Functional MRI of task switching in children with Specific Language Impairment (SLI)

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Abstract

The objective of this study was to examine executive functioning in children with Specific Language Impairment (SLI) using functional MRI. Six children with SLI and seven control children participated in this study and received a task-switching paradigm. No specific deficit in executive control was observed at the behavioural level in children with SLI. However, the neuroimaging data did show remarkable differences between the SLI and control children. The children with SLI recruited frontal and cingulate areas, normally associated with executive control, even when the task did not require them in the children without SLI. This might indicate that the task was more demanding for the SLI group and that compensatory mechanisms were engaged for successful task performance.

Introduction

Specific Language Impairment (SLI) is characterized by a deficit in the production or comprehension of language despite normal cognitive development and educational opportunities (Ahmed, Lombardino, & Leonard, 2001). The most described and commonly known problems are language related and include phonological problems, problems with language morphology, and difficulty with sentence structures (Joanisse & Seidenberg, 1998). SLI is more frequently observed in boys than in girls and the prevalence is around 7 percent (Leonard, 1998).

Two different types of hypotheses have attempted to explain SLI. The first hypothesis presumes that people with SLI suffer from a deficit or delay that is specific to the language domain, particularly to grammar. A competing view posits that SLI is caused by a non-linguistic processing deficit (see for an overview Ullman & Pierpont, 2005). More and more evidence supports the latter view. The problems that children with SLI encounter, are not merely restricted to the language domain. Several studies have indicated that, compared to chronological-age peers, children with SLI have a limited working memory capacity (Marton & Schwartz, 2003; Weismer, Evans, & Hesketh, 1999), attention problems (Niemi, Gunderson, Leppaesaari, & Hugdahl, 2003), motor skill problems, and temporal processing deficits (Ullman & Pierpont, 2005). Although one can argue that most of the tasks used in these studies involve a strong language component, the results do imply a more general deficit in executive control. This executive control is said to encompass several inter-related processes, such as, planning, mental flexibility, attentional control, and utilization of feedback and is mainly put into effect during tasks or situations that are novel, complex, or induce a conflict situation (see for an overview of definitions, Anderson, 1998; Zelazo, Muller, Frye, & Marcovitch, 2003). Executive control is strongly associated with frontal-lobe activation (Duncan & Owen, 2000; Koechlin, Ody, & Kouneiher, 2003).

Structural brain anomalies, measured with magnetic resonance imaging (MRI), in children with SLI have been reported in a number of studies (see for an overview Ullman & Pierpont, 2005). Regional anomalies have been found in language-related areas such as, a decrease in the volume of the left pars triangularis, which is part of Broca's area (Gauger, Lombardino, & Leonard, 1997), a decrease in the volume of the left posterior perisylvian region (Jernigan, Hesselink, Sowell, & Tallal, 1991), and children with SLI are less likely to have a leftward asymmetry of the planum temporale, a part of Wernicke's area (Bishop, 2000; Plante, Swisher, Vance, & Rapcsak, 1991). However, anomalies have also been found in areas related to executive control. Jernigan and colleagues report that children with language impairment have an increased asymmetry in prefrontal areas such as the orbitofrontal, dorsolateral , and medial frontal cortex (1991). That is, in normal controls the frontal areas mentioned are symmetrical, while in the children with language problems the left hemisphere is reduced relative to the right. Kabani and colleagues report cortical atrophy in the anterior regions of the frontal cortex in adults with SLI (1997). Especially, these brain areas are associated with executive control functions as response inhibition (Fassbender et al., 2004; Tamm, Menon, & Reiss, 2002) , utilization of feedback (Hornak et al., 2004), and switching between rules and tasks (DiGirolamo et al., 2001). Thus, the anomalies found in these frontal regions support the notion that SLI is a more general, executive control, deficit.

In comparison to studies on structural brain differences, only a limited amount of studies have examined brain activity in children with SLI. (review Hugdahl et al., 2004; Ullman & Pierpont, 2005). To our knowledge, only four studies have examined brain activity in subjects with SLI during task performance. In one study brain activity was examined by SPECT (Lou, Henriksen, & Bruhn, 1984), in the second study with PET (Vargha-Khadem et al., 1998), and in the remaining two studies functional MRI (fMRI) was used (Liegeois et al., 2003) (Hugdahl et al., 2004). In each of these studies the subjects had to perform a language task, respectively, object naming, word repetition, verb generation, and passive listening to language stimuli. However, none of these studies has examined the relation between SLI, brain activation, and executive control. Therefore, the main aim of the present study was to examine brain activation in children with SLI during the performance of an executive control task.

The task used for this study is based on the task-switching paradigm (Dibbets & Jolles, in press). This paradigm is held to be appropriate for the exploration of executive control and involves the performance of two relatively easy cognitive tasks (Monsell, 1996; Rogers & Monsell, 1995). The task-switching paradigm has also proved to be a sensitive tool for examining developmental differences in executive control {Cepeda, 2001 #25} and for detecting executive dysfunctioning {e.g., \ Cepeda, 2000 #26}. In the 'nonswitch', or 'repeated' condition, the participant is repeatedly presented one of the two tasks (e.g., AAAA or BBBB). In the other condition, the 'switch' condition, the participant switches from one task to the other (e.g., ABBAAB). Performance is usually slower and less accurate in the switch than in the nonswitch condition. These so-called switch costs are thought to reflect a stronger engagement of executive processes during the switch condition, like the inhibition of the irrelevant task set, switching to the relevant task set, and the maintenance and manipulation of two different mental task sets in working memory. A deficit in executive control can be expressed as a stronger impairment in the switch than in the nonswitch condition, leading to an enlargement of the switch costs.

Several fMRI studies have examined task switching-related activation in adults (e.g., DiGirolamo et al., 2001; Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; Ruge et al., 2005; Rushworth, Hadland, Paus, & Sipila, 2002). Additional activation during the switch condition was mainly observed in dorsolateral and medial frontal areas, the presupplementary motor area, and parietal areas. Exactly these dorsolateral and medial frontal areas show an atypical asymmetry in children with SLI.

The present study was conducted for two main reasons. First, to seek further evidence for an executive control deficit in children with SLI using a task-switching paradigm. Second, to explore differences in (frontal) brain activation between children with and without SLI during the performance of the task-switching paradigm.

Materials and Methods

Subjects

Six children with SLI and seven age-matched control children took part in this study. In order to reduce errors due to developmental differences between boys and girls, only boys were eligible for the study. All subjects were right-handed. The mean age of each group was 6 years and 10 months (sd SLI: 8.4 months; sd control: 6.3 months). The socioeconomical background, with respect to family composition, education level, employment status, and age of the parents, was highly similar in both groups. The children with SLI were recruited from a special school for children with speech- and language disorders, the control children from local primary schools. Parents provided written informed consent for participation of the children. The diagnosis of SLI was made by a team of professionals, including linguists, psychologists, speech therapists and audiologists using standard, neuropsychological, tests. The children with SLI performed at least two standard deviations below average on language tests, with normal nonverbal performance (mean IQ = 94.3, sd = 5.2). All children with SLI had both expressive and receptive language problems, with the expressive problems dominating. Children with a history of neurological disease, trauma, psychiatric problems, developmental disorders (other than SLI), contraindication for fMRI, or an IQ < 85 were excluded from participation. All children received a small present and a snapshot of their anatomical brain scan for participation.

Neuropsychological tests

Four language tests and two nonverbal tests were administered for two main reasons. First, to objectively confirm the nature of the language problems in the children with SLI and to assess that they are specific for SLI and not present in the control children. Second, to detect a possible discrepancy in verbal and nonverbal test performance in the SLI group. The language tests assessed were: Phonological processing, Speeded naming, Sentence repetition, and Repetition of nonsense words. During the last two tasks, the children had to repeat sentences or nonwords that were read aloud by the experimenter. The phonological processing test was divided in two parts. In the first part, phonemes of words were read aloud and the child had to select an image that depicted a word containing that particular phoneme. For example, selecting a picture of a shoo after hearing the phoneme ‘sh’. In the second part, the child had to substitute phonemes. For example, say ‘live’ but replace ‘l’ by ‘g’. The correct answer in this case would be ‘give’. During the speeded naming test, children had to indicate as fast and accurate as possible the size, colour, and shape of geometrical figures presented on a sheet. All these tests stemmed from the NEPSY (A Developmental Neuropsychological Assessment; (Korkman, Kirk, & Kemp, 1998). This combination of subtests can be used to detect developmental language problems in children (Korkman et al., 1998). The two nonverbal tests were Hand movements from the K-ABC, Kaufman Assessment Battery for Children (Kaufman & Kaufman, 1983), and Block Design from the WISC-R, Wechsler Intelligence Scale for Children-Revised, (Wechsler, 1974).

Functional MRI test

The stimuli were presented on a screen and viewed via a mirror mounted on the head coil. The software used was programmed in E-prime (Psychology Software Tools, http://www.pstnet.com/).

The task-switching paradigm used, was the Switch Task for Children (STC) which was developed at our department (see for a detailed description, Dibbets & Jolles, in press). The STC is presented as an adventure game and does not require reading skills, which makes it suitable for young children and children with SLI. The task consists of two similar, yet conflicting, tasks: the "day-task" and the "night-task". During the day-task, an orange house and a blue house with a white cat in between them were presented against a daytime sky. The position of the houses, left and right, varied across trials. The child could select one of the two houses by pressing the accompanying button. Selecting the orange house, correct response, resulted in finding a treasure chest. Selecting the blue house was punished by marking this house with a pink cross sign. The absence of a response was neither rewarded nor punished. During the night-task the houses and cat were presented against a night time sky and selection of the blue house was rewarded while selection of the orange house was punished. The total duration of each trial was 6500 ms (2 TRs) and both response accuracy and response time, RT, were recorded. During the scan session two different conditions were presented: the switch condition and the nonswitch condition (block design). In the nonswitch condition, one task was repeatedly presented for 8 trials (e.g., day-day-day-day… or night-night-night-night…). In the switch condition, 8 trials of the day- and night-task were randomly mixed and presented at a ratio of 1 to 1 (day-night-night-day…). A signal screen indicated whether only the day-task, only the night-task, or a mix of both tasks would be presented for the next 8 trials. A total of eight 8-trial blocks were presented with alternating nonswitch and switch conditions. The onset of each block was synchronized with the scanner and the time between two blocks was at least 6 seconds. During the scan session, the white cat on the screen changed colour to keep the participant motivated and to give an indication of the remaining test time. The task started and ended with a passive resting state (each 15 TRs) in which no response was required. The STC was practiced in a simulation scanner about two weeks prior to the actual scan session.

fMRI scanning

The children were scanned using a 1.5T MRI scanner (Philips Gyroscan ACS-NT, Eindhoven, The Netherlands) with a Synergy head coil. Head fixation was accomplished by a foam padding. Functional images were based on a T2* weighted gradient echo sequence with the following parameters: flip angle = 90º, TE = 48 ms, TR = 3250 ms, field of view = 224 x 96 x 224, imaging matrix = 128 x 128, slice thickness = 3 mm, slice gap = 0 mm. Scanning orientation was axial and slice order was interleaved. A total of 200 images for all slices was collected. For each subject a sagittal T1-weighted anatomical image was acquired at the beginning of the session (140 slices, imaging matrix = 256 x 256, slice thickness = 1 mm, no gap).

Behavioural data analysis

Neuropsychological test data were transformed to standard z-scores. Dependent measures of the STC were the total number of errors, including omitted responses, and the mean response time in each condition (switch and nonswitch). Only correct responses were used for calculating the mean response time. Switch costs were calculated by subtracting the mean RT in the nonswitch condition from the mean RT in the switch condition (RT costs) and by subtracting the total number of errors in the nonswitch condition from the total number errors in the switch condition (error costs). Both the behavioural and neuropsychological test data were analysed using parametric tests (analysis of variance [ANOVA], and GLM with repeated measures). In each analyses group, SLI versus control, functioned as a between-subjects factor. Bonferroni tests were used to adjust the significance level when multiple or pair wise comparisons were made. The rejection criterion was $p < .05$.

Image analysis

The functional MRI data were statistically analysed using Brainvoyager QX 1.3 software package (www.brainvoyager.de). Preprocessing procedures consisted of 3D motion correction, slice scan time correction, spatial Gaussian smoothing (4 mm), and temporal filtering (Highpass filter: 3 and linear trend removal). For each individual, functional and anatomical images were spatially coregistered and transformed into standard Talairach space (Talairach & Tournoux, 1988). Although this transformation is based on an adult brain, several studies have indicated that this transformation can also be applied on functional MRI data of children (Burgund et al., 2002; Kang, Burgund, Lugar, Petersen, & Schlaggar, 2003). The loci of activation found, were checked by comparing them to the individual anatomical images. Two children with SLI were not included in the data analysis, one because of movement artefacts and one child due to fear for the scanner. Thus the fMRI-data of 4 children with SLI and 7 control children were analysed. To reduce the risk of false-positive findings, a minimal cluster size of 50 pixels was taken.

The differences between the switch and nonswitch condition in each group were evaluated using a GLM taking the hemodynamic response function and resting state activation into account. Group differences were analysed using a random effects GLM with separate subject predictors. Within group corrections were made by setting q(FDR) < .05. For all neuroimaging analyses the minimum absolute t-value was set at 4.00.

Results

Neuropsychological data

Table 1 summarizes the data of the neuropsychological tests. As expected, had the children with SLI more problems with the following language-related tasks: Phonological processing, Speeded naming, and Sentence repetition, $Fs(1, 10) > 8.01$, $Ps < .05$. No differences were found on Repetition of nonsense words, $F < 1$, and on the nonverbal tasks, Hand movements and Block design, $Fs(1, 10) < 3.65$.

Insert Table 1 about here

The Switch Task for Children (STC)

Figure 1 displays the total number of errors (upper panel) and mean RTs (lower panel) for each group on the STC. On average, the children with SLI made more errors, $F(1, 9) = 7.12$, $P < .05$, and responded slower, $F(1, 9) = 8.52$, $P < .05$, than the children without SLI. Furthermore, both groups were slower in the switch than on the nonswitch condition, $F(1, 9) = 26.75$, $P < .005$. The observed difference in errors between the switch and nonswitch condition failed to reach significance, $F(1, 9) = 3.80$, $P = .08$. No group x condition interactions were obtained, $Fs < 1$, and no difference in switch costs, both error costs and RT costs, was observed between the two groups $Fs <1$.

Insert Figure 1 about here

Neuroimaging

Four planned statistical comparisons were performed, 2 within-group analyses and 2 between-group analyses for each condition, nonswitch and switch.

Within group: [Switch – Nonswitch]

Control group:. The comparison of the switch condition versus the nonswitch condition should reflect the neural correlates of additional cognitive processes related to task switching. A full listing of loci, Talairach coordinates, cluster size, t-values, and anatomical areas is given in Table 2a. The most prominent activations in the control group were found in right temporal areas, left and right frontal areas, in the left postcentral gyrus, the left parietal lobe, and in the left hippocampus (see Figure 2a).

SLI group. Additional activation during performance of the switch condition was found in three areas: Left superior and medial temporal gyrus and right angular gyrus (see Table 2b and Figure 2b).

Insert Table 2 about here

Insert Figure 2 about here

Between groups: [SLI – Control]

Nonswitch condition: Table 3a summarizes the differences in activation between the SLI and control group during performance of the nonswitch condition. In all cases, the SLI group showed an increase in activation compared to the control group. This increased activation was, among others, observed in the left and right frontal areas and in the left superior parietal lobe.

Switch condition: Differences in activation between the SLI and control in the switch condition are summarized in Table 3a. As was the case in the nonswitch condition, children with SLI exhibited an increase in brain activation relative to the children without SLI. This increase was mainly observed in the left and right frontal areas, temporal lobe, and in the cingulate regions.

Insert Table 3 about here

Discussion

This study was performed for two main reasons. First, to detect a possible executive deficit in children with specific language impairment, SLI, by using a task-switching paradigm. Second, to explore differences in brain activity between normal control children and children with SLI during the performance of this paradigm. To this end a modified switching task, the Switch Task for Children (STC), was presented in an fMRI-environment.

The neuropsychological data indicated that, as can be expected, the children with SLI had more problems with the language-related tasks, but not with the nonverbal tasks. Unlike other authors, we do not find a difference between the two groups on the Repetition of nonsense words (e.g., Gray, 2003; Marton & Schwartz, 2003). A possible explanation can be found in the task used. The Repetition of nonsense words seems to be a relatively easy task, the mean z-score of both groups, 14.7, lies well above the average z-score of 10. The other language tasks in this study, demanded a large input from working memory capacity, whereas in the Repetition of nonsense words at most 5 syllables needed to be reproduced. However, the exact reason for not finding a difference between the groups on this task is not clear.

The behavioural data of the STC are in line with other task-switching studies in children and adults (Allport, Styles, & Hsieh, 1994; Jutta Kray, Eber, & Lindenberger, 2004; J. Kray & Lindenberger, 2000). That is, the children responded slower in the switch than in the nonswitch condition, reflecting a stronger engagement of executive processes during the switch condition. However, no specific deficit in executive control was observed for the SLI group. The switch costs, defined as the difference in performance between the switch and nonswitch condition, did not differ between the control and SLI group. The mean RT costs for the control and SLI groups were 317 ms and 352 ms, respectively; the corresponding error costs were 1.6 and 0.8. Enlarging the power by using the simulation scan data, leading to 6 children with SLI and 7 control children, did not change the switch costs results, $Fs < 1$. The only group difference obtained in the STC, was a general slowing and a higher overall error rate for the SLI group. This general slowing in children with SLI has been reported before and is ascribed to a global limitation in processing capacity (e.g., Windsor & Hwang, 1999). Altogether, the behavioural data of the STC do not provide evidence for a specific executive control deficit in children with SLI, but point in the direction of a more general information processing deficit, for example a slower or more limited capacity of information processing.

In contrast to the behavioural data, the fMRI [switch – nonswitch] contrast does reveal a different pattern in the control and SLI group. In the control group, additional activity during the switch condition was mainly observed in the right temporal areas, left and right frontal areas, the left parietal lobe, and in the left hippocampus. This activation pattern strongly corresponds with patterns observed during a similar task-switching paradigm in adults (e.g.,DiGirolamo et al., 2001; Dreher & Grafman, 2003; Dreher, Koechlin, Ali, & Grafman, 2002), and adds therefore, to the literature on switch-related brain activity. The [switch – nonswitch] contrast in the children with SLI revealed a completely different pattern. Additional activation during the switch condition was observed in the left superior and medial temporal gyrus, and in the right intraparietal sulcus, but not in the frontal brain areas. Although, only the data of four children were analysed, the contrast of each of the children revealed this pattern. Subtracting the nonswitch from the switch activity, using the nontransformed data, revealed in each child more activity in right temporal and parietal areas, but no additional frontal activation was observed. The additional activation in the right parietal area during switching has been observed before in task-switching studies (DiGirolamo et al., 2001; Dreher & Grafman, 2003; Dreher et al., 2002), however left medial and superior temporal activation have, to our knowledge, not been associated with task switching. Instead, involvement of these areas is normally associated with language operations and memory retrieval (see for an overview, Cabeza & Nyberg, 2000; Ullman, 2004). A possible explanation for the additional temporal activation in children with SLI is that, they encounter more problems with the verbalization of the rules during task performance (e.g., during the day the treasure is hidden in the orange house) or that they have more problems with the access or retrieval of the task-related information.

From the between-group analyses it can be deduced that the SLI group shows more elaborate brain activation during performance of the STC, in both the nonswitch and the switch condition. Additional activation during the nonswitch condition was found in left and right frontal areas and in the left superior parietal lobe. During the switch condition, the children with SLI displayed more activation in left and right frontal areas, the temporal lobe, and in cingulate areas. The additional frontal and parietal activation during the nonswitch condition is normally associated with executive control functions, such as used during task switching. This activation can also explain the lack of switch-related frontal activation in the SLI group. During both the switch and nonswitch condition frontal areas were activated, resulting in an absence of activity in the [switch – nonswitch] contrast.

To our knowledge, only one other study reports the absence of frontal activation during task switching (DiGirolamo et al., 2001). In this study, the switch versus nonswitch contrast revealed frontal activity in young adults, but not in older subjects. Like in our study, the lack of activation can be explained by the presence of frontal activation during the nonswitch condition. A possible explanation is that older adults compensate for decreased cognitive abilities by recruiting a variety of frontal areas (Cabeza, 2002). This compensational view can also be applied to the current study. The findings do suggest that the task was more demanding for the children with SLI. Recruitment of additional frontal and cingulate areas might signal the increased effort for successful task performance in children with SLI.

The present study has a number of limitations. First of all, the number of participants in this study is small. Although, the individual results do match the group data, the statistical power is limited, restricting the ability to generalize the results. Second, a block design rather than an event-related design was used. The latter design has a number of advantages, such as the ability to exclude incorrect trials and the option to examine the effect of negative feedback. In addition, it enables to separate the actual task switching effects from working memory load effects. In the present study, these effects are mixed. An event-related design makes it possible to compare the switch trials within the switch condition, that is a day trial after a night trial or vice versa (ABA), with the nonswitch trials, a repetition of day or night trials (AA or BB), while the memory load remains identical. The only disadvantage of an event-related design is the relatively large number of trials needed. For the present study a block design was used in order to minimize the task duration during scanning. Furthermore, a pilot study indicated that presenting the Switch Task for Children in an event-related fashion resulted in many errors with some children not mastering the task at all. In the future, it would be interesting to develop a task that enables to further explore brain activity related to executive control in children with SLI using an event-related design.

One last topic mentioned is that of the clinical relevance of the present study. If children with SLI indeed have a more general information processing deficit, more comprehensive intervention programs than the traditional language therapy are needed. An early identification of such problems can help to further develop new remediation and intervention methods. It is relevant in this respect that the present findings show involvement of prefrontal structures which are known to be involved in executive control but also in the effective use of strategies. It is thus probable that training interventions directed at more effective 'coping mechanisms' and compensation for the deficient information processing may provide new avenues for neuropsychological rehabilitation of the condition.

In conclusion, the data from the current experiment add to the view that SLI is not restricted to problems in the language domain. The major finding of the present study is the discrepancy found between the behavioural and neuroimaging data. A deficit in executive control was not directly observed at the behavioural level, but the neuroimaging data do show remarkable differences between the SLI and control group. These findings stress the importance of the utilization of fMRI in cognitive research. The children with SLI recruited frontal and cingulate areas, normally associated with executive control, even when the task did not require them in the children without SLI. This might indicate that the task was more demanding for the SLI group and that compensatory mechanisms were engaged for successful task performance.

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Table captions.

Table 1. Mean standardized results, SD, and range on the neuropsychological tasks

Table 2a. Loci showing greater activation during the switch condition in the control group.

Table 2b. Loci showing greater activation during the switch condition in the SLI group.

Table 3a. Loci showing different activation in children with and without SLI in the nonswitch condition.

Table 3b. Loci showing different activation in children with and without SLI in the switch condition.

Figure captions.

Figure 1. Total number of errors (top panel) and mean response times (bottom panel) in the switch and nonswitch condition for each group.

Figure 2a. Additional activity during the switch condition in the control group. For coordinates, cluster size, t-values, and locations see Table 2a.

Figure 2b. Additional activity during the switch condition in the SLI group. For coordinates, cluster size, t-values, and locations see Table 2b.

	Control group (n = 7)	SD	Range	SLI group (n = 4)	SD	Range
Verbal tasks						
Phonological processing	14.43	2.0	12 – 16	7.75 *	2.4	6 – 11
Speeded naming	11.57	2.3	8 – 14	6.75 *	3.4	2 – 10
Sentence repetition	11.57	2.7	7 – 15	6.50 *	0.6	6 – 7
Repetition of Nonsense words	14.71	2.7	11 – 19	15.00	2.0	14 – 18
Nonverbal tasks						
Hand movements	13.14	1.7	10 – 15	11.00	2.0	10 – 14
Block design	13.00	1.4	11 – 15	10.75	3.1	8 – 15

* Significant difference between the two groups

Talairach coordinates							
x	y	z	Cluster size	t value	Location	Brodmann areas	Frame figure 2a
Left and right frontal areas							
22	41	-1	90	4.72	Right superior frontal gyrus	10/11	C
-21	-1	51	56	4.44	Left superior frontal gyrus	6	B
-38	54	9	215	4.76	Left medial frontal gyrus	46	D
-24	53	7	132	4.58	Left medial frontal gyrus	10	D
-25	-28	70	171	5.04	Left postcentral gyrus	4	A
-54	-8	13	139	4.42	Left postcentral gyrus	48	E
Right temporal areas							
53	-13	4	64	4.38	Right superior temporal gyrus	48	D
51	-12	-14	422	4.62	Right medial temporal gyrus	20	G
64	-41	-1	102	4.53	Right medial temporal gyrus	21	C
63	-30	-18	712	5.40	Right inferior temporal gyrus	20	G
54	-66	1	112	4.16	Right inferior temporal gyrus	37	C
Other areasF							
-29	-26	-9	113	4.37	Left hippocampus		F
-47	-38	49	67	4.12	Left inferior parietal lobe	40	B

Table 2a

Talairach coordinates							
x	y	z	Cluster size	t value	Location	Brodmann areas	Frame figure 2b
Left temporal areas							
-43	-38	19	113	4.32	Left superior temporal gyrus	41	B
-37	-2	-17	83	4.20	Left medial temporal gyrus	21	C
Other areas							
32	-43	37	60	4.27	Right intraparietal sulcus	40	A

Table 2b

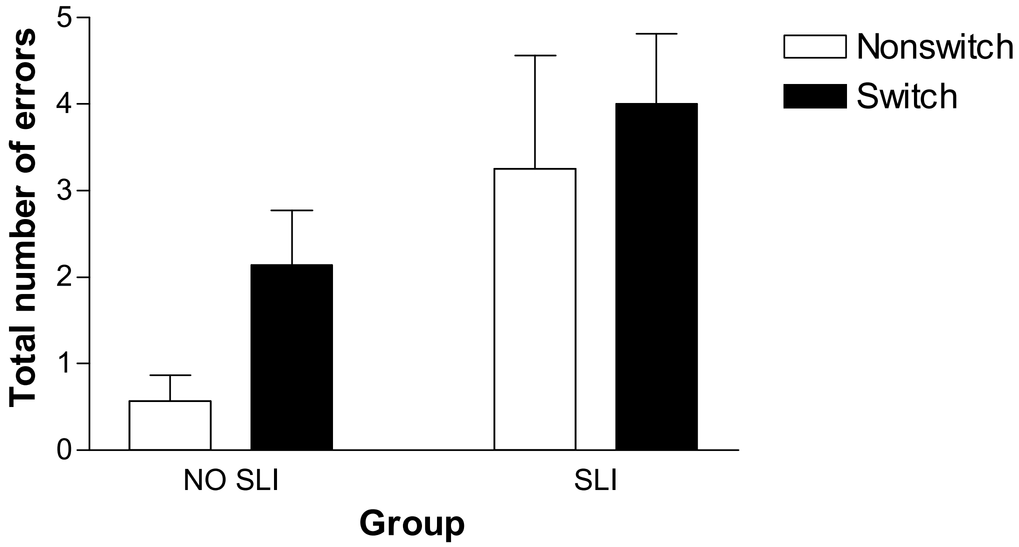
Talairach coordinates						
x	y	z	Cluster size	t value	Location	BA
Left and right frontal areas						
27	58	-5	148	4.52	Right superior orbitofrontal lobe	11
-3	31	53	101	4.35	Left superior medial frontal lobe	8
-50	11	34	124	4.34	Left precentral gyrus	44
-39	-7	18	115	4.29	Left rolandic operculum	48
Other areas						
-26	-71	51	73	4.33	Left superior parietal lobe	7
-28	-7	11	50	4.55	Left putamen	
-30	-92	-1	163	4.55	Left medial occipital lobe	18
14	-94	19	55	4.55	Right superior occipital lobe	17

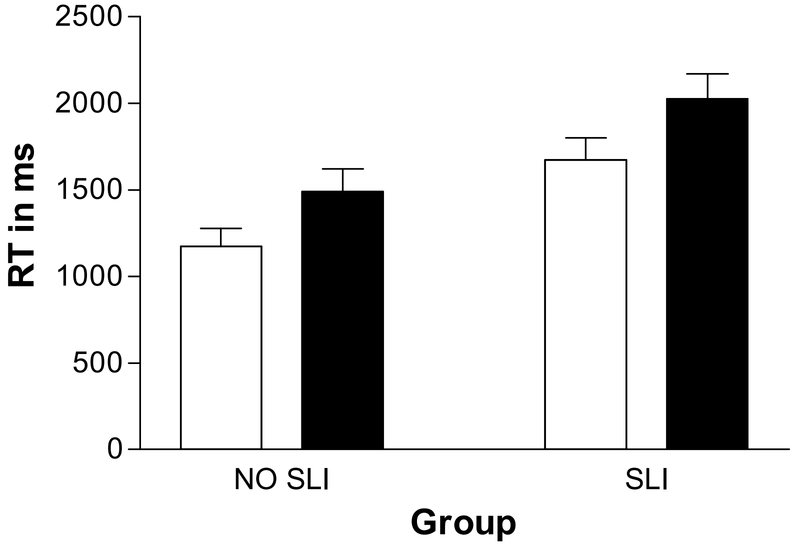
Table 3a

Talairach coordinates						
x	y	z	Cluster size	t value	Location	BA
Left and right frontal areas						
21	17	-15	92	4.35	Right inferior orbitofrontal lobe	11
-18	36	-14	90	4.81	Left medial orbitofrontal lobe	11
18	63	5	98	4.25	Right superior frontal lobe	10
21	31	28	98	4.58	Right superior frontal lobe	9
27	63	10	69	4.25	Right superior frontal lobe	10
12	68	13	114	4.33	Right medial frontal lobe	10
29	50	4	55	4.25	Right medial frontal lobe	10
-12	44	21	246	4.42	Left medial frontal lobe	10
-42	28	32	58	4.98	Left medial frontal lobe	44
47	26	28	136	4.45	Right inferior frontal lobe	44
-51	16	7	93	4.43	Left frontal inferior operculum	48
32	-16	46	113	4.38	Right precentral gyrus	6
-50	5	26	124	4.33	Left precentral gyrus	6
52	6	34	598	4.51	Right postcentral gyrus	4
47	-20	33	128	4.47	Right postcentral gyrus	3
-56	-1	18	124	4.45	Left postcentral gyrus	48
10	14	49	85	4.43	Right SMA	6
Left and right temporal areas						
56	-42	16	50	5.47	Right superior temporal lobe	42
-54	-34	-2	99	4.82	Left medial temporal lobe	21
Other areas						

-20	-63	50	181	4.41	Left superior parietal lobe	7
-9	-29	33	222	4.54	Left cingulum (mid)	32
-11	28	25	50	4.34	Left cingulum (anterior)	32
12	15	34	133	4.44	Right cingulum (mid)	32
16	48	13	80	4.40	Right cingulum (anterior)	32
33	-25	13	156	4.68	Right Heschl gyrus	48
31	-17	17	91	4.39	Right insula	48
-19	18	1	352	5.30	Left putamen	
21	8	-1	104	5.07	Right putamen	
16	9	16	238	4.67	Right caudate nucleus	
-19	-80	38	196	5.12	Left superior occipital lobe	19
18	-82	38	81	4.29	Right superior occipital lobe	19

Table 3b


Total number of errors
5
4
3
2
1
0
NO SLI
SLI
Group
Nonswitch
Switch


RT in ms
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2000
1500
1000
500
0
NO SLI
SLI
Group

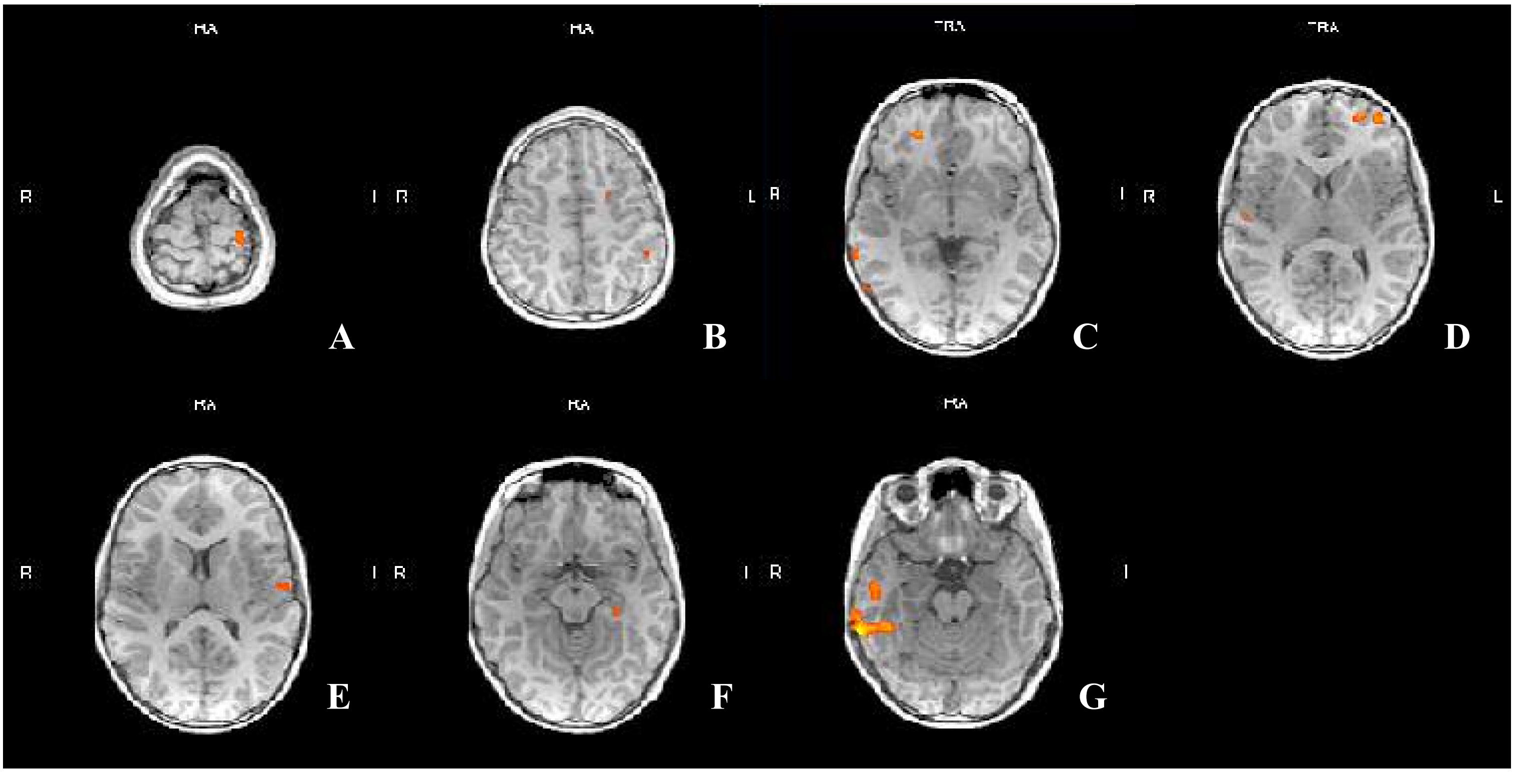

Figure 2a: No SLI

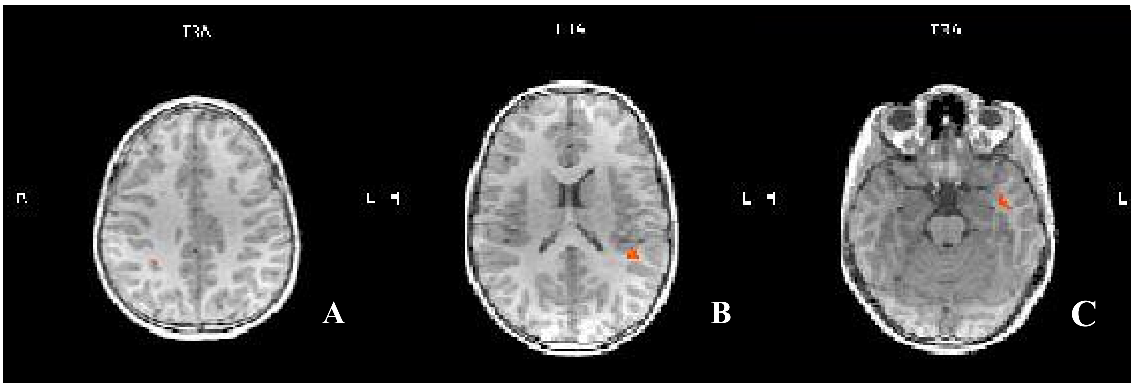

Figure 2b: SLI