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Age-related behavioural and neurofunctional patterns of second language word learning: Different ways of being successful

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ABSTRACT

This study aimed at investigating the neural basis of word learning as a function of age and word type. Ten young and ten elderly French-speaking participants were trained by means of a computerized Spanish word program. Both age groups reached a similar naming accuracy, but the elderly required significantly more time. Despite equivalent performance, distinct neural networks characterized the ceiling. While the young cohort showed subcortical activations, the elderly recruited the left inferior frontal gyrus, the left lingual gyrus and the precuneus. The learning trajectory of the elderly, the neuroimaging findings together with their performance on the Stroop suggest that the young adults relied on control processing areas whereas the elderly relied on episodic memory circuits, which may reflect resorting to better preserved cognitive resources. Finally, the recruitment of visual processing areas by the elderly may reflect the impact of the language training method used.

1. Introduction

Healthy ageing is characterized by important anatomical, neurochemical and metabolic changes including changes in the hemodynamic response (Ances et al., 2009); as well, changes in receptors, neurotransmitters and enzymes have been reported thus affecting sensory and cognitive abilities (Cabeza, 2001). However, not all cognitive domains are equally vulnerable to ageing. Hence, whereas episodic and autobiographical memory have been shown to decline with normal ageing, semantic memory appears to be preserved and even enriched with age (Baltes, Staudinger, & Lindenberger, 1999; Reuter-Lorenz et al., 2000). Age-related neurofunctional reorganization in healthy elderly persons has been shown to occur for many cognitive abilities, including semantic encoding and semantic retrieval (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002; Reuter-Lorenz et al., 2000). Specifically, neuroimaging research shows that older adults engage more brain regions than younger adults performing the same tasks at equivalent levels (Cabeza, 2001, 2002; Reuter-Lorenz et al., 2000). These changes are considered to be the brain's normal reaction to the challenge imposed by age-related neural decline. For example, highly proficient elderly adults show changes in the left hemisphere-right hemisphere balance during memory tasks (Cabeza, 2002), an observation that has been interpreted as evidence for compensatory adapted plasticity with ageing (Cabeza, 2001; Cabeza, Anderson, Locantore, & McIntosh, 2002; Reuter-Lorenz et al., 2000). On the same line, some kind of adapted plasticity explains the relative preservation of language abilities with age (Craik & Bosman, 1992). To summarize, these findings suggest that healthy ageing brings a delateralization of word processing, by scaffolding, resulting from the recruitment of secondary networks. These changes are considered to be a supportive mechanism, which contributes to preserve cognition in older adults. They also reflect changes in the set and nature of cognitive processes contributing to a given task, and may as well reflect the reliance on semantic strategies. Thus, given that semantic processing is known to be particularly well preserved and even developed with ageing (Baltes et al., 1999; Reuter-Lorenz et al., 2000), the cognitive potential of semantic memory in the elderly remains to be further explored.

On the other hand, explicit memory and inhibitory processing abilities are sensitive to age-related cognitive decline (for a complete review see Craik & Bialystok, 2006); however, training can improve performance in the elderly (Churchill et al., 2002; Kramer, Larish, Weber, & Bardell, 1999). The ageing brain's potential for experience dependent neuroplasticity has been explored by means of learning tasks. In this regard, neurofunctional changes

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have been reported concurrently with increased mnesic performance in the elderly. Thus, Nyberg et al. (2003) employed a visuo-spatial method, called the "loci mnemonic method" to young and elderly participants and showed that all those individuals who benefited from the learning method (i.e. showed improved performance) presented increased activity in occipito-parietal regions. The authors (Nyberg et al., 2003) argued that increased activation in the posterior regions reflected spatial imagery processes, stimulated by the visuo-spatial approach of the "loci mnemonic method". Interestingly, a deactivation of the left dorsal prefrontal cortex in the elderly was also revealed, concurrently with a lower performance of the old participants compared to the young ones (Nyberg et al., 2003). Conversely, Aizenstein et al. (2006) showed that successful explicit learning was correlated with an under-regulated activation in the left dorsal prefrontal cortex, and an over-activation in the right dorsal prefrontal cortex in a group of elderly participants, as compared to a group of young participants. Since the performance was equivalent across age groups, the right over-activation observed in the elderly was interpreted to play a compensatory role, somehow balancing the under-activation observed in the left dorsal prefrontal cortex. In their longitudinal study on dual-task training, Erickson et al. (2007) compared young and elderly participants at the beginning and consolidation phases of learning to explore the impact of proficiency on the neural basis of learning. Similar accuracy scores across age groups were reported, but response times were longer in the elderly group. As well, training induced changes in activation in areas that are particularly sensitive to atrophy, specifically the dorsolateral and ventrolateral prefrontal cortex, bilaterally. Thus, age-related functional decline is not an inevitable process, but it can be reduced with training.

To summarize, previous evidence (Aizenstein et al., 2006; Erickson et al., 2007; Nyberg et al., 2003) suggests that neuroplastic changes observed in young and elderly learners reflect the type of training method used (Nyberg et al., 2003). Also, young and elderly show distinct activation patterns at the early stages of learning, and a reduction of these differences after training (Erickson et al., 2007). Furthermore, the evidence suggests that the prefrontal cortices can be under-regulated or up-regulated in the elderly, as compared to the young (Aizenstein et al., 2006), where over-activations reflect compensatory mechanisms triggered by age-related increased cognitive demands (Reuter-Lorenz, 2002; Reuter-Lorenz & Lustig, 2005). Finally, functional magnetic resonance imaging (fMRI) studies have also demonstrated that in order to maintain performance, healthy older subjects under-recruit efficient-task-specific areas (Goh, 2011; Peelle, Troiani, Wingfield, & Grossman, 2010) whereas they over-recruit non-canonical cortical circuits (Cabeza, 2002; Park & Reuter-Lorenz, 2009).

In second-language learning, there is strong evidence of cross-linguistic facilitation with cognates, which is reflected by shorter response times and smaller error rates on naming tasks (Costa, Santesteban, & Cano, 2005; Ivanova & Costa, 2008), although the cognate advantage is reduced with learning consolidation. By definition, cognates are words that share both phonology and semantics between the mother tongue (L1) and a foreign language (L2, L3, ...). Conversely, non-cognates share semantics but not phonology with L1. Thus, in non-proficient bilingual speakers the cognate advantage has been related to the double semantic and phonological overlap with L1 (Costa, Caramazza, & Sebastian-Galles, 2000; Dijkstra, Grainger, & Van Heuven, 1999; Francis, 1999; Schelletter, 2002).

Nevertheless, the neural substrate responsible of this cognate advantage has only been addressed in two neuroimaging studies (De Bleser et al., 2003; Raboyeau, Marcotte, Adrover-Roig, & Ansaldo, 2010). Using positron emission tomography, De Bleser et al. (2003) reported similar L1 activations when naming L2 cognates whereas significant activation in the left frontal and temporo-parietal areas when processing non-cognates only, suggesting that non-cognates have a greater cognitive load than cognates. In our previous longitudinal study on second language (L2) word learning (Raboyeau et al., 2010), young adults showed neuroplastic changes as a function of word type (cognates and non-cognates) and learning phase (early phase and ceiling). In particular, they significantly activated the anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex with both word types and at both moment of measure (shallow and deep learning phase). However activation was higher at the early learning phase, probably reflecting a bigger cognitive load imposed by the first stages of L2 word learning. With regards to the significant activations of the premotor cortex and the supplementary motor area (SMA) observed at ceiling, they suggest "fine tuning" of lexical processing mechanisms, at the level of articulatory planning (Raboyeau et al., 2010).

Considering that word selection in the weaker language requires cognitive control (Abutalebi et al., 2008) and that attentional and inhibitory abilities are at the core of second language learning (Green, 1998; Hernandez, Martinez, & Kohnert, 2000), the reported decline in attentional and inhibitory resources with ageing (Craik, 1983) should also be seen in second language learning. Although previous evidence suggested that learning induces age-related neuroplastic changes, word learning in a second language, and especially the cognate effect, has not yet been studied as a function of age. Therefore, in the present study we examine the neurofunctional correlates of L2 word learning as a function of age (young and elderly), word type (cognates-non-cognates), and learning phase (early learning phase and ceiling). In line with our previous work (Raboyeau et al., 2010), it is expected that cognitive effort involved in recalling newly learnt L2 words will be reflected by a significant activation of the ACC, and the dorsolateral prefrontal cortex, both in young and elderly participants. However, given that ageing brings a decline in inhibitory processing (Craik & Bialystok, 2006), it is expected that the elderly will show smaller clusters in the ACC as compared to the young. Moreover, in line with Erickson et al. (2007), it is also expected that age-related differences in brain activity will be reduced with proficiency. Finally, given evidence in the literature regarding the influence of age on the reliance of specific strategies and considering that semantic processing is considered to be preserved (Burke, MacKay, & James, 2000) and even developed with ageing, we predict that they will recruit semantic processing areas to perform the task, and more particularly regarding the perceptual features of the words.

2. Materials and methods

2.1. Participants

Ten young participants (5 men, 5 women; mean age: 22.7 ± 2.0 years) and ten old adults (4 men, 6 women; mean age: 70.2 ± 4.0 years) participated in the study. All participants were French speakers and did not considered themselves as bilinguals; given that Montreal has a large English speaking community, all of them had been exposed to English. They had no previous knowledge of Spanish. Participants underwent pre-experimental neuropsychological testing to control for cognitive status, and rule-out mild cognitive impairment (Crum, Anthony, Bassett, & Folstein, 1993), memory (Grober, Buschke, Crystal, Bang, & Dresner, 1988), or attentional deficits (Stroop, 1935) (see Table 1). Exclusion criteria were: (1) a history of neurological or psychiatric illness, (2) metal implants non-compatible with the fMRI environment, (3) any deficit detected by the tests named above, and (4) uncorrected visual deficits. Participants were matched for education level across age groups (see Table 1); they provided written and