When metaphors go literally beyond their territories: The impact of age on figurative language

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As one of the most integrated components of language, the understanding of metaphors has sparked some of the greatest interest and debate with regard to how and where it is sustained by the brain. Traditionally, the right hemisphere was thought to be the locus of metaphor comprehension. However, the recent literature reported in this article suggests that the processing of metaphors is the product of a complex interplay and cooperation between the two hemispheres. In fact, the question of how the aging brain processes metaphors remains unresolved. The present study aims to provide insight into the nature of changes in the processing of metaphors in normal aging. We describe the different patterns of interhemispheric activation in younger and older adults during processing of literal and conventional metaphorical meanings of words. A total of 10 younger adults and 10 older adults were scanned via 3T functional magnetic resonance imaging while performing a semantic judgment task using pairs of words: targets with literal or conventional metaphorical relationships and distractors paired with concrete or abstract words. The metaphorical-literal contrast showed significant increased activity in the superior frontal gyrus bilaterally in both groups and in the inferior frontal gyrus and the posterior cingulate cortex in the older group only. Both groups showed a left lateralization. We concluded that aging is associated with changes in the pattern of neural activity when processing conventional metaphors. The results are analyzed in the light of the recent literature proposing age-related neurofunctional reorganization, namely the HAROLD and PASA phenomena in the context of language processing.

Keywords: aging, language, conventional metaphors, functional reorganization, functional magnetic resonance imaging

1. Introduction

Figurative language allows speakers to communicate by expressing meanings that go beyond the literal interpretation of words. Several forms of figurative language exist, including idioms, speech forms or expressions of a given language that are peculiar grammatically or cannot be understood from the individual meanings of their

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elements (e.g., *under the weather*); proverbs, which briefly express some practical truth, moral belief, or social norm (e.g., *a stitch in time saves nine*); irony, the use of words to express something different from and often opposite to their literal meaning; and metaphor, a figure of speech that involves an explicit or implicit comparison between two relatively unlike ideas (e.g., *the road was a ribbon of moonlight*). Among these various types of figurative language, the metaphor has sparked some of the greatest interest and debate in the research community with regard to how and where it is processed by the brain. A wide range of studies have attempted to determine what characteristics are distinctive to the processing of metaphors by contrasting it with the processing of literal meanings. Consequently, they have identified a number of factors that can influence, modulated, or even confound the components involved. Intrinsic factors such as the degree of meaning salience (Giora et al. 2000), novelty (Mashal et al. 2007; Ahrens et al. 2007; Mashal et al. 2009), semantic distance (Mashal et al. 2005), and sentence context (Kacinik & Chiarello 2007) are well recognized. Some of these factors impose comparisons not only with literal meanings, but also between different kinds of metaphors. For instance, metaphors may be nominal (i.e., involve the metaphorical use of a noun such as *my job is a jail*) or predicative (i.e., involve the metaphorical use of a verb such as *the rumour flew through the office*) (Torreano et al. 2005). Other types include conventional (familiar) and novel (unfamiliar) metaphors (Mashal et al. 2007; Mashal et al. 2009). Finally, polysemous words (i.e., words having more than one meaning) can also have metaphorical meanings (Brownell et al. 1990), as in the case of *warm* meaning both *moderately hot* and *loving*. In this context, generalizing results has been difficult. Additionally, extrinsic factors such as the type of task performed or the methodology of the study may also challenge the strength of the conclusions (Giora 2007).

Notwithstanding the above-mentioned discussion, the debate on the processing of metaphors has centered on the possibility of a hemispheric specialization (or dominance), a problem that has been investigated by many scholars of language during the last 25 years. Traditionally, the right hemisphere (**RH**) has been recognized as the locus of metaphor comprehension (for a review, see Kacinik & Chiarello 2007). Therefore, its integrity was a requisite for the successful interpretation of metaphorical meanings. This view was supported principally by studies of individuals with RH damage who showed altered comprehension of this kind of figurative language (Brownell et al. 1984; Brownell et al. 1990; Kempler et al. 1999). A number of studies employing divided visual field and neuroimaging

techniques have also provided support for this hypothesis (Anaki et al. 1998; Bottini et al. 1994; Mashal et al. 2007). By contrast, some researchers have argued against the exclusive involvement of the RH, suggesting that both literal and nonliteral (metaphorical) meanings are processed in the left hemisphere (**LH**), even though they may solicit different pathways (Rapp et al. 2004; Lee & Dapretto 2006; Stringaris et al. 2007). In a recent revision of the problem, Giora (2007) points out to a subverted classical division of labor between hemispheres in the light of all the evidence currently available. In a more conciliatory position, some authors have supported a shared right-left hemispheric contribution, proposing a mechanism of interhemispheric cooperation (Gagnon et al. 2003; Eviatar & Just 2006; Kacinik & Chiarello 2007).

Taken together, the results reported in this wide scope of existing literature suggest that the processing of metaphors is the product of a complex interplay and cooperation between the two hemispheres. But what is the nature of this cooperation? Do both hemispheres contribute to specific linguistic components? Is one hemisphere involved in a more general kind of computation? Or perhaps one hemisphere provides the additional attentional resources needed to accomplish a complex cognitive task? It is widely known that, according to the limited resource theory, the brain has a limited processing capacity and resources such as attention must be allocated according to the complexity of the tasks (Banich 1998). With these questions in mind, some researchers have provided evidence that suggests the contribution of the RH to the processing of metaphors is, at least to some extent, the expression of its complementary role of supplying the additional attentional resources needed for this effortful kind of processing (Tompkins 1990; Monetta et al. 2006).

In view of this extensive debate, yet another question needs to be addressed. Most importantly, the issue of how the aging brain processes metaphors has remained almost untouched, despite the multitude of studies on aging and cognition. The resulting lack of insight can be an important limitation to obtaining a complete picture of the problem for two reasons: First, to arrive at general conclusions, the results of studies of younger participants are frequently compared with those of older participants, which can constitute a source of error. Second, possible changes in interhemispheric cooperation during the life span could provide some insight into the nature of each hemisphere contribution. To the best of our knowledge, only one study to date has attempted to deal with this question: Using event-related potentials, Bonnaud et al. (2002) aimed to compare electrophysiologi-

cal data for young and older adults during a semantic judgment task involving the comprehension of metaphorical links. They reported larger amplitudes of the N400 elicited by metaphorical relationships between pairs of words in comparison with non metaphorical semantic links in both groups. Interestingly, their results showed that the older adults made significantly fewer errors when making semantic judgments involving metaphors than did the younger adults. This difference in accuracy is consistent with the reported relative preservation of semantic aspects of language during aging (for a review, see Wingfield & Grossman 2006). Unfortunately, the authors did not report any data regarding the hemispheric interplay during the processing of metaphors.

In a more general context, a considerable number of studies have integrated different sources of evidence suggest that a relationship exists between age-related changes in neural architecture, interhemispheric dynamics, and changes in cognitive function (Coffey et al. 2001; Cabeza et al. 1997; Cabeza 2001; 2002; Sarter & Bruno 2004). Two different phenomena have been proposed to account for these changes: the hemispheric asymmetry reduction in older adults (**HAROLD**) and the posterior-anterior shift with aging (**PASA**). Integrating different sources of data, mainly from psychology and neurosciences of aging, the HAROLD model (Cabeza 2002) proposes that the prefrontal cortical activity tends to be less lateralized in older adults with maintained performance when compared with younger adults. Two different hypotheses have been proposed: the *compensation view*, according to which this reduction could be a way of counteracting the neurocognitive decline associated with aging, and the *dedifferentiation view*, according to which these modifications reflect a kind of hurdle to recruiting specialized neural mechanisms. In addition to these well-established changes, the PASA phenomenon, an age-related increase in frontal activations in contrast with decreased posterior activations, has been also reported in older adults (Davis et al. 2008). Taken together, these findings can be interpreted as an indication of the capacity for a functional malleability of the aging brain. Evidence supporting these phenomena comes from research on episodic, semantic, and working memory as well as visual perception. Nevertheless, little is known about the determinants of possible age-related neurofunctional reorganization for language processing with respect to the HAROLD and PASA phenomena. Only a few recent neuroimaging studies have explored this hypothesis and described differences in the activation profiles between young and older adults (Grossman et al. 2002; Faustmann et al. 2007; Ouelette-Plamondon et

al. 2006; Ouelette-Plamondon et al. *submitted*). However, it appears that the neurofunctional reorganization that allows for the maintenance of language processing with successful aging is more global. It seems to imply a more widespread network resulting from changes in lateralization (activation of bilateral areas) as well as changes in the anterior-posterior and cortico-subcortical patterns of activation.

In summary, the nature of the interhemispheric cooperation during the processing of metaphors has not yet been studied in the context of aging. Hence, the present study aims to provide insight concerning the direction and nature of changes in the processing of the metaphorical meaning of words during normal aging. We used functional magnetic resonance imaging (fMRI), to compare the brain activity of healthy young and older adults while performing a semantic judgment task with and without metaphors.

2. Experiment

2.1. Method

Participants. We recruited 10 young adults (4 male, 6 female) ranging in age from 20 to 29 years (mean age: 23.3 years, standard deviation (SD): 2.7) and 10 older adults (6 male, 4 female) ranging in age from 61 to 70 years (mean age: 64.4 years, SD: 2.9). Participants had no history of brain injury or psychiatric disorder and showed normal results on neuropsychological tests of working memory and vocabulary (Brown-Peterson task and WAIS-III subtest respectively). All participants were right-handed native speakers of French with a high level of education ($\geq$ 13 years) (mean years of education: 18.2 years, SD: 1.51, range: 15-20). All participants gave informed consent after reading the protocol, which had been reviewed and approved by the *Comité mixte d'étique de la recherche du Regroupement de Neuroimagerie de Québec* at the *Institut universitaire de gériatrie de Montréal*. This committee follows the guidelines of the Tri-Council Policy Statement of Canada, the Civil Code of Quebec, the Declaration of Helsinki, and the Nuremberg Code.

Tasks and procedure. Participants were presented with a semantic judgment task in which they had to decide whether they perceived a semantic relationship between two words in French. They were asked to answer as accurately and rapidly as possible by pressing one of two buttons (yes/no). Responses were obtained via an MR-compatible right-hand button response box (BrainLogics). Half of

the participants were required to answer 'yes' with their index finger and 'no' with their middle finger, and the other half had the opposite response pattern. To ensure that the instructions were understood, a short practice session was administered with a different set of stimuli before starting the acquisition. Experimental stimuli were based on 25 polysemous words, with both a literal meaning and a conventional metaphorical meaning, obtained from the stimuli used by Mercure (2004). These 25 words were used to form 100 pairs of words belonging to 1 of 4 possible types: 50 target pairs, with 25 having a literal relationship (**LT**) and 25 having a metaphorical relationship (**MT**) (e.g., LT: *chaleur* 'heat' and *four* 'oven'; MT: *chaleur* 'heat' and *passion* 'passion') and 50 distractor pairs in which 25 of the polysemous words appeared accompanied by a concrete word (**CD**) and 25 were accompanied by an abstract word (**AD**) (e.g., CD: *chaleur* 'heat' and *tambour* 'drum'; AD: *chaleur* 'heat' and *décision* 'decision'). According to the concrete (literal) or abstract (metaphorical) nature of the semantic link in the target pairs, distractor pairs were constructed by using a concrete or an abstract word allowing for the control of the concreteness effect (concrete/literal, abstract/metaphorical). All the word pairs were constructed using nouns and were controlled by their lexical frequency (CARDEX) and number of letters.

Participants were also asked to perform a reference task, which consisted of 100 pairs of letter strings for which participants had to indicate whether both strings shared the same type of case (upper or lower: e.g., dddddd/TTTTT). All the stimuli of the experimental and reference tasks were presented twice in a counterbalanced order. The pairs of stimuli were generated by a Macintosh computer and presented centrally on a computer screen using the E-Prime software (v1.2, Psychology Software Tools, Inc.). An LCD projector (EMP-8300 XGA, Epson) displayed stimuli on a screen placed behind the scanner. Participants viewed the screen via a double-mirror fastened to the head coil. Pairs of stimuli were displayed for 2500 ms and preceded by a fixation point lasting 500 ms. A variable interstimulus interval (500 ms, 750 ms, 1000 ms, 1250 ms, and 1500 ms) was used. Response times longer than the time limit of 2500 ms were not registered. Two runs with four blocks of stimuli (25 pairs) and four blocks of letter strings (25 pairs) each were used. The order of presentation of the experimental task and the reference task was counterbalanced amongst participants. Blocks of stimuli or letters alternated during the run within each block. Trials of different types (literals, metaphors, concrete distractors, abstract distractors) were presented pseudorandomly.

Functional MRI acquisition. Participants were scanned while performing the tasks, in a single session, using a 3T Siemens Trio Magnetom MRI Scanner at the *Unité de neuroimagerie fonctionnelle* (http://www.unf-montreal.ca/) of the I*nstitut universitaire de gériatrie de Montréal*. The session started with a localizer scout to position the participant's head. A T1-weighted three-dimensional volume (176 slices; voxel size: 1x1x1 mm^3; matrix size: 256x256) for anatomical localization was then acquired. Two runs of T2*-weighted functional acquisitions followed. Functional images were acquired with an echo-planar image sequence sensitive to BOLD contrast (TE: 30 ms, TR: 2000 ms, α flip angle: 90°). The volume covered the whole brain with a 64x64 and 30 slices (voxel size: 4x4x4.8 mm^3). The slice thickness was 4 mm with a 0.8 mm interslice gap in an inclined axial plane aligned with the anterior commissure-posterior commissure axis. Two runs consisting of 410 volumes each were acquired during the experiment. The first two volumes of each run were discarded to reach steady-state magnetization.

Data analysis. Data was analysed using the fMRIstat software developed by Worsley et al. (2002) (available at http://www.bic.mni.mcgill.ca/users/keith/). The first two frames in each run were discarded. Images from each run were first realigned to the third frame for motion correction and were smoothed using a 6 mm full-width half-maximum (FWHM) isotropic Gaussian kernel. fMRI data's statistical analysis was based on a linear model with correlated errors. For the purpose of the imaging analysis, only correct answers were considered in the design matrix (errors and no responses were excluded). The design matrix of the linear model was first convolved with a difference of two gamma hemodynamic response functions timed to coincide with the acquisition of each slice. Temporal drift was removed by adding a cubic spline in the frame times to the design matrix. Spatial drift was removed by adding a covariate in the whole volume average. Then, the correlation structure was modelled as an autoregressive process of degree 1. The autocorrelation parameter was estimated at each voxel from the least squares residuals. The Yule-Walker equations were used after a bias correction for correlation induced by the linear model. The autocorrelation parameter was first regularized by spatial smoothing and then used to 'whiten' the data and the design matrix. The linear model was then re-estimated by using least squares on the whitened data to produce estimates of effects and their standard errors. The resulting effects and standard effect files were then spatially normalized by non linear transformation into the MNI standard proportional stere-

otaxic space using the algorithm proposed by Collins et al. (1994). Anatomical images were also normalized to the MNI 305 standard proportional stereotaxic space using the same transformation. Runs and participants were combined using a mixed effect linear model with fixed effect standard deviations taken from the previous analysis. The ratio of the random effects variance to the fixed effects variance was estimated, and then regularized using spatial smoothing with a Gaussian filter. The variance of the effect was then estimated by the smoothed ratio multiplied by the fixed effects variance. The amount of smoothing was chosen to achieve 100 effective degrees of freedom (Worsley 2002). Intragroup analysis was performed by making the following direct comparisons: [MT – reference], [MT – AD], and [MT – LT]. These data were submitted to a T-test. Statistical maps were thresholded at $p < .05$, correcting for multiple comparisons using the minimum between a Bonferroni correction and random field theory (Worsley et al. 1996). The significance of peaks is reported using the minimum p value of the single peak analysis (in terms of t-statistics) and cluster analysis. All peaks that reached $p < .05$ corrected are reported. Predicted peaks (ROI) that reached $p < .0001$ uncorrected are also reported, indicated by a * in the tables. Peaks were considered predicted if they coincide with those of Rapp et al. (2007), and were constituted of: inferior frontal gyrus (opercular and triangular parts), superior, middle, and inferior temporal gyrus, precuneus, temporal pole, and hippocampus. These regions were considered bilaterally in order to account, if present, for the HAROLD phenomenon. Finally, a lateralization index was calculated for the activated regions such as [(right – left) / (right + left)] × 100. This lateralization index varies from -100 (completely left lateralized activation) to +100 (completely right lateralized activation), with 0 representing complete symmetry (e.g., Blanchet 2001). The indices were also split for half-brain comparisons. For the lateralization index, the value $x = 0$ was used to separate right from left voxels.

3. Results

3.1. Behavioral Results

There was no significant difference between the performances of the two groups. The average number of errors for the younger group was: 0.8 (SD = 1.03) for LT; 10.2 (SD = 4.83) for MT; 0.040

(SD = 0.52) for CD; and 2.90 (SD = 3.7) for AD. For the older group the average number of errors was: 0.5 (SD = 0.71) for LT; 6.7 (SD = 2.79) for MT; 0.1 (SD = 0.32) for CD; and 2.1 (SD = 2.85) for AD. The response times for each condition were analyzed and compared across each group. For the younger group, the mean response times were 1052.12 ms (SD = 197.51) for LT; 1174.81 ms (SD = 223.87) for MT; 1169.01 ms (SD = 227.66) for CD; and 1175.81 ms (SD = 202.37) for AD. For the older group, the mean response times were 1176.75 ms (SD = 156.55) for the LT; 1350.90 ms (SD = 171.40) for the MT; 1322.74 ms (SD = 150.95) for the CD; and 1374.78 ms (SD = 156.78) for the AD. Data were submitted to a 2 (Stimuli: targets and distractors) x 2 (Type: LT/CD and MT/AD) x 2 (Group: young and older adults) ANOVA. At an alpha level of 5%, no significant main effect was obtained for either stimuli, type, or group. However, two interactions reached the significant level: Type x Group ($F_{[1,18]} = 10.493$, $p = .005$) and Stimuli x Type ($F_{[1,18]} = 26.134$, $p < .001$). Then, we performed a 2 (Stimuli: targets and distractors) x 2 (Type: LT/CD and MT/AD) MANOVA with repeated measures for Group (young and older adults). At an alpha level of 5%, a significant main effect was obtained for both groups for targets according to Type ($F_{[1,18]} = 44.36$, $p < .001$). No significant differences according to Type were found when analyzing distractors. Taken together, these results suggest that both young and older adults behaved similarly regardless of the Stimuli (targets/distractors) or Type (literal/concrete and metaphors/abstract). In addition, they indicate that the literal targets were processed significantly faster than the other conditions.

3.2. fMRI results

Different patterns of neural activity were associated with the processing of polysemous words in their metaphorical meaning depending on age.

Metaphors versus reference task. When the metaphor condition was subtracted from the reference task [MT – reference], a significant increase in activity was observed in the older group in the right superior temporal gyrus (BA 22), the right fusiform gyrus (BA 37), the middle occipital gyrus bilaterally (BA 19), the left precuneus (BA 7), the right cingulate gyrus (BA 31), and the right cerebellum. In the younger group, a significant increase in activity was obtained in the left fusiform gyrus (BA 37), the left inferior parietal lobule (BA 40), and the left precuneus (BA 7) (see Tab. 1).

Table 1. Activation coordinates (X, Y, Z) of anatomical areas in MNI stereotaxic space from the Metaphors versus Reference contrast.
Abbreviations: FG = fusiform gyrus; ITG = inferior temporal gyrus; MTG = middle temporal gyrus; STG = superior temporal gyrus; IPL = inferior parietal lobule; MOG = middle occipital gyrus; IOG = inferior occipital gyrus; PCu = precuneus; CG = cingulate gyrus.

Anatomical area		Young Adults					Older Adults				
		X	Y	Z	t-stat	Cluster	X	Y	Z	t-stat	Cluster
FG	(37) R						42	-62	-12	4.13	1696
	(37) L	-34	-52	-14	3.48*	200					
ITG	(37) R						50	-62	-8	4.29	1696
MTG	(37) R						48	-54	0	3.31	1696
STG	(22) R						60	-52	20	3.75	296
IPL	(40) L	-64	-18	24	3.56*	72					
MOG	(19) R						38	-76	8	5.38	1320
	(19) L						-42	-84	22	3.80*	240
IOG	(19) R						36	-60	-10	3.28	1696
PCu	(7) L	-12	-74	40	3.52*	96	-6	-66	52	3.68	1080
CG	(31) R						18	-54	16	3.50*	120
Cerebellum	R						28	-60	-12	4.19	1696

* significance at $p < .0001$ uncorrected for multiple comparison

Metaphors versus abstract distractors. When metaphors were compared with abstract distractors [MT – AD], the older group showed a significant increase in activity in the superior temporal gyrus bilaterally (BA 22), the left middle temporal gyrus (BA 21), the inferior temporal gyrus bilaterally (BA 37), the left inferior frontal gyrus (orbital and triangular parts) (BA 47, 45), and the right cingulate gyrus (BA 31). Significant effects in the younger group were observed in the left prefrontal cortex (BA 10), the right cingulate gyrus (BA 31), and the precuneus bilaterally (BA 7) (see Tab. 2).

Table 2. Activation coordinates (X, Y, Z) of anatomical areas in MNI stereotaxic space from the Metaphors versus Distractors contrast.
Abbreviations: STG = superior temporal gyrus; MTG = middle temporal gyrus; ITG = inferior temporal gyrus; IFG = inferior frontal gyrus (orbital and triangular parts); PFC = prefrontal cortex; CG cingulate gyrus; PCu precuneus.

Anatomical area		Young Adults					Older Adults				
		X	Y	Z	t-stat	Cluster	X	Y	Z	t-stat	Cluster
STG	(22) L						-40	-38	18	4.50	688
	(22) R						44	-54	14	3.72*	264
TG	(21) L						-58	-40	-8	4.50	648
ITG	(37) L						-58	-48	-10	3.48	648
	(37) R						50	-64	0	3.49*	216
IFG	(47) L						-36	22	0	4.03*	256
	(45) L						-52	26	14	4.28*	240
PFC	(10) L	-14	50	2	3.77*	88					
CG	(31) R	10	-52	28	4.38	2120	12	-30	26	3.67*	184
PCu	(7) R	6	-58	40	4.05	2120					
	(7) L	-6	-58	30	3.87	2120					

* significance at p < .0001 uncorrected for multiple comparison

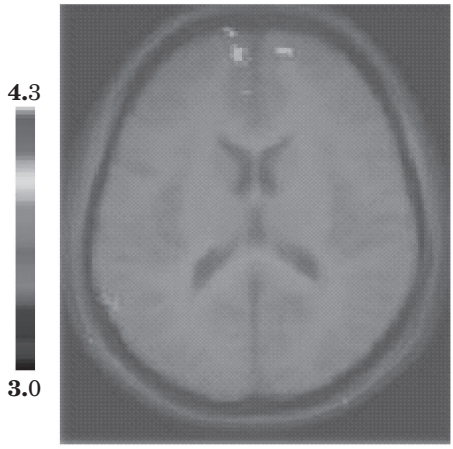
Metaphors versus literals. Finally, when metaphors were compared with literal judgments [MT – LT], a significant increase in activity was observed in the older group in the superior frontal gyrus bilaterally (BA 10), the left inferior frontal gyrus (orbital part) (BA 47), and the right cingulate gyrus (BA 31). In the younger group, a significant increase in activity was observed only in the superior frontal gyrus bilaterally (BA 10) (see Tab. 3, Fig. 1, Fig. 2A and Fig. 2B).

Table 3. Activation coordinates (X, Y, Z) of anatomical areas in MNI stereotaxic space from the Metaphors versus Literals contrast.
Abbreviations: SFG = superior frontal gyrus (BA 10); IFG = inferior frontal gyrus (orbital part) (BA 47); CG = cingulate gyrus (BA 31).

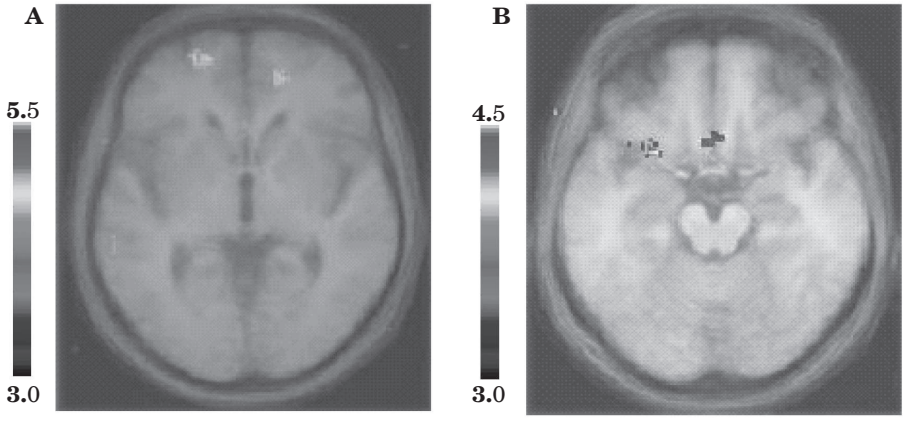
Anatomical area		Young Adults					Older Adults				
		X	Y	Z	t-stat	Cluster	X	Y	Z	t-stat	Cluster
SFG	(10) L	-6	60	16	4.27	440	-20	58	-2	5.49	416
	(10) R	12	62	16	3.86*	112	16	48	-2	4.12*	200
IFG	(47) L						-28	12	-18	4.53	224
CG	(31) R						8	-72	6	3.62*	160

* significance at p < .0001 uncorrected for multiple comparison

Figure 1. Young adults: Metaphors versus Literals.



Figures 2A and 2B. Older adults: Metaphors versus Literals.



Lateralization indices. The younger group showed a left lateralization index of -100 for the contrast [MT – reference], whereas the older group had a right lateralization index of +50. The younger group had a right lateralization index of +54 for the contrast [MT – AD], and the older group showed a left lateralization index of -47. Finally, both groups showed a left lateralization index for the contrast [MT – LT]: -59 for the younger group and -33 for the older group.

4. Discussion

The goal of this study was to provide insight concerning the direction and nature of changes in the processing of metaphors during normal aging. Therefore, we sought to describe the patterns of brain activation during the processing of the conventional metaphorical meanings of words.

As a main result, we found that, in the presence of similar performances and when compared with younger adults, the patterns of brain activation implicated in processing conventional metaphors shown by older adults involve a more widespread network resulting from changes in lateralization (more bilateral activations) as well as in the anterior-posterior profiles.

Interpreting these results in the light of the HAROLD phenomenon requires some special considerations. The HAROLD phenomenon was first described in the context of reduced lateralization of prefrontal activity exclusively. Nevertheless, as is well known, brain areas implicated in language processing include a more widespread network. Therefore, the HAROLD phenomenon is here understood as the manifestation of a reduction in hemispheric asymmetries from a more general point of view. Indeed, the description of brain activation patterns and the lateralization index combine to show a neural substrate that is more distributed over both hemispheres in older adults. The lateralization index was taken into account as follows: If the absolute value of the lateralization index was greater for younger adults than for older adults, the results were deemed consistent with the HAROLD phenomenon. By contrast, if the absolute value of the lateralization index was similar for both groups or greater for older adults, the phenomenon was disconfirmed. In the older group, a reduction in the lateralization of brain activity was found for two of the three contrasts ([MT – reference] and [MT – LT]), while the third contrast ([MT – AD]) remained relatively comparable to that of the younger group. We will focus the present discussion on the classical comparison between metaphorical and literal meanings ([MT – LT]).

The lateralization index for both groups favors the left hemisphere when metaphorical and literal meanings were compared (-59 for the younger group and -33 for the older group). However, the older group showed a reduction in lateralization according to the bias toward increased activation in the RH (see Tab. 3). This change coincides with one of the possible outcomes described by Cabeza in his original paper and is therefore congruent with the HAROLD phenomenon (Cabeza 2002).

Interestingly, and despite the left hemisphere lateralization index result, both groups showed a bilateral anterior pattern of activation in the superior frontal gyrus (BA 10). These regions are typically associated with the retrieval of information when divided attention is required (Anderson et al. 2000). In other words, the activation of this area could be the result of an additional effort to maintain an actual running task in a pending state for subsequent retrieval and execution while a second task is completed. In accordance with the standard pragmatic model (Grice 1975; Searle 1979), in trying to make sense of metaphors, the literal interpretation is rejected and replaced with an appropriate nonliteral interpretation. From a behavioral point of view, literal targets were processed significantly faster than metaphors, which is consistent with the standard pragmatic model. In this context, the activation of the superior frontal gyrus could imply that comprehending the conventional metaphorical meaning of words requires the sharing of attentional resources. The literal meaning is maintained available in a pending state while the metaphorical meaning is activated, and is rejected only after the metaphorical interpretation is accepted. If this interpretation is accurate, one of the major differences between understanding the conventional metaphorical meaning of words and the literal meanings of words is that the former imposes a double task condition on the brain, whereas the latter does not.

As mentioned above, a more extensive pattern of activation was observed in the older group. In addition to the bilateral superior frontal gyrus (BA 10), activations were observed in the left inferior frontal gyrus (orbital part) (BA 47) and the right cingulate gyrus (BA 31). The left inferior frontal gyrus (BA 47) is known to be implicated in processing semantic relationships when a certain amount of strategic and/or memory processes is required (for a review, see Friederici 2002), which may be the case during the comprehension of polysemous words with metaphorical meanings. Finally, the left inferior frontal gyrus (BA 47) has been identified as significantly activated during divided and selective attention (Nebel et al. 2005). Taken together, these findings suggest that the activation of the left inferior frontal gyrus in older adults could result from a need for additional attentional resources. Finally, the right cingulate gyrus has been reported to be significantly activated in healthy older adults with poor comprehension, but only for stimuli that were accurately interpreted (Grossman et al. 2002). This finding could reflect an effective compensation mechanism when older adults experience certain difficulties or are exposed to a complex task requiring semantic processing.

From a general perspective, this need for the additional recruitment of brain areas in older adults could reflect the demanding character of higher-order cognitive functions during aging (Van der Linden & Hupet 1994). It is now well known that older adults require supplementary resources to process complex cognitive tasks. Reuter-Lorenz et al. (1999) suggested that older adults may benefit from engaging additional brain areas (sometimes bilaterally) to accomplish complex tasks that require exclusive unilateral brain activations in young adults. Such an extended brain network appears to allow, at least in part, the maintenance of performance at a complex level (as in the understanding of metaphors). This result suggests that the impact of brain lesions on the ability to process the metaphorical meanings of words could differ according to age. From a neurofunctional point of view, if the network required for processing of such a complexity engages additional brain areas, including those in the RH, it could mean that this ability would be impaired by lesions in more brain areas, thus increasing the prevalence of impairment. At the same time, since the brain regions required with age appear to be similar to those contributing to word processing recovery (Marcotte & Ansaldo 2010), it could also be the case that the presumed higher prevalence of impairment would be followed by less recovery. However, this prediction is made only on a neurofunctional basis and does not take into account the possible counterbalancing effect of the continuing enrichment of semantic memory that characterizes aging. Consequently, systematic studies of the impact of brain lesions on the processing of the metaphorical meaning of words according to age, and on its recovery, are clearly needed.

Interestingly, in the younger group, none of the typical regions associated with the processing of metaphors (inferior frontal gyrus, opercular and triangular parts; superior, middle, and inferior temporal gyrus; precuneus; temporal pole; hippocampus) were significantly activated, and neither was the RH activated exclusively. This disparity could be the result of a very precise contrast allowing the identification of the specificity of the processing of metaphors in opposition to that of literal meanings. In fact, studying the conventional metaphorical meanings of words could be the best way to eliminate possible confounds related to sentence context and novelty. However, one has to question the validity of conventional metaphorical meaning as an expression of a truly neuropragmatic event, since, in this case, the metaphorical meaning is probably lexicalized and does not require context-dependent processing.

In contrast to the consistencies of the present study with the HAROLD phenomenon, our results seem to conflict with the PASA phenomenon. In fact, the PASA phenomenon seems to be challenged by studies looking at linguistic abilities. For example, Ouellet-Plamondon et al. (*submitted*) reported a shift in the direction opposite to that described by the PASA phenomenon when both older and younger adults performed a semantic judgment task. Similarly, the results obtained in the present study showed significant activations of posterior brain areas (right posterior cingulate gyrus) in the older group for the contrast [MT – LT] that were not observed in the younger group. It is important to consider that, in contrast to most other cognitive functions, language has been recognized as being preserved or even improving with age. More specifically, Bonnaud et al. (2002) reported a better performance by older adults compared with younger ones when identifying the metaphorical relationships between words. This consideration is of great relevance when attempting to understand the direction of the changes described in the present study. In this context, our results provide clues about the direction of the activation shift when (1) a bilateral frontal activation is already present in young adults and (2) language processing is implicated.

5. Conclusions

In conclusion, this study suggests that the neural bases for processing the conventional metaphorical meaning of words require more than a right-hemisphere-based neural network. Moreover, this network appears to evolve with age, as it is more widespread and involves different brain areas in older adults with similar performances. These results may reflect some of the neurofunctional reorganization that occurs with age and supports the general notion of cognitive reserve (Stern 2009). Alternatively, they may be the expression of neural compensation and/or of recourse to a different cognitive strategy. In any case, despite the complexity of the questions, this study shows the interest of studying the neural bases of nonliteral language abilities as a vivid example of the complexity and multideterminism of the neurofunctional organization of the brain engaged in every-day social behaviour.

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