

# Partially shared neural mechanisms of language control and executive control in bilinguals: Meta-analytic comparisons of language and task switching studies

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## ABSTRACT

The extent to which bilingual language control (BLC) is related to domain-general executive control (EC) remains unclear. The present study applied activation likelihood estimation (ALE) meta-analyses to identify commonalities and distinctions in the brain regions across domains reported in neuroimaging studies. We specifically compare results from two experimental tasks: language switching, a typical measure of BLC, and task switching, an experiment that measures EC. Conjunction analyses showed a domain-general pattern between language switching and task switching, with convergent activity in the left dorsolateral prefrontal cortex (DLPFC), pre-SMA/dACC complex (pre-supplementary motor area/dorsal anterior cingulate cortex), and left precuneus. Regarding domain-specificity, contrast analyses revealed stronger convergence of activation in the left fusiform gyrus and occipital gyrus in language switching compared to task switching, and conversely, stronger convergence of activation in the left DLPFC in task switching. Overall, these findings illustrate the partially overlapping nature of the neural circuits involved in BLC and EC.

## 1. Introduction

On a daily basis, bilinguals appear to effortlessly manage ‘two languages in one mind’ while speaking and listening. Many bilinguals also demonstrate the ability to switch fluently between their two languages or speak in one language without apparent intrusions from the other. The general consensus regarding how language switching proceeds is that bilinguals recruit at least some mechanisms of executive control (EC) to manage language switching (Bialystok et al., 2009; Hernandez, 2009). However, the extent to which these two control processes interact remains unclear. While some behavioral (e.g., Declerck et al., 2017; Timmer et al., 2018; Timmer et al., 2019), electrophysiological (Declerck et al., 2021; Timmer et al., 2017), and neuroimaging (e.g., De Baene, Duyck, Brass and Carreiras, 2015; Weissberger et al., 2015) studies have demonstrated shared mechanisms of bilingual language control (BLC) and EC, others have argued that there is little overlap between these two domains of control (Branzi et al., 2016a; Calabria et al., 2015; Calabria et al., 2012; Cattaneo et al., 2015; Prior and Gollan, 2013).

To explore the relationship between BLC and domain-general EC, we conducted activation likelihood estimation (ALE) meta-analyses on previous studies to identify commonalities and differences of neural correlates for BLC and EC. Given that BLC is typically measured through language switching tasks (for a review, see Declerck and Philipp, 2015) and EC is often measured using task switching tasks (for reviews see Kiesel et al., 2010; Vandierendonck et al., 2010), we first performed two separate ALE meta-analyses of neuroimaging studies on language switching or task switching and tested for brain regions associated with each domain. We then conducted conjunction and contrast analyses which allowed us to examine the degree of neural overlap across language and task switching as a continuum (i.e., completely overlapping, partially overlapping, or non-overlapping).

### 1.1. Bilingual language control and language switching

Language control for bilingual speakers is responsible for selecting a target language, as appropriate depending on the context, and avoiding interference from the nontarget language (Declerck and Philipp, 2015;

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Liu et al., 2021a, b, c, d; Liu et al., 2019a; Liu et al., 2019b; Liu et al., 2020). The language switching task is an often-used experiment to examine BLC processes (for a review, see Declerck and Philipp, 2015). In the language switching task, bilinguals name individually-presented trials of pictures or digits in their first (L1) or second language (L2) based on visual language cues (e.g., national flags). The task creates a situation in which bilinguals must either switch from the language currently being used to the other language (switch trials) or stay in the same language (repetition trials). A “language switch cost”—calculated by the difference in response times (RTs) and/or accuracy between trial types (switch trials vs. repetition trials)—has been widely used as a psychological index of language control (Green, 1998).

To shed light on the brain activity that is associated with BLC, researchers have conducted fMRI and PET studies on bilingual language switching tasks (e.g., de Bruin et al., 2014; Guo et al., 2011; Liu et al., 2021a, b, c; for a review, see Calabria et al., 2018). Abutalebi and Green (2008) proposed a neurocognitive model of bilingual language switching, which consisted of five brain regions for bilingual language switching: the left dorsolateral prefrontal cortex (DLPFC), anterior cingulate cortex (ACC), caudate nucleus, and bilateral supramarginal gyri (SMG). Subsequent studies conducted quantitative meta-analyses to identify the critical brain regions related to language switching (Luk et al., 2012; Sulpizio et al., 2020; Tao et al., 2021). Although there have been inconsistencies in the identified BLC network reported in these meta-analyses, it is agreement that the brain regions involved in BLC mainly comprise the dorsal ACC/pre-supplementary motor complex (i.e., dACC/pre-SMA complex), the left PFC, the left caudate, and the bilateral inferior parietal lobules (IPL) (for a review, see Calabria et al., 2019).

## 1.2. Domain-general executive control and task switching

Domain-general EC refers to the ability to carry out goal-directed behavior using a set of cognitive processes (e.g., inhibition, working memory, and cognitive flexibility) (Diamond, 2013). The task switching task is most often used to examine the cognitive flexibility component of EC processes (Diamond, 2013). In contrast to the language switching task performed by bilinguals, in a task switching experiment, participants switch between distinct task sets (e.g., switching between naming colors or shapes) instead of between different languages. A “task switch cost”—calculated by the difference in response times (RTs) and/or accuracy between trial types (switch trials vs. repetition trials)—has been widely used as a psychological index of measure of EC (Monsell, 2003). In the present study, there are two reasons as to why we focused on task switching instead of another measure of EC. First, among all the components of EC process, task switching has the greatest similarity with language switching. Second, a multitude of studies seeking to compare BLC to EC have done so by using language switching and task switching tasks (De Baene et al., 2015; Weissberger et al., 2015).

The neural correlates of task switching have been investigated in several studies (e.g., Braver et al., 2003; De Baene and Brass, 2011; Gold et al., 2013). In one meta-analysis, Kim et al. (2012a) identified a distributed network of brain regions associated with task switching, including medial and lateral PFC and parietal, temporal, and occipital cortices, as well as subcortical structures (i.e., caudate and thalamus). However, only the inferior frontal junction (IPJ) and posterior parietal cortex (PPC) were common areas associated with different types of task switching. Moreover, evidence from recent studies suggested that, although there was an agreement that frontal and parietal regions were typically responsible for the task switching, the observed specific brain regions associated with task switching across studies were rather complex and inconsistent (Kim et al., 2012b; Tao et al., 2021; Wager et al., 2005; Woringer et al., 2019).

## 1.3. The relationship between bilingual language control and executive control

In the bilingual literature, the well-known inhibitory control model (ICM) assumes that language control occurs between task schemas (Green, 1998) and a domain-general mental process used to achieve a specific goal. Among the claims put forth by the ICM is the possible link between BLC and EC. Following the ICM, the more recent multiple-demand (MD) hypothesis further suggested that BLC may share neural mechanisms with domain-general EC (Duncan, 2010; Fedorenko et al., 2013). Specifically, the MD hypothesis proposed an extensive domain- and process-general frontoparietal network involved in the processing of diverse cognitive tasks. This network appears to be more active when cognitive demands are higher in a variety of tasks including working memory, task switching, conflict monitoring, language switching, among others (Assem et al., 2020; Fedorenko et al., 2013). These findings imply that BLC and EC may share some neural bases, such as in the frontoparietal network as implicated argued by the MD hypothesis. Taken together, the ICM and MD hypotheses both posit that BLC and EC may rely on similar neural circuits. However, there have been inconsistent findings in subsequent studies on the relationship between BLC and EC (Branzi et al., 2016a; Declerck et al., 2017).

Previous research examining the interaction between BLC and EC have mainly used three research designs to compare bilinguals' performance in language switching and task switching. Correlational studies, in which the relationship is examined between language switching costs and task switching costs (e.g., Calabria et al., 2012; Declerck et al., 2017; Prior and Gollan, 2013). The logic behind this experimental design is that if the language switching and task switching share cognitive mechanisms, then bilinguals' performance in the two tasks should correlate to some extent. Training studies explore whether bilinguals' performance in task switching is affected by explicit training in language switching (e.g., Liu et al., 2019c; Liu et al., 2016; Timmer et al., 2019). The inference that can be drawn from this design is that if training in language switching influences task switching performance, both domains share some cognitive processes. Finally, neuroimaging methods are also used to examine the cross-talk between language switching and task switching (e.g., De Baene et al., 2015; Weissberger et al., 2015). In fMRI studies, comparing brain activity in language versus task switching tasks provides illustrative data on the overlap of these two domains. Although these three methodological approaches have furthered our understanding of the relationship between BLC and EC, it is unclear as to whether they completely overlap, partially overlap, or do not overlap at all.

## 1.4. The present study

The main goal of the present study was to explore the degree of neural overlap between BLC and EC. We conducted a systematic literature search of the neuroimaging studies on language switching and task switching and conducted ALE meta-analyses separately for language switching and task switching experiments to identify brain activation patterns associated with the two tasks. We then conducted conjunction and contrast analyses on the two above meta-analytic maps to assess their neural commonalities and differences.

We hypothesize that our meta-analyses will reveal partially overlapping neural activation patterns for language switching and task switching. Specifically, we expect neural correlates of the two tasks to converge in the frontoparietal regions (such as DLPFC, IPL, and pre-SMA/dACC complex) as predicted by the MD hypothesis (Duncan, 2010). Moreover, based on previous fMRI studies on these two types of switching tasks (e.g., Kim et al., 2012a; Luk et al., 2012; Sulpizio et al., 2020; Tao et al., 2021), we hypothesize that there will also be divergent brain regions activated in each task.

## 2. Materials and methods

### 2.1. Literature search and exclusion criteria

A literature search was conducted in the Web of Science and PubMed databases until November 2020 using the terms “language switch\*” or “task switch\*” in combination with “neuroimaging”, “brain imaging”, “fMRI” or “PET”. A total of 457 studies (239 from PubMed and 218 from Web of Science) employing language switching and 2208 studies (1137 from PubMed and 1071 from Web of Science) using task switching were obtained. Additional studies (three studies for language switching and four studies for task switching) were also identified in relevant review articles. After removing duplicates, 300 language switching studies and 1402 task switching studies were retained.

The candidate studies were first screened by their titles and abstracts. Studies containing any of the following characteristics were excluded from further analyses: (1) not published in English; (2) did not use fMRI or PET; (3) did not include healthy human participants; (4) not primarily focused on language switching or task switching; (5) did not report whole brain results; (6) did not provide coordinates of brain areas. After applying these exclusion criteria, a total of 64 language switching studies and 142 task switching studies remained. These remaining studies were screened by their full-texts using the same six exclusion criteria. The final sample in our meta-analyses includes 19 language switching studies (31 experiments and 209 foci in total) and 41 task switching studies (46 experiments and 507 foci in total) (see Fig. 1 and Table 1).

### 2.2. Activation likelihood estimation

We used GingerALE V3.0.2 (<http://brainmap.org/ale/>) to conduct coordinate-based meta-analyses using the modified activation-likelihood estimation (ALE) algorithm (Eickhoff et al., 2009; Turkeltaub et al., 2012). The modified ALE algorithm takes the maximum probability associated with any one focus reported in an experiment, with a “Non-Additive” correction to minimize within-experiment effects (Turkeltaub et al., 2012). GingerALE compares foci compiled from multiple neuroimaging studies, estimates the probability of the spatial

distribution of coordinates, and then calculates the functional convergence of these probabilities. Before the analyses, we converted the coordinates reported in the Talairach space to the MNI space using the “convert Foci” tool within GingerALE. To identify consistent brain activation for language switching and task switching, two separate meta-analyses were conducted. ALE maps were thresholded at an uncorrected  $p < .001$  with 1000 permutations and a minimum cluster size of  $150 \text{ mm}^3$ , in accordance with previous meta-analyses on bilingual language processing (Sulpizio et al., 2020; Tao et al., 2021). Furthermore, to identify commonalities and distinctions in active brain regions during language and task switching, we also performed conjunction and contrast analyses in GingerALE. Based on previous practice in meta-analyses (e.g., Tao et al., 2021), the correction for conjunction and contrast analyses was thresholded at an uncorrected  $p < .01$  with 5000 permutations and a minimum cluster size of  $100 \text{ mm}^3$ .

### 2.3. Data visualization

For visualization purposes, BrainNet Viewer (Xia et al., 2013) was used to reproduce the figures below.

## 3. Results

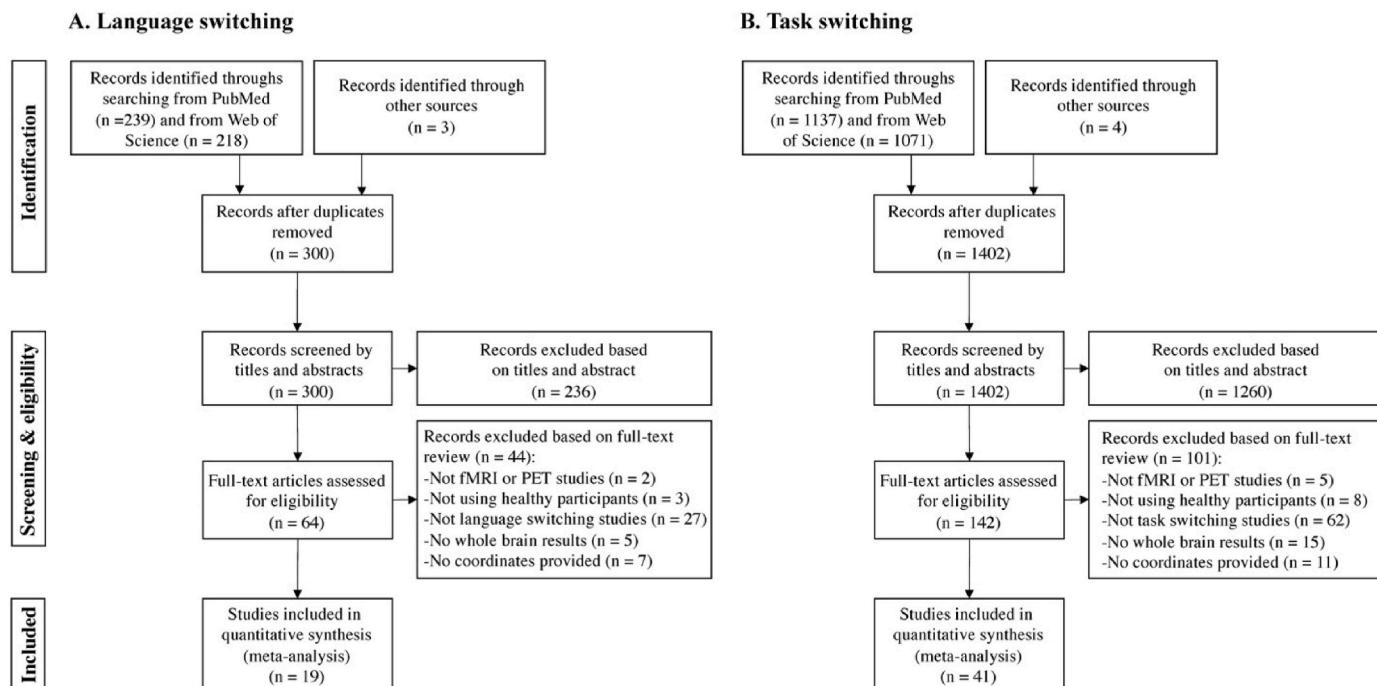
### 3.1. Separate meta-analyses on language and task switching studies

#### 3.1.1. Language switching

The meta-analysis of 31 language switching experiments showed a subset of activated clusters associated with language control (see Table 2 and Fig. 2), including the left precentral gyrus extending into the inferior frontal gyrus (IFG) and middle frontal gyrus (MFG), pre-SMA/dACC complex (BA 6/24), left caudate, right STG, occipital areas comprising bilateral middle occipital gyrus (MOG), bilateral fusiform and lingual gyrus, parietal areas comprising left superior parietal Lobule (SPL), bilateral precuneus (BA 7), and the left cerebellum.

#### 3.1.2. Task switching

The meta-analysis of 46 task switching experiments showed significantly converging activation in the left IPL extending into the precuneus



**Fig. 1.** PRISMA flow diagram of the literature selection for (A) language switching tasks and (B) task switching tasks.

**Table 1**

Language switching and task switching studies included in the meta-analyses.

	Participants	Age (mean or range)	Method	Tesla strength	Contrast	Stimuli	Foci
<b>Language switching (N = 19)</b>							
De Baene et al. (2015)	32	22.4	fMRI	3 T	Switch > non-switch	Pictures	4
de Bruin et al. (2014)	17	21.82	fMRI	1.5 T	Switch > non-switch	Pictures	5
Fu et al. (2017)	21	22	fMRI	3 T	Switch > non-switch	Pictures	4
Garbin et al. (2011)	19	20	fMRI	1.5 T	Switch > non-switch	Pictures	35
Guo et al. (2011)	24	—	fMRI	3 T	Switch > non-switch	Pictures	44
Hernandez (2009)	12	21.04	fMRI	3 T	Switch > non-switch	Pictures	4
Hernandez et al. (2001)	6	21.07	fMRI	3 T	Switch > non-switch	Pictures	3
Hosoda et al. (2012)	20	26.1	fMRI	3 T	Switch > non-switch	Digits	12
Kang et al. (2017)	16	22.1	fMRI	3 T	Switch > baseline	Pictures	5
Ma et al. (2014)	22	22.6	fMRI	3 T	Switch > baseline	Pictures	10
Price et al. (1999)	6	30.5	PET	—	Switch > non-switch	Words	3
Reverberi et al. (2015)	23	23.01	fMRI	3 T	Switch > non-switch	Pictures	8
Stasenko et al. (2020)	24	20	fMRI	3 T	Switch > non-switch	Words	5
Wang et al. (2009)	15	20.5	fMRI	3 T	Switch > non-switch	Digits	11
Wang et al. (2007)	12	19.5	fMRI	1.5 T	Switch > non-switch	Pictures	15
Weissberger et al. (2015)	20	21	fMRI	3 T	Switch > baseline	Digits	10
Zhang et al. (2014)	21	24.38	fMRI	3 T	Switch > non-switch	Words	8
Zhang et al. (2019)	22	19.9	fMRI	3 T	Switch > non-switch	Pictures	11
Zhang et al. (2015)	16	21.3	fMRI	3 T	Switch > non-switch	Digits	12
<b>Task switching (N = 41)</b>							
Badre and Wagner (2006)	10	18–25	fMRI	3 T	Switch > non-switch	Number-letter pairs	9
Barber and Carter (2005)	13	20–35	fMRI	3 T	Switch > non-switch	Letters	4
Braver et al. (2003)	13	19–26	fMRI	1.5 T	Switch > non-switch	Words	5
Chiu and Yantis (2009)	16	20–32	fMRI	3 T	Switch > non-switch	Digits	3
Crone et al. (2006)	19	—	fMRI	1.5 T	Switch > non-switch	Pictures	25
De Baene and Brass (2011)	19	22.0	fMRI	3 T	Switch > non-switch	Shapes and color	5
De Baene et al. (2015)	32	22.4	fMRI	3 T	Switch > non-switch	Pictures	7
Dibbets et al. (2010)	14	28.6	fMRI	1.5 T	Switch > non-switch	Pictures	3
DiGirolamo et al. (2001)	16	25/69	fMRI	1.5 T	Switch > non-switch	Digits	68
Dove et al. (2000)	16	21–29	fMRI	3 T	Switch > non-switch	Symbols	13
Garbin et al. (2010)	19	22.55	fMRI	1.5 T	Switch > non-switch	Shapes and color	9
Gazes et al. (2012)	47	25.2/65.2	fMRI	3 T	Switch > non-switch	Letters	18
Gold et al. (2013)	80	31.9/64.2	fMRI	3 T	Switch > non-switch	Shapes and color	7
Gu et al. (2008)	21	24.8	fMRI	1.5 T	Switch > non-switch	Icons	18
Halaris et al. (2009)	21	14–17	fMRI	1.5 T	Switch > non-switch	Arrows	8
Hedden and Gabrieli (2010)	17	21.6	fMRI	3 T	Switch > non-switch	Letters	22
Hosoda et al. (2012)	20	26.1	fMRI	3 T	Switch > non-switch	Digits	4
Jamadar et al. (2010a)	18	25	fMRI	1.5 T	Switch > non-switch	Letter-digit pairs	9
Jamadar et al. (2010b)	12	37.42	fMRI	1.5 T	Switch > non-switch	Letter-digit pairs	6
Kim et al. (2012b)	16	23.6	fMRI	3 T	Switch > non-switch	Arrows	20
Kimberg et al. (2000)	9	—	fMRI	1.5 T	Switch > non-switch	Letter-digit pairs	9
Liston et al. (2006)	19	—	fMRI	3 T	Switch > non-switch	Square-wave	11
Luks et al. (2002)	11	24–45	fMRI	1.5 T	Switch > baseline	Digits	4
Madden et al. (2010)	40	22.4/69.6	fMRI	3 T	Switch > non-switch	Words	11
Nee et al. (2011)	27	23.9	fMRI	3 T	Switch > non-switch	Faces and body part	3
Philipp et al. (2013)	23	26	fMRI	1.5 T	Switch > non-switch	Shapes and color	3
Piguet et al. (2013)	18	24.9	fMRI	3 T	Switch > non-switch	Faces and color	5
Ravizza and Carter (2008)	14	27.14	fMRI	3 T	Switch > non-switch	Letters and shapes	11
Rodehake et al. (2014)	213	14.6/25.2	fMRI	3 T	Switch > non-switch	Dot and arrows	7
Rodríguez-Pujadas et al. (2013)	36	23.06/23.67	fMRI	1.5 T	Switch > non-switch	Shapes and color	34
Ruge et al. (2005)	18	25.5	fMRI	3 T	Switch > non-switch	Squares	2
Smith et al. (2004)	20	28.7	fMRI	1.5 T	Switch > non-switch	Arrows	10
Sohn et al. (2000)	12	18–36	fMRI	1.5 T	Switch > non-switch	Letter-digit pairs	6
Wager et al. (2005)	39	18–40	fMRI	3 T	Switch > non-switch	Shapes	15
Weissberger et al. (2015)	19	21	fMRI	3 T	Switch > non-switch	Shapes and color	6
Witt and Stevens (2012)	134	19.5	fMRI	3 T	Switch > non-switch	Shapes and color	27
Witt and Stevens (2013)	83	22	fMRI	3 T	Switch > non-switch	Shapes and color	23
Woodcock et al. (2010)	8	20.7	fMRI	3 T	Switch > non-switch	Shapes and color	18
Wylie et al. (2006)	13	24.5	fMRI	1.5 T	Switch > non-switch	Shapes and color	18
Yeung et al. (2006)	15	19–24	fMRI	3 T	Switch > non-switch	Faces and words	12
Yoshida et al. (2010)	16	—	fMRI	1.5 T	Switch > non-switch	Shapes and color	9

and SPL, bilateral DLPFC (BA 9/46), pre-SMA/dACC complex (BA 6/32), bilateral insula, right precuneus, and right SPL (see Table 3 and refer back to Fig. 2).

### 3.2. Conjunction analysis

The conjunction analysis between language switching and task switching showed convergence of activation in the left DLPFC (BA 9), left precuneus (BA 7), and pre-SMA/dACC complex (BA 6/32) (see Fig. 3 and Table 4).

### 3.3. Contrast analyses

#### 3.3.1. Language switching vs. task switching

To identify the brain regions primarily associated with language and task switching, contrast analyses were conducted. The analyses revealed that language switching showed stronger activation in the left MOG extending into fusiform gyrus and inferior occipital gyrus compared to task switching (see Fig. 4 and Table 5).

**Table 2**  
Results of the meta-analysis on language switching studies.

Cluster	Region	R/L	BA	MNI coordinates			Volume (mm <sup>3</sup> )	Peak ALE value
				x	y	z		
1	Precentral Gyrus	L	6	-52	-2	42	2760	.023
	Inferior Frontal Gyrus	L	9	-50	8	32		.017
	Middle Frontal Gyrus	L	6	-52	8	42		.014
	Precentral Gyrus	L	6	-38	0	42		.011
2	Medial Frontal Gyrus	R	6	2	2	64	2352	.019
	Superior Frontal Gyrus	R	6	6	20	56		.018
	Superior Frontal Gyrus	L	6	2	18	66		.015
3	Fusiform Gyrus	L	19	-40	-80	-8	968	.025
4	Cuneus	R	18	10	-100	16	888	.017
5	Cuneus	R	17	22	-98	8		.015
6	Inferior Occipital Gyrus	R	19	48	-76	4	496	.016
	Middle Occipital Gyrus	R	19	46	-78	-6		.016
7	Precuneus	L	7	-10	-68	54	488	.015
8	Superior Parietal Lobule	L	7	-38	-56	56	416	.016
9	Fusiform Gyrus	R	19	32	-80	-10	392	.017
10	Lingual Gyrus	L	17	-8	-98	6	360	.015
	Lingual Gyrus	L	17	-8	-96	2		.015
11	Lingual Gyrus	R	18	10	-82	0	272	.017
12	Middle Occipital Gyrus	L	18	-18	-88	-6	264	.016
13	Posterior Cerebellum Declive	L	-	-26	-78	-12	240	.014
14	Precuneus	R	7	4	-68	42	216	.017
15	Caudate	L	-	-12	22	-4	208	.016
16	Superior Temporal Gyrus	R	21	66	-16	-6	200	.016
17	Cingulate Gyrus	L	24	-4	12	44	184	.015
18	Cingulate Gyrus	L	32	6	18	42	184	.014
	Anterior Cerebellum Lobe	L	-	-36	-56	-32	176	.014

### 3.3.2. Task switching vs. language switching

Compared to language switching, task switching showed stronger activity in the left DLPFC, which falls within the MFG structure (see Fig. 4 and Table 5).

## 4. Discussion

The present meta-analyses analyzed the degree of neural overlap between BLC and EC. Consistent with the ICM model and MD hypothesis, when comparing brain activation associated with switch costs from previous studies employing language switching and task switching tasks, conjunction analyses revealed three common brain regions—the left DLPFC, left precuneus, and pre-SMA/dACC—for both switching domains. Moreover, contrast analyses revealed that the left occipital gyrus and left fusiform gyrus were more activated in language switching, while the left DLPFC was more activated in task switching. Together, our analyses suggest that frontal-parietal regions play a critical role in both language and task switching, but that there are other regions specifically associated with language switching (i.e., left occipital gyrus, left fusiform gyrus) or task switching (i.e., left DLPFC). These findings underscore the partial overlapping nature of BLC and EC.

### 4.1. Commonalities and differences in brain regions associated with language switching and task switching

The finding that the convergence of left DLPFC, pre-SMA/dACC complex, and left precuneus is common in both language switching and task switching studies (De Baene et al., 2015; Tao et al., 2021). However, our findings also showed differences in the convergence of clusters between the two switching domains, which is somewhat inconsistent with a few studies included in this meta-analysis (De Baene et al., 2015; Weissberger et al., 2015). These brain regions will be discussed below in more detail.

#### 4.1.1. The left DLPFC

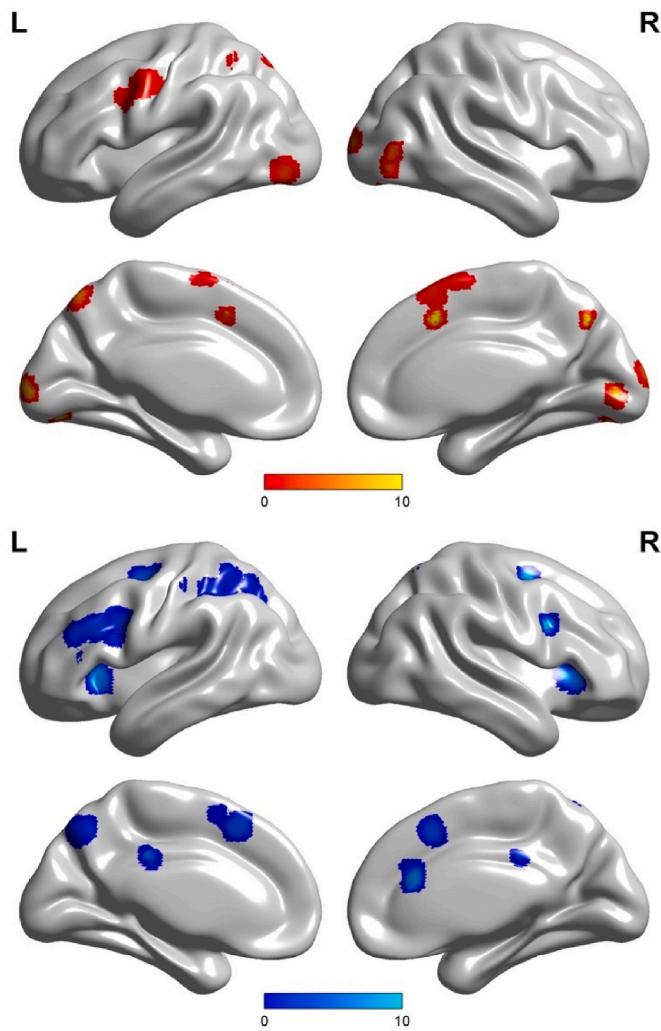
The left DLPFC (BA9) was consistently activated, with robust overlap between language and task switching. The left DLPFC is involved in a broad range of cognitive processes that are associated with domain-

general cognitive control, such as inhibition, task switching, and working memory (Tao et al., 2021). Notably, the left DLPFC is responsible for the implementation and maintenance of task sets by engaging conflict resolution processes (Hyafil et al., 2009). Because both language switching and task switching must overcome interference from the previously implemented task set, the left DLPFC may be recruited more strongly in switching compared to non-switching conditions. Evidence from MEG studies confirms the critical role of the DLPFC in both language switching and task switching. For instance, Blanco-Elorrieta and Pylkkänen (2016) directly compared neural correlates of language switching and category switching tasks. Their results showed that the DLPFC was active in both tasks.

Although there was an overlap in the left DLPFC (BA9) for language and task switching, our contrast analyses yielded stronger convergence of activation in the left DLPFC (BA9/46) for task switching compared to language switching. This implies that a broader range of the left DLPFC area was engaged in task switching versus language switching. We speculate that this discrepancy might be due to the fact that there are more variabilities in task switching than language switching. Moreover, the imbalanced number of language and task switching studies (31 and 46, respectively) in our analyses, as well as the larger number of variables in task switching, may have exacerbated the imbalance of variables between the two switching domains, leading to a broader area of the left DLPFC in task switching compared to language switching. However, future studies should be conducted to investigate whether this is the case.

#### 4.1.2. The pre-SMA/dACC complex

The pre-SMA/dACC complex was also consistently activated in both switching domains. The pre-SMA/dACC complex has been attributed to conflict monitoring and resolution in both linguistic and non-linguistic tasks (Botvinick et al., 2001; Calabria et al., 2018). The activity of the pre-SMA/dACC complex has been consistently reported when performing cognitive control tasks such as Stroop, flanker, or task switching experiments (Botvinick et al., 2004; Carter et al., 1999; Hyafil et al., 2009), as well as during language switching tasks (Branzi et al., 2016b; Liu et al., 2021a, b; Guo et al., 2011; Yuan et al., 2021). For example, Abutalebi et al. (2012) reported that the pre-SMA/dACC was the only



**Fig. 2.** Overview of significant clusters (uncorrected  $p < .001$  and cluster size  $> 150 \text{ mm}^3$ ) in the ALE meta-analysis for language switching (upper panel) and task switching (lower panel).

area common during highly proficient bilinguals' performance on a language switching task and a flanker task. Moreover, De Baene et al. (2015) compared the neural correlates of language and task switching and found that the pre-SMA was recruited in both tasks.

#### 4.1.3. The left IPL and precuneus

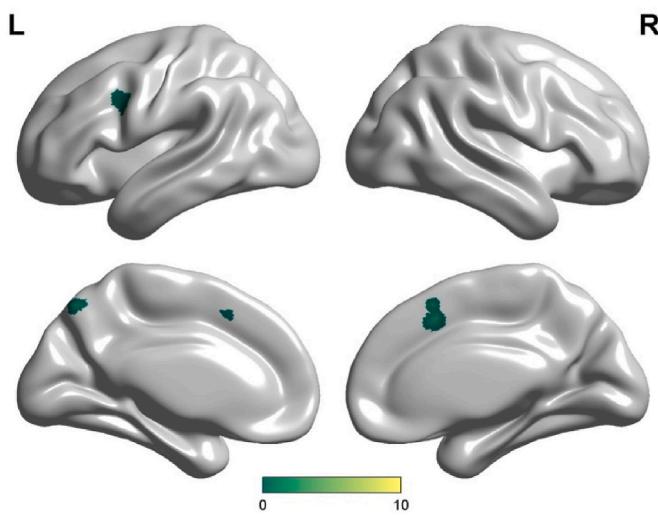
Contrary to our hypothesis, the left IPL was not consistently identified across language and task switching tasks. The left IPL is commonly associated with the maintenance of language and task representations (Abutalebi and Green, 2007; Calabria et al., 2019). During language and task switching, the left IPL is responsible for representing and maintaining cue-related potential response or stimulus-response mappings (Bunge et al., 2003; De Baene, Albers and Brass, 2012). From the present meta-analyses, however, we observed activation in the left IPL during task switching but not language switching. This may emerge because there was a relatively large number of experiments that reported left IPL involvement during task switching, but very few studies have found evidence of this during language switching. For language switching, the effect sizes were too small to produce the significant cluster required in our analyses. Nevertheless, left precuneus was consistently detected across the two switching domains. In line with previous studies (e.g., Barber and Carter, 2005), we argue that the consistent activation in the left precuneus during language and task switching reflects attentional shifting.

**Table 3**  
Results of the meta-analysis on task switching studies.

Cluster	Region	R/ L	BA	MNI coordinates			Volume ( $\text{mm}^3$ )	Peak ALE value
				x	y	z		
1	Inferior Parietal Lobule	L	40	-42	-40	48	6648	.039
	Precuneus	L	7	-6	-74	44		.034
	Superior Parietal Lobule	L	7	-32	-50	56		.023
	Superior Parietal Lobule	L	7	-26	-62	50		.022
	Inferior Parietal Lobule	L	40	-32	-46	44		.020
	Precuneus	L	7	-22	-68	40	3432	.020
	Middle Frontal Gyrus	L	9	-46	24	28		.036
	Inferior Frontal Gyrus	L	9	-44	8	30		.026
	Middle Frontal Gyrus	L	9	-40	34	24		.024
	Superior Frontal Gyrus	L	46	-52	36	16	2728	.021
3	Superior Frontal Gyrus	L	6	-6	20	50		.036
	Medial Frontal Gyrus	R	6	8	20	46		.022
	Medial Frontal Gyrus	L	6	-2	8	56	1392	.020
	Middle Frontal Gyrus	L	6	-28	-4	56		.029
4	Middle Frontal Gyrus	L	6	-28	8	60		.018
	Insula	R	13	34	24	0	1048	.029
	Insula	L	-	-34	20	-2	912	.029
5	Cingulate Gyrus	R	32	4	30	22	872	.029
	Cingulate Gyrus	L	31	0	-30	32	440	.022
6	Inferior Parietal Lobule	L	40	-52	-30	52	312	.021
	Precuneus	R	7	20	-58	56	304	.021
	Inferior Frontal Gyrus	R	9	44	10	30	256	.022
7	Middle Frontal Gyrus	R	6	28	-2	56	248	.022
	Superior Parietal Lobule	R	7	30	-72	52	176	.019

#### 4.1.4. The left fusiform gyrus and occipital gyrus

The left fusiform gyrus and occipital gyrus were more consistently activated in language switching than in task switching. The left fusiform gyrus is typically related to processing visual word forms (Price and Devlin, 2003). However, the left fusiform gyrus has also been implicated in language switching (Anderson, Chung-Fat-Yim, Bellana, Luk and Bialystok, 2018; Guo et al., 2011; Ma et al., 2014; Lei et al., 2014), in which it plays an important role in lexical-semantic processing (Abutalebi et al., 2007). It should be noted that despite the lack of activity of the left fusiform gyrus for task switching in our analyses, this brain

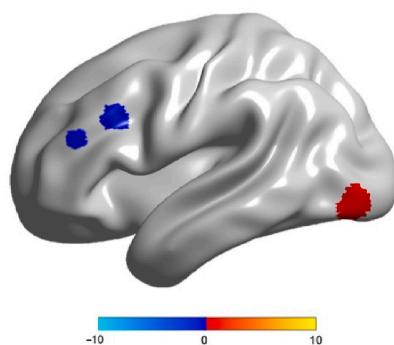


**Fig. 3.** Conjunction across ALE meta-analyses of language switching and task switching.

**Table 4**  
Conjunction analysis between language switching and task switching.

Cluster	Region	R/ L	BA	MNI coordinates			Volume (mm <sup>3</sup> )	Peak ALE value
				x	y	z		
1	Inferior Frontal Gyrus	L	9	-48	8	32	280	.017
2	Cingulate Gyrus	L	32	6	18	42	168	.014
3	Precuneus	L	7	-10	-68	52	72	.014
4	Medial Frontal Gyrus	L	32	-2	14	44	16	.012
5	Superior Frontal Gyrus	R	6	6	18	52	16	.011
6	Medial Frontal Gyrus	L	32	-4	14	46	8	.011

Notes: R/L, right/left. These presented clusters were thresholded at uncorrected  $p < .01$  with 5000 permutations.



**Fig. 4.** Regions specifically activated by language switching (red) and task switching (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

region has been associated with task switching in a few previous studies (Hyafil et al., 2009; for a review, see Kim et al., 2012a, ). De Baene et al. (2015) found a common activation within the left fusiform gyrus in language switching and task switching. Nevertheless, few studies have

discussed the role of the left fusiform gyrus during task switching, and thus it still remains an open question. Similarly, as the left occipital gyrus was not typically activated during language switching, the potential role of the left occipital gyrus in language switching remains unclear and merits further examination in future studies.

#### 4.2. A partial overlap between BLC and EC

Examining the relationship between BLC and EC has produced inconsistent results. Some behavioral studies have found a correlation between BLC and EC (Declerck et al., 2017; Timmer et al., 2019), whereas others have not (Branzi et al., 2016a; Prior and Gollan, 2013). However, in most of these studies, the relationship between BLC and EC was viewed as an “all-or-nothing” phenomenon. Neuroimaging studies have been able to examine this relationship as an interactive continuum in which brain regions associated with language and task switching may partially or completely overlap, or not overlap at all. In recent years, two studies have directly compared the neural correlates of language and task switching (De Baene et al., 2015; Weissberger et al., 2015). Although some brain regions were consistently observed across both types of switching, the findings were rather inconsistent across studies. We speculate that the variability in individual differences and task manipulation across the studies may contribute to these inconsistent findings. To avoid these potential confounders, in the current study, we examined the relationship between BLC and EC by employing ALE meta-analyses. Based on the observed commonalities and differences in brain regions associated with language and task switching, we argue that there is partial overlap between the neural areas involved in BLC and EC, and thus, there are partially-shared mechanisms that underpin both types of control.

Notably, in the present study, the observed overlapped brain regions for the two switching domains were mainly in the frontoparietal network, which is in accordance with the MD hypothesis (Duncan, 2010). The MD hypothesis assumes that there is a network, which is activated during several cognitively demanding tasks, constituting of the parietal cortices, DLPFC, and pre-SMA/dACC complex. In our analyses, this network consistently was activated in both language and task switching, providing evidence of a possible link between BLC and EC on an overarching level. These findings also align with the ICM (Green, 1998) which proposes that BLC relies (at least partly) on domain-general EC processes.

#### 4.3. Limitations and future directions

Although the present study offers compelling descriptions of how the neural bases of BLC and EC are related, there are several limitations that should be considered. Firstly, both BLC and EC can be divided into several sub-components (e.g., BLC includes reactive control and proactive control; EC includes inhibition, working memory, and cognitive flexibility/switching; for reviews, see Braver, 2012; Declerck, 2020; Diamond, 2013). Our analyses, however, only address reactive BLC as measured by language switching tasks and the cognitive flexibility-/switching component of EC as indexed by task switching tasks. Although language and task switching tasks are classic measures of BLC or EC, respectively, our findings are limited to language and task switching tasks. To fully capture how brain networks of BLC are related to those of EC, future meta-analyses should include studies measuring a larger spectrum of sub-components of BLC and EC. Secondly, our analyses included more task switching studies than language switching studies. This imbalance in sample sizes might bias the neural basis computed using contrast analyses. To the best of our knowledge, however, there is no way of evaluating the potential bias. Nevertheless, it is worth acknowledging that the number of studies recruited in both switching domains all met the minimum requirements which would lead to reliable findings for the ALE meta-analyses (Eickhoff et al., 2016). Thirdly, the shared neural correlates across the two switching domains were only

**Table 5**

Contrast analyses between language switching and task switching.

Cluster	Region	R/L	BA	MNI coordinates			Volume (mm <sup>3</sup> )	Z
				x	y	z		
<b>LS &gt; TS</b>								
1	Middle Occipital Gyrus	L	18	-32	-86	-6	784	2.989
	Fusiform Gyrus	L	19	-37.5	-80.3	-10.2		2.911
	Fusiform Gyrus	L	19	-34.7	-80	-6		2.911
	Inferior Occipital Gyrus	L	19	-38	-80	-2		2.636
<b>TS &gt; LS</b>								
1	Middle Frontal Gyrus	L	9	-42	20	30	400	2.727
2	Middle Frontal Gyrus	L	46	9	-50	26		2.669
				-50	36	20	336	3.239

Note: LS, language switching; TS, task switching; R/L, right/left. These presented clusters were thresholded at uncorrected  $p < .01$  with 5000 permutations.

dependent on the spatial overlay in the brain. Hawes et al. (2019) have proposed that spatial co-activation does not necessarily indicate similar functional activation. In the current study, although we observed some commonalities and differences in the neural correlates underlying BLC and EC, and discussed their potential functional roles, the specific nature of how these overlapping regions function still remains unclear. In future work, new analytical methods such as a multi-voxel pattern analysis (MVPA) and representational similarity analysis (RSA) should be conducted to specifically decode patterns of activation within overlapping regions across switching domains. These innovative analyses may reveal a more detailed relationship between BLC and EC.

## 5. Conclusion

Language switching and task switching correlate with shared and distinct brains regions. The strong common clusters of convergence in the left DLPFC, pre-SMA/dACC complex, and left precuneus implicates the frontoparietal network in switching tasks. The distinctiveness of the two switching domains was found in the left occipital regions and the DLPFC. Specifically, the left occipital regions (e.g., fusiform gyrus) were more activated in language switching, whereas the left DLPFC showed more activity for task switching. Taken together, these findings suggest a partial overlap between BLC and EC.

## Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## Declaration of competing interest

The authors declare that they have no conflict of interest.

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