**Research Assessment Exercise 2020**
**Impact Case Study**

University: **The University of Hong Kong (HKU)**
Unit of Assessment (UoA): **UoA33 Linguistics and Language Studies**
Title of case study: **Neurolinguistics Research on Chinese Dyslexia Reduces the Incidence of Postoperative Language Disorders**

## (1) Summary of the impact

Dr. Wai Ting Siok's research work on language neuroscience has led clinical practitioners in China to develop culture-specific brain maps to protect the language functions of patients during brain surgery, thereby reducing the incidence of postoperative language disorders from 70% to 4.5% and improving the health outcomes of stroke patients. The groundbreaking research undertaken by Siok and her team at HKU has drawn international attention to evidence that the neural networks used for reading may be culture-specific, as print-sound mapping varies substantially across writing systems. It had previously been assumed that a common cognitive mechanism underlay reading development in different cultures, and that reading disabilities such as dyslexia had a universal biological origin.

## (2) Underpinning research

Reading acquisition requires application and explicit instruction. Extensive experimental studies using alphabetic languages such as English have shown that phonological awareness is the most robust predictor of alphabetic reading. Neuroimaging studies have consistently shown that a posterior brain region in the left hemisphere – the left temporoparietal region – is activated during phonological or reading-related processing, and deficits in this region will lead to reading disabilities. About two decades ago, it remained a popular assumption that a common cognitive mechanism underlay reading development in different cultures and that dyslexia in different cultures had a universal biological origin. The research work done at the University of Hong Kong in the Department of Linguistics by Professor Li Hai Tan and Dr. Wai Ting Siok using functional magnetic resonance imaging (fMRI) and magnetic resonance imaging (MRI) has instead suggested that the biological abnormality of atypical reading is dependent on culture.

Siok joined the University's Department of Linguistics in 2004. Tan worked at the University of Hong Kong from 1999 until 2014, and is now a Professor at the Shenzhen Institute of Neuroscience. Siok and Tan established the State Key Laboratory of Brain and Cognitive Sciences in 2005 and were instrumental in securing two National Strategic Basic Research Scheme grants ("973" Scheme) from the Ministry of Science and Technology of China, one in 2005 (RMB25,000,000) and one in 2012 (RMB39,000,000). Their work, published in *Nature*, investigated brain mechanisms underlying reading disability in Chinese and provided compelling evidence that the brains of developmental dyslexics differ depending on the language they speak [3.1]. Chinese dyslexics had reduced activation controls in the left middle frontal gyrus region during a reading task, but did not show differences from normal subjects in the left temporoparietal region that had been shown to be abnormal in alphabetic dyslexics. The left middle frontal gyrus is crucial for normal Chinese reading and is supposed to be responsible for the mapping of orthography-to-phonology and orthography-to-semantics. The left temporoparietal systems are important for phonemic analysis and letter-sound conversion, and phonological processing skills have been found to be the core predictor of alphabetic reading. Siok's finding is important as it reveals a significant variation between the neural substrates of Chinese and English impaired reading. Siok and her team further demonstrated that Chinese dyslexic children exhibited reduced gray matter volume in a left middle frontal region when compared with normal reading controls [3.2], and that Chinese dyslexic children had deficits not only in the phonological domain but also in the visual-spatial domain [3.3]. These results suggest that the structural and functional basis for dyslexia varies between alphabetic and nonalphabetic languages. Their work is the first and only study that examines whether weak reading-related activity in the left middle frontal region of Chinese dyslexics is associated with reduced gray matter volume in that region. Developmental

dyslexia is a severe reading disability without deficiency in intelligence, sensory acuity, verbal skills, motivation and educational opportunities. Estimates of the number of Chinese-speaking children affected vary quite widely – between 2% and 10% – as there is no standardised test currently in use.

The research team's main finding that the left middle frontal gyrus plays a pivotal role in Chinese reading has now been replicated by numerous neuroimaging studies published in internationally refereed journals by other researchers (for example, by David Boas and his team at Harvard, published in *Experimental Brain Research*, 2008, 184:427–433; James Booth and his team at Northwestern University, published in *Brain Research*, 2006, 197–207; and Zhao Jizong and his team at Beijing Tiantan Hospital, published in National Medical Journal of China, 2013, Vol. 93, No. 11, 824–826.) Siok has been invited to give several keynote speeches on her research into Chinese dyslexia. These include speeches at the International Symposium on Cognition and Neuroscience in Singapore in March 2019, at the Forum on the Frontiers in Linguistics and Brain Science in Shenzhen in December 2017, and at the Science of Learning-Strategic Research Theme Education and Neuroscience Second Symposium in Hong Kong in June 2015.

In addition to the discovery that the left middle frontal region plays a pivotal role in Chinese reading processing, Siok and her team also found that handwriting helps children to better memorise Chinese characters [3.4] while keyboard usage may negatively impact on children's reading performance [3.5], arousing substantial concern about whether typewriting on electronic devices may increase the prevalence of reading disabilities. Some scholars have advocated that children's use of digital devices should be limited, and that beginning readers should not be allowed to use pronunciation-based inputting methods (i.e., Hanyu Pinyin). However, preventing children from using digital devices is unlikely to succeed. Siok has therefore explored other options for preserving children's reading and writing skills. In a recent study, Siok found that students using orthographic-based inputting methods (such as Cangjie or Quick methods) performed better than students using pronunciation-based inputting methods (such as Hanyu Pinyin) in Chinese reading and dictation [3.6].

**(3) References to the research**

[3.1] Siok, W. T., Perfetti, C. A., Jin, Z., & Tan, L. H. (2004). Biological abnormality of impaired reading constrained by culture. *Nature*, 431, 71–76.
[3.2] Siok, W. T., Niu, Z. D., Zhen J., Perfetti, C. A., & Tan, L. H. (2008). A structural–functional basis for dyslexia in the cortex of Chinese readers. *Proceedings of the National Academy of Sciences of the United States of America*, 105, 5561–5566.
[3.3] Siok, W. T., Spinks, J. A., Jin, Z., & Tan, L. H. (2009). Developmental dyslexia is characterized by the co-existence of visuospatial and phonological disorders in Chinese children. *Current Biology*, 19, 890–892.
[3.4] Tan, L. H., Spinks, J. A., Eden, G., Perfetti, C. A., & Siok, W. T. (2005). Reading depends on writing, in Chinese. *Proceedings of the National Academy of Sciences of the United States of America*, 102, 8781–8785.
[3.5] Tan, L.H., Xu, M., Chang, C.Q., & Siok, W.T. (2013). China's language input system in the digital age affects children's reading development. *Proceedings of the National Academy of Sciences of the United States of America*, 110 (3), 1119–23.
[3.6] Siok, W. T., & Liu, C. Y. (2018). Differential impacts of different keyboard inputting methods on reading and writing skills. *Scientific Reports*. 8, 17183.

Significant Grants

As Principal Investigator:
Grant Title: The Biological basis of reading disability in Chinese children
Sponsor: Research Grants Council (RGC) General Research Fund (GRF)
Period of Grant: 2009–2013 Value of Grant: HK$1,199,340

Grant Title: Neuroimaging studies of reading disability in Chinese children
Sponsor: RGC General Research Fund (GRF)
Period of Grant: 2007–2009 Value of Grant: HK$976,288

As Co-Investigator:
Grant Title: Brain positioning system to protect cortical language functions
Sponsor: Shenzhen Peacock Team Program Grant, Shenzhen Municipal Government
Period of Grant: 2016–2020 Value of Grant: RMB30,000,000 (approx. HK$34,000,000)

Grant Title: Brain mechanisms underlying Chinese language processing and the neurogenetic basis for its disorder
Sponsor: National Basic Research Program (also known as the "973" Program), Ministry of Science and Technology of China
Period of Grant: 2012–2016 Value of Grant: RMB39,000,000 (approx. HK$44,000,000)

**(4) Details of the impact**

Siok's groundbreaking research enables Chinese neurosurgeons to protect the language functions of patients suffering from stroke, glioma, and other brain disorders during brain surgery. It offers valuable insights into the treatment and training approaches appropriate for Chinese dyslexia, and suggests teaching methods that are optimised for native and second language learners of Chinese.

**Medical Applications**

The dissemination of Siok and Tan's findings have alerted Chinese neurosurgeons to issues with applying the western brain map in brain surgeries of Chinese patients suffering from stroke, brain palsy, and other brain disorders [5.1]. Incidence of postoperative language disorders in China used to be much higher (70%) than in the US (20%) [5.2]. A 2015 Ministry of Health report indicated that there are about two million new cases of stroke per year and among them about 40% have severe language disorders. Finding ways of preventing postoperative language disorders and helping stroke patients regain their physical, cognitive and language functions has become an important health issue in China, as stated in the "Healthy China 2030" plan. Based on Siok and Tan's findings and with the support of their 973 grant, a group of neurosurgeons at Shanghai's Huashan Hospital performed awake surgery and intraoperative language mapping on patients with glioma to map their language regions. The neurosurgeons reported that an additional brain area, the left middle frontal gyrus, Brodmann's areas 6/9, was unique in Chinese production and that the language maps for Chinese and English are different. Importantly, with the use of this Chinese-specific language map, the incidence of postoperative language disorders had significantly reduced from 70% (as reported previously) to 4.5% (in their study based on 66 patients) [5.2 & 5.3].

Siok is part of a team that won a Shenzhen Peacock Team Program Grant (RMB30,000,000; 2016–2020) awarded by the Shenzhen Municipal Government to develop a clinical scheme to protect the cortical language functions of brain-disordered patients [5.4, 5.5]. A brain positioning system (BPS) for the Chinese Language has been developed by the Shenzhen Institute of Neuroscience, with Siok as one of the Principal Investigators, making use of the brain findings reported by Tan and Siok. This system has been adopted by three major hospitals in China for brain-surgery planning since 2010. Three additional hospitals have signed a strategic agreement to use the system [5.5].

The BPS helps to precisely map the language regions of individual patients so as to protect language functions during brain surgeries. One hundred and thirty-two brain patients had their fMRI scans performed at Hospital 1 to identify personalised language networks using the language tasks designed in accordance with the HKU team's studies, and the brain surgeries were performed at another hospital. Sixty percent of the patients regained their language functions in full within six months of the surgery. Brain surgeries on 29 frontal-lobe epilepsy patients were performed at Hospital 2. All of them recovered their language functions within three to six months. Three

patients at the Hospital 3 had glioma near the Broca's area and their language functions recovered one month after the surgery [5.5]. Siok's findings further provided guidelines for Chinese neurosurgeons at Hospital 4. According to its Director of the Department of Neurosurgery, the department has "adopted Siok's findings that the left middle frontal regions play an important role in Chinese language in [its] brain surgery planning in order to protect the language functions of brain patients and to reduce the rate of postoperative language disorders. During the period from 2014 to 2018, [it] had performed 30 surgeries and 93% of patients have their language functions fully recovered within six months" [5.6].

**Raising Public Awareness of Changes Needed to Educational and Treatment Practices**

Siok's findings on Chinese dyslexia have received wide international attention. News stories were carried by over 150 international media outlets including Associated Press, AFP Reuters, CNN, BBC, ABC, CBC, TIME, Forbes, Newsweek, New York Times, Washington Post, The Wall Street Journal, The Guardian, USA Today, China Daily, and, most recently, The Economist [5.7]. In addition to press reports, Siok's research findings have been cited on numerous public websites on the issue of dyslexia. These include the China Dyslexia Foundation (http://www.chinadyslexia.org/china-dyslexia-blog/2015/11/26/dyslexia-in-chinese-disability-of-a-different-character), DyslexiaHelp (http://dyslexiahelp.umich.edu/latest/dyslexia-in-chinese), and Aulexic (http://www.aulexic.com.au/dyslexia-exist-languages-english/). Her findings are also quoted on the History of Dyslexia Wikipedia page (https://en.wikipedia.org/wiki/History_of_dyslexia_research).

The extensive media coverage has brought global awareness of Siok's "cultural-specific" perspective on neural circuits for reading. This has led to changes not only in the direction research on Chinese reading has taken in the past 15 years (from arguing that a universal set of predictors underlies Chinese and alphabetic languages, to showing that Chinese and English are served by different cognitive skills), but also in the treatment approaches for Chinese reading and dyslexia. Based on Siok's 2009 study in *Current Biology*, Connie Ho, Professor of Educational Psychology and Founder of the Hong Kong Specific Learning Difficulties Research Team, has commented that, "This means that intervention methods for Chinese and English dyslexics may be different… the former may focus more on orthographic [or spelling and writing] training, while the latter may focus on phonological [or sound] training" [5.8]. Siok regularly receives emails asking for details of her research, most recently from a schoolteacher at a bilingual school in Alberta, Canada, looking to use Siok's findings to improve her students' Mandarin reading comprehension [5.9].

**(5) Sources to corroborate the impact**

[5.1] Statement from the Director of the Department of Neurosurgery, Hospital 4.
[5.2] Interview with Tan for the *Southern Daily* in 2016 with incidence rates of postoperative language disorders in China.
[5.3] Wu et al., (2015). Direct evidence from intraoperative electrocortical stimulation indicates shared and distinct speech production center between Chinese and English languages. *Human Brain Mappings*, *36*, 4972-4985.
[5.4] Details from the Shenzhen Peacock Programme website.
[5.5] Statement from the Shenzhen Institute of Neuroscience.
[5.6] Statement from Hospital 4.
[5.7] Press clippings from *The Economist*.
[5.8] Interview with the *South China Morning Post* dated April 11, 2016.
[5.9] Email correspondence from a teacher in Alberta, Canada.