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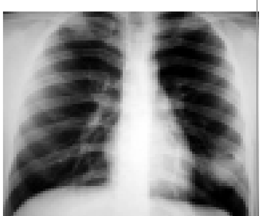

Cover Picture:
Chest radiograph (posteroanterior projection) shows a lower zone opacity with an air crescent sign.
(Refer to pages 93-100)

Editorial

Brain differences between bilinguals of differing proficiency: an empirical look at an emotional issue

M W L Chee

Difficulty with acquiring a second language is not by any stretch of the imagination an illness. Yet in some communities where social and political pressures to achieve proficiency in the mother tongue exist, those who are not facile in language acquisition experience suffering not dissimilar to what persons with a chronic illness experience: emotional pain, a sense of deficiency, restriction of access to educational and sometimes, career opportunities. Politicians and parents alike may argue the case for and against expecting children to be bilingual but in many instances, emotive arguments have been raised without the support of empirical evidence. If it is truly a more thoughtful society we wish to build and one where reason serves to guide action more than emotion, it behooves us to study the brain, the source of our ability to acquire language.

My laboratory has been involved in the characterisation of the bilingual brain for several years[1-5]. One of our goals was to seek clues as to why, despite being immersed in the same environment, some individuals have difficulty acquiring a second language even though they have an excellent command of their first language. Several lines of evidence suggest that phonological working memory (PWM) plays a crucial role in determining language acquisition ability[6]. Working memory is a psychological construct based on observations on short-term memory. It refers to a short-term capacity limited system whose contents are organised into phonological and visuo-spatial sections. While there are many criticisms of this construct, it has motivated memory research in a resounding manner over the years and a credible alternative platform to study short-term memory that has broad-based appeal has yet to emerge.

Previous theoretical and behavioural work points to the existence of two dissociable components in PWM: a subvocal rehearsal system and a short-term phonological store. Functional imaging results suggest that the subvocal rehearsal system is located in Broca's area (Brodmann's area (BA) 44), left premotor cortex (BA 6) and supplementary motor area (BA 6) whereas the phonological store resides in the left inferior parietal cortex (BA 40)[7,8]. The obligatory role of the frontal opercular areas in phonological processing has been recently demonstrated using repetitive transcranial magnetic stimulation (rTMS)[9].

PWM is thought to temporarily store unfamiliar sound patterns, while more permanent representations are being constructed for long-term memory storage[6]. In support of these postulates, a number of behavioural studies have shown that measures of PWM, such as digit span, word and non-word repetition, predict the outcome of native language acquisition in children[10-12] as well as foreign language acquisition in both children[13] and adults[14,15]. It has also been observed that polyglots have a larger PWM capacity than non-polyglots[16]. Further, neuropsychological studies of

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patients with defective short-term memory[17], and children with specific language impairment and low achievement[18,19] provide additional support for the hypothesis that the PWM plays a crucial role in language acquisition. Taken together, these findings point to a compelling link between PWM and language acquisition and suggest that PWM is important for successful language acquisition.

We recently reported how the neural correlates of PWM differed in young adults who achieved excellent grades in English but who differed in attainment as regards their second language (Chinese)[3]. In this study, language proficiency was indexed by scores attained in standardised language examinations that evaluated both oral and written language skills. To reduce the confounding effects of factors that could influence second language acquisition, volunteers were matched for educational environment, scholastic performance, and performance in a number of standardised neuropsychological tests of non-verbal and verbal skills. Persons who were proficient in both English and Chinese were termed Equal Bilinguals and those who were proficient in English but not Chinese were termed Unequal Bilinguals.

To evaluate the neural correlates of PWM, participants were scanned while performing an auditory n-back test. Successful performance of this task requires continuous updating and temporal re-ordering of phonological information. We used stimuli that were phonologically unfamiliar to the volunteers to ensure that task performance would be minimally facilitated by prior linguistic experience with respect to the test items. Item load was varied in order to reveal PWM load-dependent effects on activation. Functional magnetic resonance imaging (fMRI) detects subtle changes in signal arising from neuronal activity driven changes in blood flow. The basic premise of this technique is that regions of the brain whose neurons are active in the processing of a particular task trigger a detectable increase in local blood flow. For convenience, we refer to this signal change as "activation" when signal increases and "deactivation" when signal decreases with respect to an experimentally-determined baseline.

We expected areas engaged by PWM to show a monotonic increase in activation[8,20]. This is a device used by researchers to differentiate an area directly involved in processing the task from one serving as a bystander participant. For example, auditory areas are activated when one listens to sounds. However, activation in these regions will not increase according to memory load whereas activation in areas involved in PWM may be expected to increase as memory load increases. We predicted that there would be group level differences in activation in brain regions involved in PWM and that this difference would be more prominent with increasing PWM load. We made no specific prediction concerning the direction of the effect as previous studies have shown both increases[21] and decreases[22,23] in brain activation after a linguistic task is learned.

Our results yielded two critical sets of observations. In Equal Bilinguals, there was increased activation in cortical areas that participate in subvocal rehearsal. This refers to greater activation of the left insula and inferior frontal regions. In Unequal Bilinguals there was greater activation in areas engaged in goal directed processing. This refers to greater activation of the cingulate and greater deactivation of the anterior medial frontal region. Differences in cortical activation suggest that it is a more optimal engagement of PWM in Equal Bilinguals rather than limitation of PWM capacity or reduced processing speed on the part of Unequal

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Bilinguals that could account for differences in second language attainment. It was significant that the behavioural data showed a close match in non-verbal abilities, several tests of memory and educational background. Further the in-scanner performance of the n-back task was matched across both groups.

Group differences in cortical activation

In addition to production or motor aspects of language, the insula and inferior frontal gyrus have been shown to participate in several language and working memory related processes[24-28]. Superior phonological working memory as it relates to the ability to repeat unfamiliar phonotactic constructs correlates with vocabulary development[29]. Thus, the observation that Equal Bilinguals activate this region more readily with increasing WM demands relative to Unequal Bilinguals may be interpreted as denoting a more facile engagement of the neural circuitry required to incorporate novel speech-like sounds into long-term phonological representations. The successful engagement of such neural circuitry may correspond to vocabulary growth[10]. This might be especially relevant to Chinese since the mapping between characters and pronunciation is not transparent unlike in an alphabetic script like English.

Several lines of evidence suggest that phonological working memory (PWM) plays a crucial role in determining language acquisition ability.

Greater activation in a number of brain regions, including the left anterior insula and Broca's area, was observed in the course of learning a difficult speech-contrast[21]. Activity in these two regions was correlated with better performance in learning this difficult speech-contrast[30]. To account for these findings, it was postulated that in the course of learning unfamiliar speech contrasts, orosensory-articulatory mappings that engage speech-planning areas (anterior insula and Broca's area) facilitate the identification of unfamiliar speech contrasts. This explanation could contribute to explaining the greater activation of the left anterior insula in Equal Bilinguals in the present study. Our results also add weight to a proposal that traditionally "motor" areas are also involved in sensory-perceptual processes[31]. It turns out that this area is important in conferring on us the capacity to mimic the actions of others (so-called mirror neurons[31]). If so, then better language acquisition skills could also be correlated with our ability to mime action.

Group differences in cortical deactivation

Deactivation, referring to a reduction of BOLD signal during task performance relative to the baseline[32] was more pronounced with increasing load in both groups. The deactivated anterior medial frontal regions we observed are part of a "default network"[32,33] that is more active during passive (baseline) than active (task) conditions in a wide variety of experiments[34,35]. We interpreted this finding as an indication of a greater need to allocate attentional resources to perform the PWM task at higher levels of load. This notion is supported by the observation that cingulate activation, a marker of having to deal with response conflict, was greater in Unequal Bilinguals.

Links among imaging findings, behavioural findings and second language attainment

While the functional imaging results and the level of second language attainment are clear enough, the equivalence of working memory and phonological test scores might raise doubt about the imaging findings. In this regard, it is critical to appreciate the objectivity of standardised scores of language attainment. We might therefore attribute the absence of significant group differences in behavioural scores to the possibility that while these tests engage PWM, they are relatively insensitive and that greater numbers (typical for behavioral experiments) of volunteers might be necessary to uncover such effects. Herein lies the potential additional contribution of neuroimaging to studying the human mind[36,37]. The notion of "intermediate phenotype" suggests the existence of persons who are genetically predisposed to certain traits but who may not express overt phenotypic abnormality.

Limits of the present study and future extensions

In our study, it was not possible to determine if the group differences in cortical activation between Equal and Unequal Bilinguals are the cause or consequence of second language attainment. However, this is clear: there is a difference in the way the brains of the two groups work when performing a task engaging PWM, even though they appear to be performing the task to the same level of competence.

One additional piece of data that would be worth studying is whether or not there are structural in addition to functional differences in the left insula in different bilinguals. While my guess is that a larger left insula might be found in polyglots, this finding might also be a consequence of rather than predictive of facile bilingualism. In support of this, regional gray matter volume in the temporal cortex has been shown to be higher in professional musicians compared to amateur musicians and non-musicians[38]. Structural differences were also observed in the parietal cortex in early acquisition, proficient bilinguals[22].

The Singaporean parents' dream of being able to classify children into potentially facile and non-facile bilinguals may one day be achieved. While more research remains to be done, we have certainly taken a few steps along the journey.

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