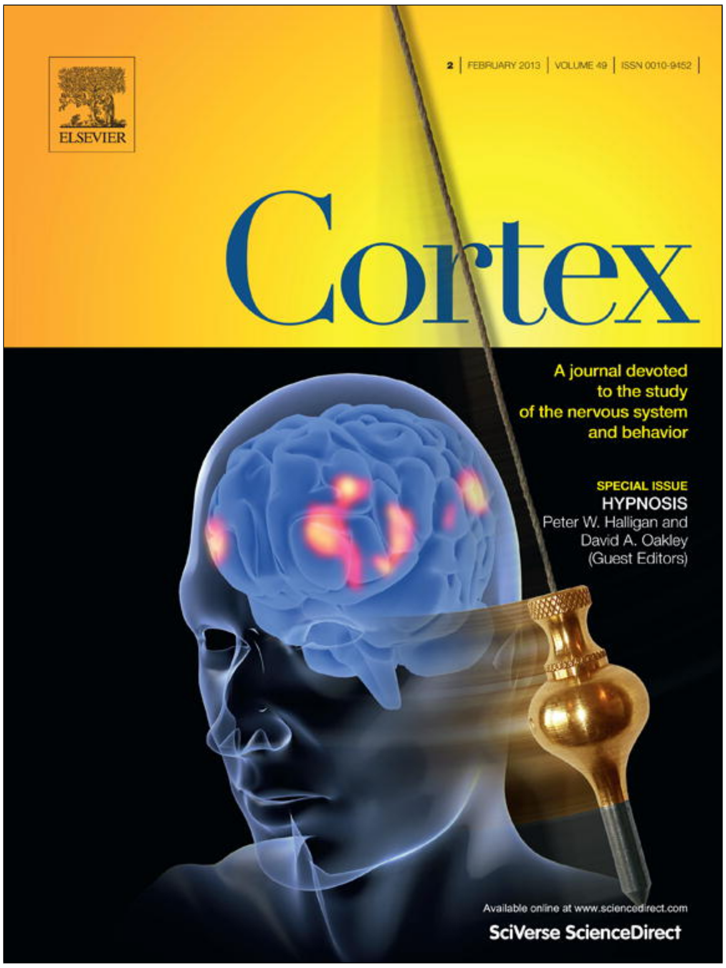
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Letter to the Editor

A neural interactive location for multilingual talent

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1. Introduction

In the recent book "Babel No More", Michael Erard (2012) provides a fascinating survey of the world's most extraordinary language learners such as the 19th-century Italian Cardinal Mezzofanti who reportedly spoke 50 languages. The author questions the cornerstone upon which multilingualism is built in the human brain and suggests that this remarkable ability should "change the brain making it different from the average one". It is interesting to know that already in the early 1900s, the German neurologist Pötzl (1925) stated that the brains of multilinguals should be somehow exceptional pointing to the left lower parietal region (LIPL) as the so-called "language talent area". His hypothesis was based upon observations of lesions in a specific area (area PGa, i.e., anterior Angular Gyrus) disrupting the ability to switch between languages. Related to the LIPL, it was recently reported that early bilingualism is associated to increased gray matter (GM) density in this region (Mechelli et al., 2004).

Compelling recent functional Magnetic Resonance Imaging (fMRI) evidence has established that the LIPL is also recruited to fulfill cognitive demands other than language especially in the context of attentional tasks. The lateral inferior parietal cortex has been shown to make a significant functional contribution in both attentional focalization and target detection mechanisms in the auditory (Shomstein and Yantis, 2006) and visual modalities (Marois et al., 2000), suggesting that it may subserve general attention processes that are modality independent (Green et al., 2011).

Nowadays, there is a growing body of evidence showing that a lifelong bilingual experience leads to benefits in several cognitive domains and protects against general cognitive decline (Bialystok et al., 2012) suggesting a cognitive blending of executive functions and bilingual expertise (but see also Calabria et al. (2012) for qualitative differences between executive functions and bilingualism).

We suggest that growing up with two or more languages and the cognitive demands imposed by the necessity to attentively 'monitor' the specific features of the various languages could be complemented by plastic alterations in the LIPL, fundamentally involved in both building phonological percepts (Golestani and Zatorre, 2004) and subserving attention functions and directly linked to the development of cognitive advantages traced in adulthood or in older age. Given this consideration, we hypothesized that the LIPL may represent the site for dynamic interchange between multilingualism and the neural development of this neurocognitive advantage. Our prediction was that, given (a) the ability to *learn a second* language increases GM volume in the LIPL (Mechelli et al., 2004) and (b) the ability to *use* more than one language tunes other cognitive functions in the brain such as attentional control (Abutalebi et al., 2012) a "multilingual talent interaction effect" (MTIe) between multilingualism and cognitive skills such as attentional control should arise in LIPL.

2. Methods

2.1. Participants

Fifteen healthy multilingual children (10 boys, 5 girls) (mean age = 9.86; SD = 1.44 years) participated in the present longitudinal study (mean scan interval = .97 years, SD = .1 years). All children grew up in a multilingual environment in South Tyrol (Italy), where German, Italian, Ladin (and English

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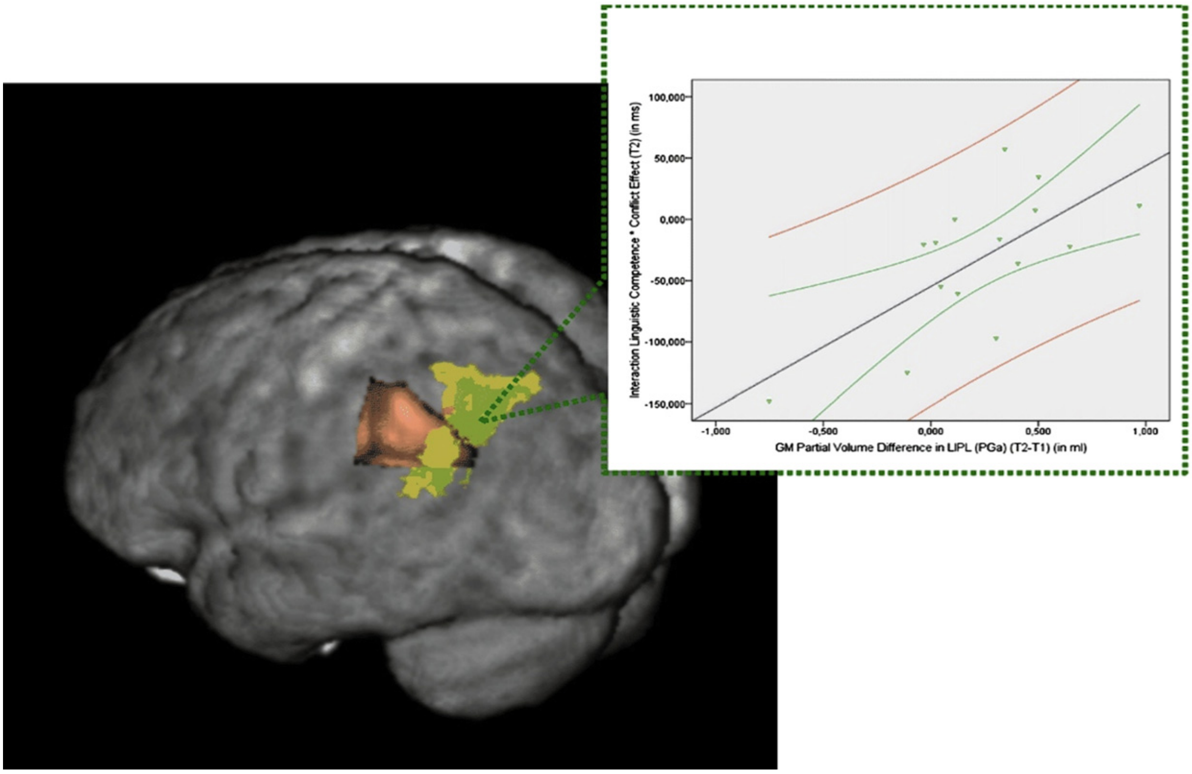

Fig. 1 – Partial correlation between "MTIe" and GM partial volume difference (T2 − T1) in LIPL (PGa) controlling for differences between GM whole-brain ratio terms (T2 − T1) calculated on the median GM whole-brain value at each time point. The YELLOW area represents the probabilistic cytoarchitectonic PGa area. The GREEN area represents the mean image of the intersection between each subjects GM segmented normalized image and the PGa "mask" image. The RED area represents the peak coordinate ($x = -48$, $y = -59$, $z = 46$) of correlation between GM density and early bilingualism in LIPL as reported in Mechelli et al. (2004). Overlays are rendered on the mean structural image of the study sample averaged across both measurement time-points (T1 & T2) with MRIcron [http://www.sph.sc.edu/comd/rorden/mricron/].

learned at school) are spoken and used. Group socio-linguistic features (including age of acquisition, exposure, proficiency, language dominance and use of the single languages) of the 4 languages characterizing the multilingual background of all subjects are reported in Supplementary Table 1. Written informed consent was obtained from all participants and the local ethics committee approved the present study, in compliance with the Helsinki Declaration.

2.2. *Design and procedure*

We used a longitudinal study design with a structural T1-weighted image of the brain acquired at two measurement time-points (see Supplementary materials for acquisition details), while each participant was tested on the Attentional Network Task (ANT)-task (see Supplementary Fig. 1 and Abutalebi et al., 2012 for a full description). In short, they were asked to respond as quickly and as accurately as possible to whether a central arrow (the target) pointed to the right or left. Both accuracy and reaction times (RTs) were recorded.

2.3. *Statistical analysis*

Given our purpose we focused on three measures: 1) the conflict effect (CE) (RT difference between incongruent–congruent trials) (see Supplementary Fig. 1); 2) the "global" multilingual competence (gMC) corrected score for each participant calculated by subtracting the mean value of all marks (total school outcome) from the mean value of the marks related to all languages (gMC) (Franceschini, 2011; Videsott et al., 2012) to capture specific differences related to linguistic competence that are not influenced by general higher competence; 3) the multilingual talent interaction effect (MTIe) representing the combined effects of the CE and the gMC calculated as the cross-product term between the two measures in order to verify if the way GM values in the LIPL may vary with a behavioral measure of attentional control (i.e., CE measures) depends on the natural development of MC over time.

Unmodulated and normalizedGM maps were also created from the T1-weighted structural image, following image segmentation. We then delineated the exact landmark of the hypothetical Multilingual Talent Area in the LIPL close to the center of gravity of area PGa (overlap with Mechelli's area = 70%) based on Pötzl's hypothesis. Partial GM volumes were computed from the PGa area of the LIPL for each subject and an estimate of total GM volume change over the two measurement points was calculated (see Supplementary material for details).

First a correlational analysis was performed to determine the nature of the relationship between the MTIe and both the CE measure and the gMC score.

Second, to directly test for an exclusive relation between the MTIe and LIPL GM differences over time, we determined partial correlation coefficients between interaction effect scores and partial Gray Matter volume (GMv) difference values (in ml) extracted from the PGa area of the LIPL while controlling for an estimate of total GM volume change over the two measurement points (see Supplementary Material online for methods).

Third, to examine the unique contribution of the MTIe in the prediction of GMv changes in the PGa area of the LIPL, a hierarchical multiple regression analysis was performed including both the CE measure and the gMC score as independent variables in step 1 and the MTIe (product term) in step 2.

3. Results

First, a significant positive correlation between the MTIe and the gMC score was highlighted ($r = .828$; $p < .0001$). On the contrary, the relationship between the interaction effect and the CE was negative ($r = -.543$; $p = .036$).

Second, the zero-order positive correlation between partial GMv differences in LIPL (T2 − T1) and the MTIe measured at T2 was $r\ (13) = .682$, $p = .005$, which remained effectively significant when controlling for individual differences between GM whole-brain ratio terms (T2 − T1) (as a measure of nonspecific effects on GMv changes), partial $r\ (12) = .620$, $p = .018$.

Third, the results of step 1 indicated that the variance in GMv in LIPL accounted for (R^2) with the two independent variables (CE and gMC) equaled .503 (adjusted $R^2 = .444$), which was significantly different from zero (F change $= 6.198$, $p = .016$). The change in R^2 by the addition of the multilingual interaction term in step 2 was significant (R^2 change $= .162$, adjusted $R^2 = .599$, F change $= 5.255$, $p = .045$) and in the second model only the MTIe contributed significantly to the explanation of GMv in LIPL ($\beta = .982$, t-value $= 2.292$, $p = .045$), while neither CE measures ($p = .180$) or MC scores ($p = .311$) alone no longer predicted partial GM values in LIPL to a statistically significant degree (see Fig. 1).

4. Discussion

In summary, the MTIe clearly captures the inverse relationship between gMC and the CE. In other words, higher levels of gMC correspond to a reduced CE. In addition, we show that the combined effect of MC and the CE coded in the MTIe is exclusively related to GMv changes occurring over time (differences between GM values measured at T2 as compared into T1) in the PGa area, while taking in account physiological changes naturally occurring during neural development. Finally, the hierarchical multiple regression underlines that the interaction effect is present and is the only significant predictor of GMv differences in PGa, clearly demonstrating that the change in GM values in LIPL depends on the inverse relationship between CE measures and gMC scores.

These results indicate that multilingualism is associated with structural adaptations in a brain region ruled by a more general structure–function principle. We suggest that this LIPL structural plasticity traced in early childhood is the result of dynamic functional requirements (i.e., attention, memory and phonological categorization functions) that are necessary for developing high levels of MC with the effect of enhancing attention functions deployed in order to monitor and control the different languages being spoken (see Bialystok, 1999).

We can, hence, strongly ascertain that multilingual talent not only can express itself as the ability to speak more than two languages but carries in itself specific changes to the brain in childhood, leading to potential cognitive profits, such as the ability to control attention (Abutalebi et al., 2012), and that speakers growing up with several languages can gain over the course of their life.

Competing financial interests

The authors declare no competing financial interests.

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Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.cortex.2012.12.001.

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