Int J Clin Exp Med 2016;9(4):7273-7280
www.ijcem.com /ISSN:1940-5901/IJCEM0016284

Original Article

Different brain activation patterns in Uygur and Chinese speakers during verb generation task: a BOLD-fMRI study

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Received September 16, 2015; Accepted February 26, 2016; Epub April 15, 2016; Published April 30, 2016

Abstract: Objective: This study is to investigate and compare the activated brain regions in Uyghur and Chinese speakers during the verb generation task with the blood oxygenation level dependent-functional magnetic resonance imaging (BOLD-fMRI). Method: Totally 15 Uyghur and 15 Chinese native speakers were included in this study. These subjects were asked to perform the verb generation task, and meanwhile the activated brain regions were analyzed and compared with BOLD-fMRI. Results: Uyghur and the Chinese speakers exhibited significant activation in multiple brain regions during the verb generation task. The dominant hemisphere for both Uyghur and Chinese speakers is the left cerebral hemisphere. However, in the Uyghur speakers, the differentially activated brain regions during the verb generation task mainly included the left inferior temporal gyrus (BA37), left inferior parietal lobule, left fusiform gyrus, and left parahippocampal gyrus, which were significantly less activated in the Chinese speakers. On the other hand, in the Chinese speakers, significant differential activation was observed in the right superior temporal gyrus (BA38) during the verb generation task, whereas the Uyghur speakers exhibited weak activation in this region. Conclusion: Differential brain activation patterns are observed for the Uyghur and Chinese speakers during the verb generation task. Compared with the Uyghur language, processing of Chinese characters may involve the right hemisphere more extensively.

Keywords: Brain language function, Uyghur, Chinese, verb generation task, blood oxygenation level dependent-functional magnetic resonance imaging (BOLD-fMRI)

Introduction

Language is a unique and sophisticated capacity of humans, and the brain processing mechanism of language has become a research focus in recent years. In China, previous related studies mainly focus on the Chinese language, while researches concerning minority languages have been rarely reported [1-3]. Specifically, up to now there are only two reports on the semantic processing in the brain functional regions regarding the Uyghur language [4, 5]. However, the motor speech brain regions for Uyghur, and the difference in the functional brain regions between Uyghur and Chinese have not yet been reported.

Uyghur and Chinese are in fact substantially different languages. Uyghur belongs to the Altaic family, with linear one-dimensional alphabetic writing, while Chinese belongs to the Sino-Tibetan language system, with two-dimensional character writing. Moreover, Chinese is a language of morphemes based on the unity of shape, pronunciation, and meaning. In contrast, the Uyghur writing only records the phonemes, and the letter itself makes no sense. Furthermore, Chinese is a language consisting of homophones with different tones, while in Uyghur, the number and position of dots are used to distinguish the letters. In addition, Chinese is read and written horizontally from left to right, whereas Uyghur is in the opposite direction. It has been shown that differences in orthography, pronunciation, and syntax for different language systems may lead to distinct cognitive strategies [6]. In addition to the common brain regions for language processing,

Table 1. General information and language function test of Uyghur and Chinese speakers

	Uyghur speakers	Chinese speakers	*P*
Sex (M/F)	7/8	8/7	0.72
Age (years)	18.3±0.5	21.4±0.7	0.27
Years of education (years)	13±1.25	15±1.31	0.11
Verbal fluency (words/min)	85.1±8.7	137.5±16	< 0.01
Listening comprehension (%)	97.6±2.2	98.9±1.5	0.46
Naming (%)	99.7±0.9	99.8±0.6	0.35
Repeating (%)	96.1±1.2	99.2±1.6	0.33
Reading (words/min)	161.3±8.1	245.1±14.6	< 0.01
Reading comprehension (%)	99±2.1	99.3±1.8	0.28

each specific language might have its own cortical representation [4].

In this study, the blood oxygenation level dependent-functional magnetic resonance imaging (BOLD-fMRI) technology was used to investigate the functional brain regions in Uyghur and Chinese speakers during word task. These subjects were asked to perform the verb generation task, and meanwhile the activated brain regions between the two groups were analyzed and compared.

Materials and methods

Subjects

Totally 15 Uyghur native speakers were included in this study, who were undergraduate freshmen in the Xinjiang Medical University. Another 15 Chinese native speakers, junior undergraduate students from the same university, also participated in the study. All these subjects presented with normal uncorrected or corrected visual acuity, with no history of any mental disorders or organic brain diseases. Before the investigation, all the subjects underwent a detailed language function test, including the language fluency, spontaneous oral expression, listening comprehension, naming, repeating, reading, and reading comprehension. In addition, handedness was assessed using the handedness rating scale (standard Chinese version). Prior written and informed consent were obtained from each patient and the study was approved by the ethics review board of the First Affiliation Hospital of Xinjiang Medical University.

Verb generation task

It has been generally believed that the completion of verb generation task needs a series of processes, including the visual processing, word comprehension, verb generation, word matching, and language code output. In this study, the verb generation task was performed as described below. For each subject, a single-word noun was first shown in the screen center for 2 s. Then, the subject was asked to focus on the "+" sign in the screen center, and imagine a two-word verb associated with the previously provided noun for 3 s. Uyghur was shown for the Uyghur subjects, whereas Chinese was shown for the Chinese subjects. The contents (meaning of the words in the task) were identical for both groups. During the stimulating period (30 s), the tasks (i.e., noun presentation and verb generation) were repeated for six times, followed by a resting period for 30 s. The stimulating and resting cycles (60 s) were repeated for nine times.

fMRI scanning

The fMRI scanning was performed on each subject during the verb generation task. The subjects were asked to gaze at the screen center and keep their heads still throughout the detection. Initial scanning signal (18 s) before the task was collected as baseline, followed by nine stimulating and resting cycles (block sequences), with a total scanning time of 9 min and 18 s.

A GE signal 3.0T MRI scanning system was used for the image acquisition, with an 8-channel cardiac coil. The craniocerebral axial T1-weighted images were first obtained using the 3D thin-slice scanning sequence, with the following scanning parameters: TR, 550 ms; TE, 67 ms; section thickness, 1.0 mm; with zero interval; field of view (FOV), 240 mm × 240 mm; and matrix, 320 mm × 192 mm. A total of 136 slices were obtained from the skull base to the parietal layer. Then, the gradient-echo echo planar imaging (GRE-EPI) sequence was used for the BOLD data acquisition, with the following scanning parameters: TR, 2000 ms; TE, 30 ms; section thickness, 5.0 mm; with zero interval; flip angle, 90°; FOV, 240 mm × 240 mm; and matrix, 960 mm × 960 mm. A total of 25 slices were obtained from the skull base to the pari-

Table 2. Activated brain regions in Uyghur speakers during verb generation task

Differently activated brain regions	Cluster p (cor)	Cluster equivk	Cluster p (unc)	Voxel p (FDR-cor)	Voxel T	Voxel p (unc)	x, y, z {mm MNI}
Left IFG, pars triangularis/BA 48	0.006	25	0.114	0.000	7.31	0.000	57, 21, 12
Left IFG, pars opercularis/BA 44				0.000	5.62	0.000	54, 24, 33
BA 48	0.003	39	0.054	0.000	7.3	0.000	-51, -9, 24
Right precuneus/BA 7	0.006	26	0.108	0.000	6.47	0.001	-12, -60, 63
Right precuneus_				0.000	5.75	0.000	-12, -57, 51
Right IFG, pars orbitalis/BA 47	0.006	24	0.121	0.000	6.25	0.000	-27, 36, -6
Right precentral gyrus	0.012	14	0.229	0.000	6.2	0.000	-42, -15, 60
Right IFG, pars opercularis	0.003	41	0.049	0.000	5.94	0.000	-54, 15, 27
Left calcarine	0.007	21	0.145	0.000	5.87	0.000	12, -84, 9
Right superior medial frontal gyrus	0.012	14	0.229	0.000	5.71	0.000	-12, 39, 45
Left middle frontal gyrus	0.01	17	0.187	0.000	5.61	0.000	27, 42, 15
Right middle frontal gyrus	0.016	10	0.308	0.000	5.52	0.000	-45, 6, 54
Right superior occipital gyrus				0.000	4.4	0.000	-30, -75, 18
Right superior frontal gyrus	0.006	25	0.114	0.000	5.15	0.000	-27, -9, 57
Right SMA				0.000	5.1	0.000	-12, -15, 60
Right SMA				0.000	4.84	0.000	-12, -18, 69
Right middle frontal gyrus	0.007	22	0.137	0.000	5.07	0.000	-48, 33, 24
Right IFG, pars triangularis				0.000	5.03	0.000	-45, 30, 9
Right inferior parietal gyrus	0.013	12	0.265	0.000	4.93	0.000	-45, -36, 51
Right IFG, pars triangularis/BA 45	0.016	10	0.308	0.000	4.78	0.000	-45, 21, 12

Statistical level: $P < 0.05$ (PDR correction) voxel > 10.

etal layer, and 279 frames were collected for each slice.

Data processing and statistical analysis

Image processing and analysis was conducted using the statistical parametric mapping (SPM) software (SPM5) (Welcome Department of Imaging Neuroscience; http://www.fil.ion.ucl.ac.uk). After the time alignment and head movement calibration, the data was standardized to the standard template of the Montreal Neurological Institute (MNI) using the SPM5 software. Each pixel was re-sampled to 3 mm × 3 mm × 3 mm. General linear model (GLM) was used to estimate the parameters for the image time series. SPM was obtained from the random effect analysis. Statistical tests were performed based on these parameters to obtain the specific t-value for each voxel. Then the map of activated parameters was superimposed on the T1 template of the standard brains from MNI (avg152) to obtain a two-dimensional activation image. The SPM plugin xjview (http://www.nitrc.org/projects/xjview/) was used to obtain the spatial coordinates for each activated region, the corresponding function positioning on the standard brains from MNI, and the size of activated voxels.

The SPSS17.0 software was used for the statistical analysis. After the normality test, two-sample *t*-test was used for the data within the same group. For the image analysis with the SPM5 software, the influence of head movement (for individual analysis) and age, sex, and mean whole-brain signals (for group analysis) were removed. The statistical threshold was adjusted to $P \leq 0.05$, with voxels (cluster size) ≥ 10 after false discovery rate (FDR) correction. $P < 0.05$ was considered statistically significant.

Results

General information and language function test of Uyghur and Chinese speakers

The baseline characteristics of the Uyghur and Chinese speakers and the results from the language function test were shown in **Table 1**. Statistical analysis indicated significant differences in the speech fluency and reading between these two groups ($P < 0.05$). However, due to the substantial different characteristics between the Uyghur and Chinese languages,

Table 3. Activated brain regions in Chinese speakers during verb generation task

Differently activated brain regions	Cluster p (cor)	Cluster equivk	Cluster p (unc)	Voxel p (FDR-cor)	Voxel T	Voxel p (unc)	x, y, z {mm MNI}
Left inferior occipital gyrus/lingual gyrus	0.103	111	0.048	0.000	12.65	0.000	-33, -87,-18
Left fusiform gyrus/lingual gyrus				0.000	6.21	0.000	-21, -90, -18
Left middle occipital gyrus				0.000	5.91	0.000	-36, -90, 3
Left superior frontal gyrus	0.27	58	0.139	0.000	11.08	0.000	-18, 60, 9
Left middle frontal gyrus				0.000	6.85	0.000	-27, 57, 9
Left middle frontal gyrus				0.000	5.39	0.000	-33, 54, 3
Left frontal Lobe	0.112	106	0.053	0.000	9.11	0.000	-30, 15, 30
Left middle frontal gyrus				0.000	6.15	0.000	-48, 6, 45
Left precentral gyrus				0.000	5.52	0.000	-39, 6, 39
Right cerebellum posterior lobe	0.2	74	0.099	0.000	6.74	0.000	36, -69, -24
Right cerebellum posterior lobe				0.000	4.82	0.000	33, -75, -30
Right cerebellum posterior lobe				0.002	4.19	0.000	33, -60, -30
Left SMA/BA 6	0.298	53	0.156	0.000	6.54	0.000	-9, 0, 66
Left SMA				0.000	6.18	0.000	0, 9, 63
Right SMA/BA 6				0.001	4.52	0.000	6, 6, 72
Left parietal lobe	0.316	50	0.168	0.000	6.53	0.000	-24, -45, 45
Left superior parietal gyrus				0.000	5.05	0.000	-30, -63, 66
Left superior parietal gyrus				0.000	4.66	0.000	-27, -57, 51

Statistical level: $P < 0.05$ (PDR correction) voxel > 50.

Table 4. Differentially activated brain regions in Uyghur speakers during verb generation task

Differentially activated brain regions (Uyghur > Chinese)	Cluster p (cor)	Cluster equivk	Cluster p (unc)	Voxel p (FDR-cor)	Voxel T	Voxel p (unc)	x, y, z {mm MNI}
Left inferior parietal lobule	0.147	10	0.001	0.000	5.33	0.000	-54, -36, -24
Left inferior temporal gyrus (BA37)	0.098	11	0.001	0.001	4.59	0.000	-45, -39, 24
Left fusiform gyrus	0.098	11	0.001	0.001	3.83	0.000	-27, -30, -12
Left parahippocampal gyrus				0.001	3.65	0.001	-30, -21, -15

Statistical level: $P < 0.05$ (PDR correction) voxel ≥ 10.

we supposed that these two indicators in the language function test were not comparable between the subject groups. Moreover, no significant differences were observed in the gender, age, years of education, and the rest indicators in the language function test between the Uyghur and Chinese speakers (all $P > 0.05$). These results suggest that these Uyghur and Chinese speakers are suitable for the following investigation.

Brain activation in Uyghur and Chinese speakers during verb generation task

The Uyghur and Chinese speakers were subjected to the verb generation task, and meanwhile the activated brain regions in these subjects were detected with BOLD-fMRI. Our results showed that, the Uyghur and Chinese speakers exhibited significant activation in multiple brain regions during the verb generation task. For these right-handed subjects, the distribution of the activated brain regions exhibited an obvious tendency to the left-sidedness. However, in the Uyghur speakers, the brain regions differentially activated during the verb generation task were mainly located in the local brain regions, including the left inferior temporal gyrus (BA37), left inferior parietal lobule, left fusiform gyrus, and left parahippocampal gyrus, which were significantly less activated in the Chinese speakers ($P < 0.05$) (**Tables 2**, **4**, **6** and **Figure 1A-C**). On the other hand, in the Chinese speakers, significantly differential activation was observed in the right superior temporal gyrus (BA38) during the verb generation

Table 5. Differentially activated brain regions in Chinese speakers during verb generation task

Differentially activated brain regions (Chinese > Uyghur)	cluster p (cor)	cluster equivk	cluster p (unc)	voxel p (FDR-cor)	voxel T	voxel p (unc)	x, y, z {mm MNI}
Right superior temporal gyrus (BA38)	0.014	16	0.000	0.000	6.37	0.000	39, 15, -33

Statistical level: $P < 0.05$ (PDR correction) voxel ≥ 10.

Table 6. Similarly activated brain regions in Uyghur and Chinese speakers during the verb generation task

Similarly activated brain regions	cluster p (cor)	cluster equivk	cluster p (unc)	voxel p (FDR-cor)	voxel T	voxel p (unc)	x, y, z {mm MNI}
Left temporal lobe/fusiform gyrus/lingual gyrus (Chinese group)				0.000	6.21	0.000	-21, -90, -18
Left temporal lobe/BA 48 (Uyghur group)	0.003	39	0.054	0.000	7.3	0.000	-51, -9, 24
Left temporal lobe/inferior temporal gyrus/BA37 (Uyghur > Chinese)	0.098	11	0.001	0.001	4.59	0.000	-45, -39, 24
Left temporal lobe fusiform gyrus (Uyghur > Chinese)	0.098	11	0.001	0.001	3.83	0.000	-27, -30, -12

Statistical level: $P < 0.05$ (PDR correction) voxel > 10.

task, whereas the Uyghur speakers exhibited weak activation in this region ($P < 0.05$) (**Tables 3**, **5**, **6** and **Figure 1D**). Taken together, these results suggest that, differential brain activation patterns could be observed in the Uyghur and Chinese speakers during the verb generation task.

Discussion

In the present study, our results demonstrated that the Uyghur and Chinese speakers exhibited significant activation in multiple brain regions during the verb generation task, which was in line with the previous findings [7]. For these right-handed subjects, the functional brain regions for language were mainly located in the left side, which was also consistent with the results from a recent study [8]. However, the activated brain regions during the verb generation task were not identical for these Uyghur and Chinese speakers, which may be related to the different characteristics of the Uyghur and Chinese languages.

It has been shown that the formation of language regions in the brain is the result of long-term adaptable contention in the language environment [9], which is not only related to the brain neural layout, but also associated with the competition of brain regions in the language training. Language is a comprehensive capability of humans, involving listening, speaking, reading, and writing. Therefore, the competition of the brain regions must be more complex, and the multipolarity of language centers is an inevitable result. Our results demonstrated that the Uyghur speakers displayed significantly differential activation in the local brain regions, such as the left inferior temporal gyrus (BA37), left inferior parietal lobule, left fusiform gyrus, and left parahippocampal gyrus, whereas relatively weak activation in these regions was observed in the Chinese speakers. It has been shown that the temporal lobe region is related to the extraction of phonetic elements, and associated with the language comprehension and generation [7]. Based on these findings, the brain region dealing with phonetics is likely to be located in the left superior temporal lobe, and the region dealing with semantics might be in the left middle temporal gyrus and inferior temporal gyrus [10]. The rear part of the left temporal region (BA37) may be the connection between the regions dealing with phonetics and semantics in word generation [11, 12].

At present, it has been widely accepted that the left fusiform gyrus covers the visual word form area [13]. This brain region can be activated in lexical and semantic tasks, which is primarily related to the semantic processing in visual perception [14-16]. Moreover, the left inferior temporal gyrus, left fusiform gyrus, and left parahippocampal gyrus, as well as the right hemisphere mirror regions, have been shown to be related to semantic rendering and lexical retrieval [12, 17]. Our results showed that the left inferior parietal lobule was activated in the subjects during the verb generation task. This phenomenon might be explained that the verb generation task required in-depth semantic analysis of the noun, and comparison and

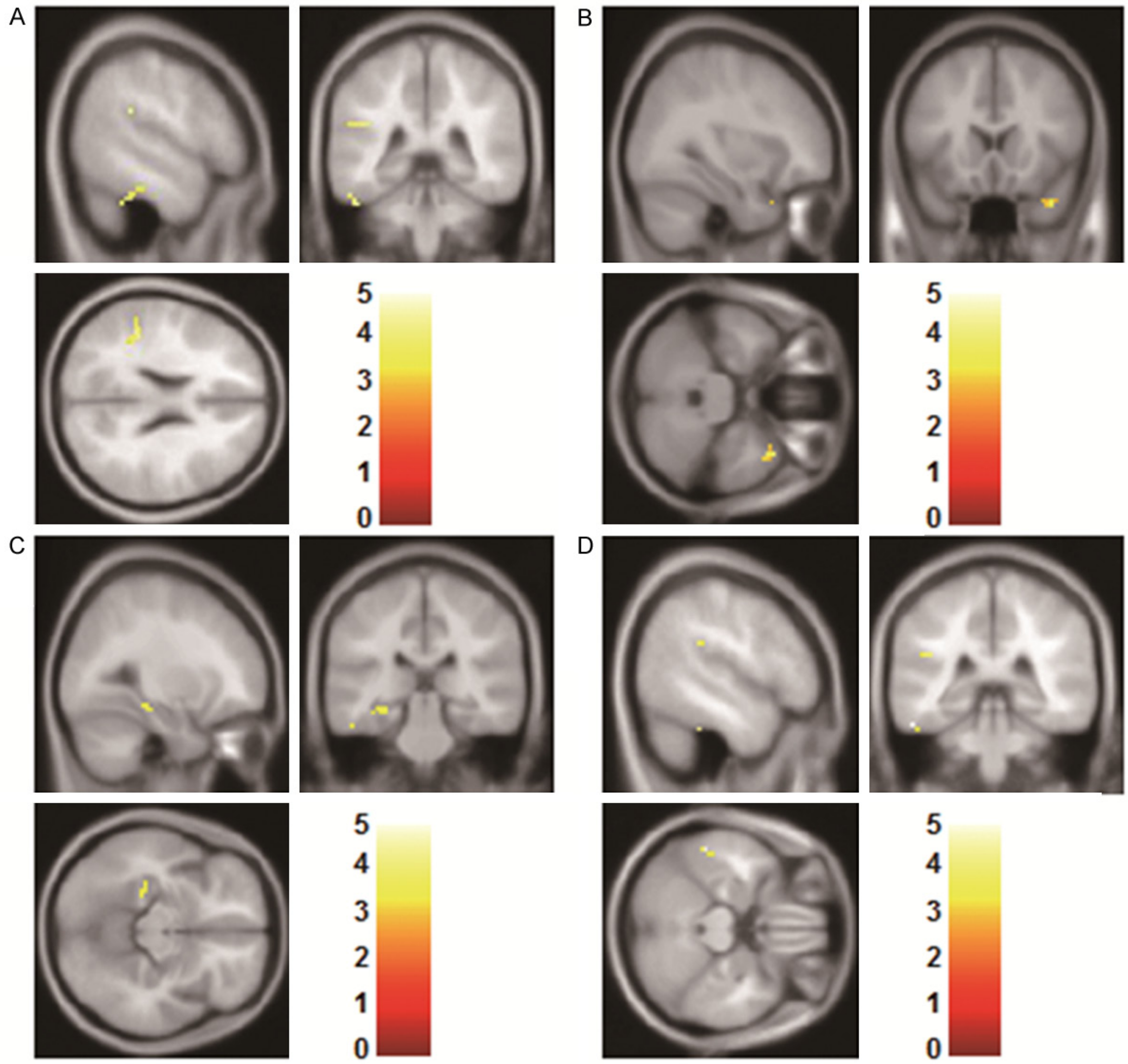

Figure 1. Activated brain regions in Uyghur and Chinese speakers during the verb generation task. The subjects were asked to perform the verb generation task, and meanwhile the activated brain regions were detected with BOLD-fMRI. (A-C) In the Uyghur speakers, the differentially activated brain regions were mainly located in the left inferior temporal gyrus (BA37) and inferior parietal lobule (A), left fusiform gyrus (B), and left parahippocampal gyrus (C). (D) In the Chinese speakers, differential activation was observed in the right superior temporal gyrus (BA38).

selection of related verbs. Further studies are still needed to elucidate the detailed mechanisms.

In this study, our results showed that the Chinese speakers displayed significantly differential activation in the right superior temporal gyrus (BA38), whereas the Uyghur speakers displayed weak activation in this region. In line with this, Tan *et al.* [4] have found that the word association task activates the right BA38 region, suggesting that the right hemisphere is more intensively involved in the processing of Chinese characters. The right hemisphere has the functions of periodic memory and visual-spatial detection [18-22], which are needed in the reading of Chinese characters constituted by a variety of strokes. The recognition of Chinese characters not only activates the visual-spelling system, but also involves the phonetic and semantic processing [23-28]. The left hemisphere is usually involved in logical analysis, as well as phonetic and semantic processing. Tan *et al.* [29] have found that the left middle frontal gyrus is involved in the visuospatial processing of Chinese characters, and the integration of phonetic and semantic analysis. Moreover, it has been demonstrated that the upper temporal lobe, particularly the left superior temporal gyrus, is related to the extraction of phonetic features, and the right superior temporal gyrus may be associated with the recognition of the unique tone and pitch of Chinese characters [30]. Taken together, the processing of Chinese characters is actually associated with a wide range of neural activity in the cerebral cortex.

In conclusion, our results showed that, the dominant hemisphere for these right-handed Uyghur and Chinese speakers is the left cerebral hemisphere. However, in the Uyghur speakers, the brain regions differentially activated during the verb generation task were mainly located in the local brain regions, including the left inferior temporal gyrus (BA37), left inferior parietal lobule, left fusiform gyrus, and left parahippocampal gyrus, while in the Chinese speakers, significantly differential activation was observed in the right superior temporal gyrus (BA38). Differential brain activation patterns were observed for the Uyghur and Chinese speakers during the verb generation task. Compared with the Uyghur language, processing of Chinese characters may involve the right hemisphere more extensively. In China, there is a Uyghur population of nearly ten million living in Xinjiang. This study might contribute to the investigation of the dominant language hemisphere and functional language regions in Uyghur native speakers, and the understanding of the universality and particularity of language processing mechanism in the brain. Moreover, our findings provide valuable information for the evaluation and treatment of language dysfunction after brain injuries in clinic.

Acknowledgements

This study was supported by the National Natural Science Foundation of China (81260181) and the Natural Science Foundation of the Xinjiang Uygur Autonomous Region (2010211B18).

Disclosure of conflict of interest

None.

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