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Marginal neurofunctional changes in high-performing older adults in a verbal fluency task

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ABSTRACT

The maintenance of a high level of performance in aging has often been associated with changes in cerebral activations patterns for various cognitive components. However, relatively few studies have investigated this phenomenon in light of lexical speech production abilities, which have not been systematically found to benefit from neurofunctional reorganization during verbal fluency tasks. In this study, functional magnetic resonance imaging was used to assess overt self-paced semantic and orthographic verbal fluency tasks performed by healthy younger and older adults within a mixed block/event-related fMRI design. Behavioral results indicated similarly high levels of performance between tasks and age groups, while whole brain analysis revealed significant task-related differences in patterns of brain activity, but no significant effect of age or task-by-age interaction across the speech conditions. Only local activity differences were found between age groups. These marginal neurofunctional changes in high-performing older adults are discussed in terms of task demands.

1. Introduction

The preservation of optimal performance in aging is usually associated with adaptive changes in patterns of brain activity for a number of cognitive abilities that tend to decline with age, including visual processing (e.g., Ansado, Monchi, Ennabil, Faure, & Joanette, 2012; Cabeza et al., 2004; Davis, Dennis, Daselaar, Fleck, & Cabeza, 2007), episodic memory (e.g., Cabeza, Anderson, Locantore, & McIntosh, 2002; Grady, Bernstein, Beig, & Siegenthaler, 2002; Grady & Craik, 2000; Morcom, Good, Frackowiak, & Rugg, 2003), working memory (e.g., Cabeza et al., 2004; Emery & Hess, 2008; Grady, Yu, & Alain, 2008; Reuter-Lorenz et al., 2000) and inhibitory control (Langenecker & Nielson, 2003; Nielson, Langenecker, & Garavan, 2002). This neurofunctional reorganization is typically characterized by more bilateral prefrontal activations in high-performing older adults compared to their younger counterparts and low-performing elderly ("Hemispheric Asymmetry Reduction in Older Adults" or HAROLD; Cabeza, 2002), as well as by an age-related decrease in occipito-temporal activations coupled with increased prefrontal activity (Posterior–Anterior Shift in Aging" or PASA; Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008).

Both phenomena have been considered to reflect a neurofunctional compensation mechanism, suggesting that the recruitment of additional brain areas helps counteract neurocognitive deterioration in order to maintain general cognitive efficiency or task-related performance at a high level (e.g., Ansado et al., 2012; Cabeza, 2002; Davis, Kragel, Madden, & Cabeza, 2012; Davis et al., 2007; Grady, 2012; Park & Reuter-Lorenz, 2009; Reuter-Lorenz et al., 2000; Stern, 2009). However, bilateral activity is not always found to benefit performance (e.g., Wierenga et al., 2008); in such cases, it may reflect less efficient processing, resulting from a reduction in the hemispheric specialization of cognitive functions or a disinhibition of non-specialized neural correlates with age (Li & Lindenberger, 1999; Rajah & D'Esposito, 2005). Moreover, some authors have proposed a Compensation-related utilization of neural circuits hypothesis (or CRUNCH), implying that age-related differences in patterns of brain activity reflect a phenomenon related to decreased neural efficiency in older adults, thus limiting their ability to cope with increasing task demands (for a review, see Reuter-Lorenz & Cappell, 2008).

Relatively few studies have examined age-related changes in patterns of neural activity for communication abilities, some of which generally remain well preserved in aging (e.g., Burke, MacKay, & James, 2000; Burke & Shafto, 2008). Although a form of compensatory neural recruitment in aging has been reported for sentence comprehension (e.g., Tyler et al., 2010; Wingfield &

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Grossman, 2006), non-lexical speech productions (Sörös, Bose, Sokoloff, Graham, & Stuss, 2011), verb generation (Persson et al., 2004) and picture naming tasks (Wierenga et al., 2008), some authors suggest that the neurofunctional reorganization sustaining language abilities is more dynamic and related to task demands (Grossman et al., 2002; Peelle, Troiani, Wingfield, & Grossman, 2010).

Very few studies have examined this phenomenon in the context of more demanding word retrieval abilities such as verbal fluency tasks, involving the spontaneous generation of as many words as possible within a limited amount of time under orthographic (words starting with a specific letter) or semantic (words from a given category) search conditions. Both fluency conditions assess language function depending on lexical-semantic store integrity, speed of information processing, auditory attention, working memory and executive processes (e.g., Boone, Ponton, Gorsuch, Gonzalez, & Miller, 1998; Rosen & Engle, 1997; Ruff, Light, Parker, & Levin, 1997). The number of words produced is typically higher in the semantic than the orthographic fluency condition for adults (e.g., Mitrushina, Boone, & D'Elia, 1999). However, performance on both kinds of tasks tends to be positively modulated by the level of education (Crossley, D'Arcy, & Rawson, 1997; Tombaugh, Kozak, & Rees, 1999; van Hooren et al., 2007). A few authors have also reported that semantic fluency is less efficient in older adults that the orthographic fluency, thus suggesting age-related differences between conditions (Crossley, D'Arcy, & Rawson, 1997; Treitz, Heyder, & Daum, 2007). Yet, behavioral cross-sectional studies indicate that the effect of age on both conditions is related, at least in part, to reduced information processing speed (Bryan, Luszcz, & Crawford, 1997; Elgamal, Roy, & Sharratt, 2011; Rodriguez-Aranda, 2003; Rodriguez-Aranda, Waterloo, Sparr, & Sundet, 2006).

At the neurofunctional level, only a handful of studies have examined cerebral activation patterns associated with a verbal fluency task in aging. Using an externally paced word generation paradigm, Meinzer et al. (2009) and Meinzer et al. (2012b) found similar performance levels and left-lateralized patterns of cerebral activations (e.g., inferior and middle frontal gyri) in healthy younger (mean ages of 24 and 26 years, ranging from 19 to 33 years) and older adults (mean age of 69 years, ranging from 61 to 88 years) on the phonemic condition. Conversely, they found that seniors performed significantly worse during the semantic condition, which was accompanied by additional right hemisphere activations (e.g., inferior and middle frontal areas, posterior parietal lobe) that were negatively correlated with performance, thus suggesting that bilateral activity may not be beneficial for verbal fluency. Similarly, Wierenga et al. (2008) reported a negative correlation between right lateral inferior frontal gyrus activity and picture naming accuracy in low-performing older adults. However, the externally paced paradigm used by Meinzer et al. (2009) and Meinzer, Seeds, et al. (2012b) differs from the usual self-paced nature of verbal fluency tasks. Externally paced verbal fluency tasks have also been associated with additional non-linguistic cerebral activations, especially in bilateral middle frontal and anterior cingulate areas (Basho, Palmer, Rubio, Wulfeck, & Muller, 2007). Moreover, using short blocks (12 s) of continuous semantic fluency tasks performed by relatively young participants (mean age of 35 years, ranging from 22 to 56 years), Nagels et al. (2012) reported that age did not influence the number of words generated, but that it was positively correlated with activations in the bilateral inferior and middle frontal gyri, the anterior cingulate gyrus, the left precentral gyrus and the right insula, which the authors interpreted in terms of functional compensatory mechanisms. Thus, the maintenance of orthographic fluency in older adults is not systematically associated with changes in patterns of activations, whereas it remains unclear whether the neurofunctional reorganization reported for semantic fluency is advantageous at the behavioral level. Such results may have also been modulated by the use of more restrictive task conditions in the above-mentioned studies. To determine if this phenomenon reflects compensatory mechanisms or reduced neural efficiency (e.g., HAROLD or CRUNCH), it is therefore necessary to examine age-related neurofunctional changes associated with high levels of performance during longer blocks of overt self-paced semantic and orthographic verbal fluency tasks, which are also more representative of lexical speech production in clinical settings.

The goal of the present study was to use blood oxygen level-dependent (BOLD) fMRI to characterize the neurofunctional expression of overt self-paced semantic and orthographic verbal fluency in healthy, well-educated younger and older adults while attempting to reduce the potential confounding effect of an age-related decline in information processing speed. Hence, unlike previous neuroimaging studies on over word generation in aging, we relied on relatively long blocks of overt self-paced speech productions (90 s), thus minimizing the effect of task demands associated with more restrictive search conditions. This was achieved within the framework of an innovative mixed block/event-related fMRI design (e.g., Donaldson, Petersen, Ollinger, & Buckner, 2001; Petersen & Dubis, 2012), allowing to assess brain activity related to individual speech productions (event-related activity), which can also be grouped retrospectively in continuous blocks to examine ongoing task demands (block-related activity). Since the aforementioned studies were limited to block-related analyzes, the flexibility of a mixed block/event-related design was used to further explore the effect of aging on block-related cerebral activations resulting from a longer self-paced verbal fluency task, as well as on activity patterns associated with successful semantic and orthographic speech productions. For exploratory purposes, focal effect of age was also assessed in light of common and differential activations between semantic, orthographic and automated (less cognitive) fluency tasks.

Under the assumption of a compensatory mechanism, it was expected that younger and older adults would show similar high-level of semantic and orthographic verbal fluency performance, which would be associated with neurofunctional reorganization in the latter group. However, to the extent that age-related differences in patterns activations mainly reflect reduced neurofunctional efficiency limiting the ability to cope with increasing task demands, long blocks of self-paced verbal fluency task should results in marginal behavioral and neurofunctional changes in older adults when compared to their younger counterparts.

2. Materials and methods

2.1. Participants

Fourteen younger (M = 24.00 years, SD = 3.86 years, range = 20–31 years, 7 women) and 14 older adults (M = 63.50 years, SD = 3.59 years, range = 60–73 years, 8 women) were recruited by means of local advertisements to participate in this study. All of them were healthy, right-handed (according to the Edinburgh Handedness Inventory; Oldfield, 1971) and native speakers of French from Québec (Canada). Both groups were well-educated (for younger adults: M = 15.93 years, SD = 1.64 years; for older adults: M = 17.29 years, SD = 2.40 years) and did not differ significantly based on that criterion. None of the participants had a history of developmental language impairment, substance abuse, or affective, psychiatric or neurological disorders. They were all screened for cognitive deficits using the French version of the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) and all scores were within the normal range (M = 29.64,