The Neural Locus of the Bilingual Advantage

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INTRODUCTION

Executive Control:

- Executive control (EC) comprises cognitive functions like task maintenance, response selection and/or suppression, conflict detection and resolution, and inhibitory control.
- EC tasks activate a network of brain areas including the left inferior frontal gyrus (LIFG), anterior cingulate cortex (ACC), middle frontal gyrus (MFG), and other areas of the prefrontal lobe (Nee et al., 2007; Niendam et al., 2012).

The 'Bilingual Advantage':

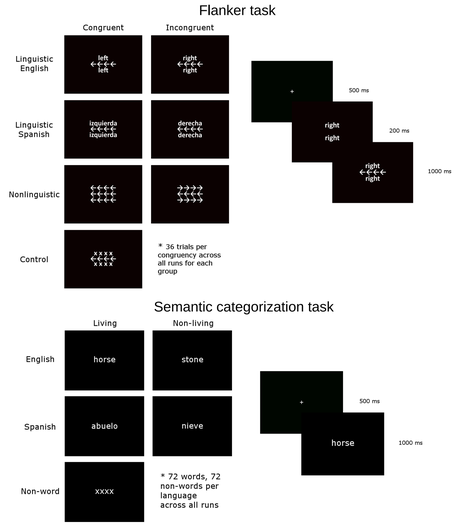
- Compared to monolinguals, bilinguals show:
  - Smaller interference effects on linguistic and non-linguistic conflict tasks like the Stroop and Simon (Bialystok et al., 2009), suggesting better conflict resolution abilities.
  - Faster overall RTs on all trials, suggesting better monitoring abilities even in the absence of conflict (Hilchey & Klein, 2011).
- The bilingual advantage is thought to arise from the experience of monitoring language context and controlling cross-linguistic influences: bilinguals recruit EC brain areas during language processing (van Heuven et al., 2008; Rodriguez-Fornells et al., 2005), and language processing areas during (non-linguistic) EC tasks (Garbin et al., 2010).
- The interplay of language and EC may affect the functional organization of these networks in bilingualism, such that they develop an interdependence on each other (Hernandez, 2009). If the language and EC networks overlap to a greater degree in bilinguals, this could explain the neural basis of the bilingual advantage.

The Current Study:

- Using fMRI and conjunction analyses, the current study identified brain regions commonly activated by linguistic EC, non-linguistic EC, and language processing. If the language and EC networks evolve together during bilingual development, such that bilinguals use language areas for EC and vice versa, a conjunction analysis should yield greater overlap for these three tasks in bilinguals compared to monolinguals.

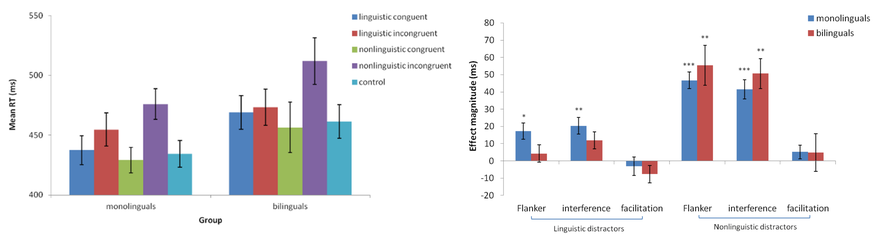
METHODS

- 15 native English monolinguals (9 female), mean age 25 (SD = 3)
- 14 Spanish-English bilinguals (8 females), mean age 24 (SD = 6)
  - Spanish proficiency = 9.1/10
  - English proficiency = 9.7/10
- EC processing: Flanker task with linguistic (words) and non-linguistic (arrows) distractors
- Language processing: semantic categorization task
- Bilinguals tested in Spanish and English over 4 runs in each task (2 runs per language); monolinguals tested in English over 2 runs in each task.
- Siemens Skyra 3T, TR 1600, TE 28ms, voxel size 3.3 x 3.3 x 3.5, 30 slices, no gap, FOV 210mm, matrix size 64x64.
- Analyses performed using SPM8, Marsbar, WFU Pickatlas. All flanker analyses at $p < 0.001$ uncorrected, semantic categorization analyses at $p < 0.0001$ uncorrected, cluster threshold 20 voxels.



BEHAVIORAL RESULTS

- Both groups showed significant Flanker (incongruent vs. congruent) and interference (incongruent vs. control) effects in all distractor conditions. Larger conflict effects occurred in non-linguistic conditions.
- There was no behavioral evidence for a bilingual advantage in interference effects ($p = 0.76$) or global RTs ($p = 0.15$), although numerically, bilinguals showed smaller linguistic interference effects.



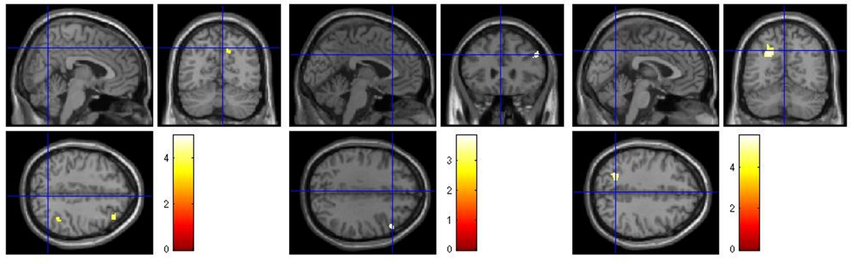
fMRI RESULTS

Flanker task

- For both groups, non-linguistic conditions generated smaller neural effects than linguistic conditions. Neither group showed any significant activation for non-linguistic conflict (Flanker or interference effects).
- Group comparisons in linguistic conflict (Flanker and interference effects):
  - Bilinguals > monolinguals: activation in EC areas like the RMFG/cingulate (BAs 9/10/11/32), bilateral MFG (BA 9/32), and LIFG (BA 45/46).
  - Monolinguals > bilinguals: R angular gyrus/superior parietal lobe (BA 40).
- To assess global effects of linguistic and non-linguistic EC, the distractors were collapsed over congruencies (e.g. (linguistic incongruent + linguistic congruent) > control). Group comparisons showed:
  - Linguistic EC, monolinguals > bilinguals: RMFG (BAs 8/9/10/46), R inferior parietal lobe/angular gyrus (BA 40), R superior parietal lobe (BA 7)
  - Nonlinguistic EC, monolinguals > bilinguals: RMFG (BA 9).
  - Bilinguals > monolinguals showed no significant activation in either type of EC.

Semantic categorization task

- Both groups activated canonical areas of the language network such as the LIFG (BAs 45/46/47) and left superior parietal lobe/angular gyrus (BA 40).
- Group comparisons showed stronger activation for bilinguals in the L superior parietal lobe/angular gyrus (BA 40), a typical area of language processing (Binder et al. 1997), which could suggest more effortful language processing for bilinguals (Kovelman et al., 2008).



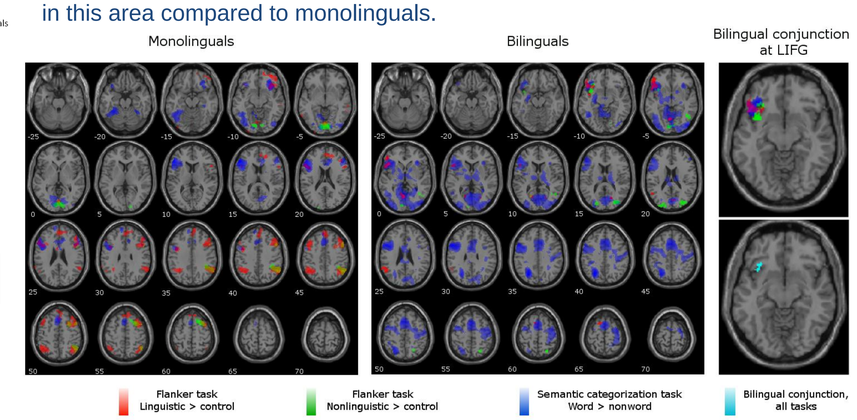
Flanker task: Linguistic EC (collapsed over congruencies) Monolinguals > bilinguals

Flanker task: Non-linguistic EC (collapsed over congruencies) Monolinguals > bilinguals

Semantic categorization task: Word vs. nonword Bilinguals > monolinguals

Conjunction analyses:

- To investigate the overlap of domain-general EC, regardless of the presence of conflict, conjunction analyses were performed using the task-vs.-control contrasts collapsed over congruency (linguistic distractors > control; non-linguistic distractors > control; words > non-words).
- The monolingual conjunction showed no significant areas of activation.
- The bilingual conjunction showed a cluster of activation in the LIFG.
- This LIFG cluster also showed a group effect in a 2 (group) x 3 (task) ANOVA, such that bilinguals showed greater mean activation (collapsed across all tasks) in this area compared to monolinguals.



DISCUSSION

- In bilinguals, the LIFG was activated by all three tasks, and to a greater overall extent than in monolinguals.
- The LIFG has previously been implicated in both linguistic EC (Kovelman et al., 2008) and domain-general EC (Ye & Zhou, 2009) and language processing (Costafreda et al., 2006).
- Monolinguals did not show any significant areas of activation in the conjunction, suggesting more disparate networks of language and EC.
- In contrast to previous research, no behavioral bilingual advantage was observed. Due to the novelty of this flanker task, interpretations of this data are tentative; more research with this paradigm is needed.

CONCLUSIONS

- The LIFG was identified as the neural locus of the bilingual advantage, as it was the site of functional overlap for linguistic EC, non-linguistic EC, and language processing for bilinguals but not for monolinguals.
- The broad involvement of the LIFG in cognitive control and language processing may selectively enhance this structure in bilinguals, reciprocally enhancing domain-general executive processing. This suggests a fundamental interdependence of the EC and language systems in bilingualism.

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