socioeconomic status (Valian, 2015), and so forth. Furthermore, studies assess proficiency, symptom onset, and other critical factors in disparate (and sometimes subjective) manners (Calvo et al., 2016). Language proficiency is commonly self-reported rather than assessed through tests (e.g., Crane et al., 2009; Crane et al., 2010; Finkbeiner, Almeida, Janssen, & Caramazza, 2006; Gollan, Montoya, Cera, & Sandoval, 2008; Gollan, Salmon, Montoya, & da Pena, 2010; Guo, Liu, Misra, & Kroll, 2011; Lawton et al., 2015; Ljungberg et al., 2013; Ljungberg et al., 2016; Nanchen et al., 2016; Paap & Greenberg, 2013; Prior & Gollan, 2011; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011; Zahodne et al., 2014).

Another caveat is that tasks that are considered to assess the same skill (e.g., inhibition) have yielded incongruous results (Paap & Greenberg, 2013), which may suggest that they do not involve the same inhibition processes or that inhibition is a much more complex construct than seems to be the case at first sight. Moreover, De Bruin et al. (2015b) propose that a publication bias may account for reports of a bilingual advantage, i.e., that null effects are much less often reported, such that one is more likely to read about the beneficial effects of bilingualism or multilingualism.

In conclusion, documentation of a bilingual advantage has been inconsistent. Whereas some articles report attenuated cognitive decline, enhanced CR, or protection against dementia, others have yielded null effects. Future research could benefit from controlling for factors including immigration background, education level, occupational status, SES, age of acquisition of the second language, and the frequency of switching between languages (among others). Additionally, language proficiency and health status could be established through testing rather than via self-report. Ideally, the study would comprise a sizeable population of individuals without dementia as a baseline and would be prospective and longitudinal. This would allow for distinguishing between bilinguals and monolinguals regarding their age of symptom onset and their age of diagnosis through examinations and meetings with a team of experts.

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