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# Bilingualism provides a neural reserve for aging populations

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ABSTRACT

It has been postulated that bilingualism may act as a cognitive reserve and recent behavioral evidence shows that bilinguals are diagnosed with dementia about 4–5 years later compared to monolinguals. In the present study, we investigated the neural basis of these putative protective effects in a group of aging bilinguals as compared to a matched monolingual control group. For this purpose, participants completed the Erikson Flanker task and their performance was correlated to gray matter (GM) volume in order to investigate if cognitive performance predicts GM volume specifically in areas affected by aging. We performed an ex-Gaussian analysis on the resulting RTs and report that aging bilinguals performed better than aging monolinguals on the Flanker task. Bilingualism was overall associated with increased GM in the ACC. Likewise, aging induced effects upon performance correlated only for monolinguals to decreased gray matter in the DLPFC. Taken together, these neural regions might underlie the benefits of bilingualism and act as a neural reserve that protects against the cognitive decline that occurs during aging.



## 1. Introduction

Cognitive decline is characterized by a slow and progressive decline of memory and cognitive abilities resulting from pathological conditions that cause brain cell death in the aging population. Although treatments are still lacking, studies show that the onset of cognitive decline and dementia can be significantly delayed by intellectual and life-style factors, including education, occupation level and leisure activities. These individual factors contribute to 'cognitive reserve' in seniors. Higher levels of cognitive reserve are associated with a reduced risk of developing cognitive decline and a lower rate of memory decline in normal aging (Stern et al., 2006). Stern et al. (2009) suggested that life experiences contribute to individual differences at the brain level, i.e., providing a neural basis for the concept of cognitive reserve (to which we may refer to as 'neural reserve'). The benefit of intellectual and life-style cognitive reserve is potentially considerable, given the socio-economic and affective impact of cognitive decline in typical aging. Delaying the onset of cognitive decline can lead to substantial economic benefits (Bialystok et al., 2004).

The concept of cognitive reserve is based on multiple observations that particularly intelligent people with a high level of education seem to fare better in the face of cognitive decline, maintaining cognitive function for a longer period of time compared to people with lower levels of education. Epidemiological studies (Garibotto et al., 2008; for a review see Valenzuela and Sachdev, 2006) have demonstrated that low levels of education are strongly correlated with a higher risk of cognitive decline. Aging-induced decline in cognitive abilities is usually associated with structural and functional changes in the brain. For instance, progressive loss of gray matter volume in anterior regions is typically observed (Jernigan et al., 2001; Raz et al., 2005) as is progressive disruption of white matter between anterior and posterior cortical regions (Pfefferbaum et al., 2005; Head et al., 2004; Madden et al., 2009; Gunning-Dixon et al., 2009).

It has been postulated that bilingualism may act as a cognitive reserve. This notion is based upon evidence that executive functions may be better 'trained' in bilinguals as compared to monolinguals (Bialystok et al., 2004, 2005, 2006). Indeed, there is a body of evidence showing that the constant juggling of two (or more) languages in multi- and bi-lingual speakers tunes their conflict resolution capacity, which in turn, transfers to non-linguistic

*Abbreviations:* DLPFC, dorsolateral prefrontal cortex; ACC, anterior cingulate cortex; RTs, reaction times

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behavioral and cognitive functions. Specifically, domain-general executive functions might benefit from brain plasticity induced by bilingualism, which then allows greater resistance to cognitive decline (Abutalebi et al., 2012; Zou et al., 2012). Brain areas underlying executive control, such as the pre-SMA/ACC (pre-supplementary motor area/ anterior cingulate cortex) and the DLPFC (dorsolateral prefrontal cortex) regions are more highly stimulated in bilingual speakers and this may result in greater cognitive reserve that compensates for the brain atrophy found in normal aging. Indeed, behavioral studies in elderly bilinguals support this notion (Bialystok et al., 2007, 2009). For instance, Bialystok et al. (2004) investigated the effect of aging on executive processes in a relatively large group of monolingual and bilingual speakers. Participants were divided into five different age group ranges (30–39; 40–49; 50–59; 60–69; and 70–79) and all performed an attentional task (i.e., Simon task). The study found that bilinguals were faster in resolving the cognitive conflicts on this specific task. Moreover, the advantage for bilinguals was more evident with increasing age. Both monolingual and bilingual speakers show effects of slowing on task performance with age. However, the difference between the two groups widened with age. Several behavioral studies report a 'bilingual advantage' on executive functions in almost every age group (infants, children and adults) (Bialystok and Craik, 2010b; Kovács and Mehler, 2009). It should be noted that this evidence is not universally accepted (see Paap and Greenberg, 2013) especially for studies focusing on children and young adults. Following children and young adults engage in many cognitively challenging activities that may be at least equivalent to the cognitive challenges provided by bilingualism. However, old adults tend to have fewer cognitively enriching experiences than younger adults, and hence, any putative advantage provided by bilingualism could be more prominent (Valian, 2015). A further hypothesis is that eventual cognitive advantages increase with experience during aging, suggesting age dependent development of cognitive reserve (Hilchey and Klein, 2011).

As to potential neural repercussions, it is well documented that bilingualism induces beneficial experience-related structural changes in terms of increased gray and white matter densities when compared to monolingual speakers. Bilingualism induces structural changes in several brain areas including the left inferior parietal lobule (Mechelli et al., 2004; Della Rosa et al., 2013), the anterior cingulate cortex (ACC) (Abutalebi et al., 2012), and in subcortical structures such as the left caudate (Zou et al., 2012), and putamen (Abutalebi et al., 2013a). These areas are part of the executive control network and this may explain why bilinguals usually have a cognitive advantage in executive control tasks. Interestingly and specifically related to aging, Luk et al. (2011) report that aging bilinguals have globally increased white matter when compared to their monolingual peers. Likewise, also showed that aging bilinguals have increased gray matter densities over the temporal poles and orbito-frontal cortex. These neural data fit relatively well with the recent evidence that bilingualism delays the onset of dementia (Bialystok et al., 2012). For instance, bilingual participants are diagnosed with dementia of the Alzheimer's Type (DAT) about 4–5 years later compared to monolinguals (Schweizer et al., 2012; Craik et al., 2010). These findings were recently confirmed and generalized to other types of dementia (such as vascular dementia) in a large study conducted in India (Alladi et al., 2013).

The main aim of the present study is to investigate the neural basis of the bilingual advantage in a group of aging bilinguals as compared to a matched monolingual control group. For this purpose, subjects carried out an attentional control task (i.e., the Flanker task) and their performance-measured in reaction times (RTs) – was correlated to brain structure. The Flanker task captures cognitive conflict resolution involving attentional control and

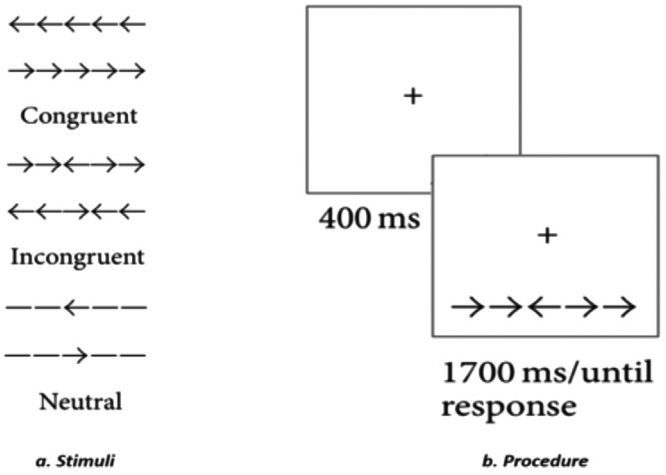


**Fig. 1.** Stimuli and procedures of the Flanker task. See Section 3.1 section for further details about the task.

inhibition processes (Fan et al., 2002). Horizontal black lines with arrowheads pointing to left or right were presented (see Fig. 1a for examples) and participants were instructed to indicate the direction of the central target arrow by pressing a dedicated response button as fast as possible. The central target is presented with congruent, incongruent or neutral flankers. The conflict effect is calculated by subtracting response times to congruent trials from those to incongruent trials (Fan et al., 2002). The Flanker task is widely used in studies of the bilingual cognitive advantage (Abutalebi et al., 2012; Calabria et al., 2011; Costa et al., 2008).

### 1.1. The ex-Gaussian distribution analysis

The distribution of RTs in attention tasks is usually positively skewed. However classical measures of central tendency (Gaussian component) neglect this variability and therefore could potentially incur the risk of masking information about the real trend of the dispersion and unique characteristics of the populations sampled, possibly leading to a Type 2 error. To provide a better fit of the RT distribution, the ex-Gaussian function involves a mathematical convolution of a normal (Gaussian) and an exponential distribution, producing the following 3 parameters: $\mu$ (mu), reflecting the mean of the Gaussian component of the distribution; $\sigma$ (sigma), the standard deviation of the Gaussian distribution, and $\tau$ (tau), the mean and the standard deviation of the exponential component. The sum of $\mu$ and $\tau$ yields the total mean of the distribution, whereas adding the square of the standard deviation of $\sigma$ and $\tau$ draws its variance. The leading edge of the distribution is reflected in $\mu$, whereas the skewness of the distribution is better reflected in $\tau$.

Application of the ex-Gaussian function has been successfully employed to compare differences between groups, such as healthy elderly subjects when compared with individuals who have dementia (Spieler et al., 1996; Verhaeghen and Hoyer, 2007). Recently, Tse et al. (2010) showed that healthy aging had clear effects on both $\mu$ and $\tau$ in a set of attentional control tasks, whereas early stage DAT only had an additional effect on $\tau$. Balota et al. (2010) demonstrated that the slow tail of the RT distribution in the Stroop task may also be useful in predicting divergence from a cognitive normal state to early stage DAT across a 12 year longitudinal follow up study. Jackson et al. (2012) showed a significant association between measures of intra-individual variability (IIV) reflected in the RTs of an attentional control task, the parameter $\tau$, reflecting an exaggeration of the slow tail of the RTs, and white matter volume in an aging population and in early-stage DAT individuals, concluding that IIV and $\tau$ are sensitive to breakdowns in executive