Neuroplasticity, Neuroimaging and Bilingualism:

Commentary on Baum and Titone

Denise Klein[1] and Kate E. Watkins[2]

McGill University[1] and Oxford University[2]

Address for Correspondence:

Denise Klein, PhD

Cognitive Neuroscience Unit, Montreal Neurological Institute

3801 University Street

Montreal, Quebec, H3A 2B4

Canada

Email: **denise.klein@mcgill.ca**

Acknowledgement note: Preparation of this manuscript was supported by grant 254547 from National Sciences and Engineering Research Council of Canada (NSERC).

Neuroplasticity, Neuroimaging and Bilingualism:

Commentary on Baum and Titone

In this comprehensive review by Baum and Titone, the authors promote the notion that bilingualism should be thought of as an agent of neuroplastic change over the lifespan. Their proposal offers a context within which to view early enrichment, one element of which is the early learning of two languages. The review points out the complexities of studying bilingualism and highlights empirical gaps in research that are critical to our understanding of how experience with language, especially exposure to two languages, might affect the neurocognitive system. The framework brings together disparate sets of studies in the literature across multiple methods, models, and disparate repertoires of descriptive terms.

The review sets the scene for those interested in the topic, to examine the misconceptions related to learning multiple languages and to become better champions for the benefits of bilingualism by obtaining greater clarity about the neural changes associated with such learning.

Recently, the dynamic nature of the human brain has been emphasized, with studies describing unrealised potential in the brain's ability to be shaped and reshaped throughout the lifespan. With growing evidence that neuroplastic changes can occur even during adulthood, a number of researchers propose that engaging in stimulating activities may be beneficial for cognition in aging and for delaying the onset of dementia (Wilson, Mendes de Leon et al., 2002; Grant and Brody, 2004). In line with this research, Bialystok and colleagues have suggested that bilingualism in particular might also provide protective effects in aging and offset the onset of dementia (Bialystok & Craik , 2010). Although intriguing, and potentially very important, at

present, very little is known about the structural brain changes which underlie these reported benefits in bilinguals. Moreover, it remains to be tested whether long-standing bilingualism confers an advantage in ageing due to the exercising of executive function, specifically inhibitory control, that is required from living in a bilingual environment (as espoused in data from the aging literature which assumes that the advantage of bilingualism is gained over a life-time of inhibiting the other language) or from some other mechanism, given that this advantage has also been described, even in young children (Peal and Lambert, 1962; Bialystok, 1986; Kovacs and Mehler, 2009). Bridging of developmental and adult literature would enable us to tease apart how different experiences with language impact the ongoing development of the brain. Moreover, we still do not know whether the mechanisms and neural underpinnings of what has been considered protection against cognitive decline related to bilingualism are similar to other factors that are thought to provide cognitive reserve and whether this protection is simply a global effect on all aspects of decline in aging, or whether the effects have some specificity related to specific disorders or specific aspects of protection.

The development of whole-brain MRI-based anatomical measurement techniques has spurred research showing that brain anatomy can change as a function of experience. It is interesting to note that the majority of brain imaging work on bilingualism has focused on young adults and not on the time in late adulthood when the potential neuroprotective effects of bilingualism are thought to emerge. Neuroplastic changes related to bilingualism generally, and vocabulary acquisition, specifically, have been documented (Mechelli et al., 2004; Lee et al., 2007). To our knowledge, what is missing is longitudinal imaging data in older bilinguals to provide anatomical correlates of multilingualism or of advantages in executive function/inhibitory

control. Nevertheless, it is reasonable to assume that the changes documented in bilingual young adults will persist into late adulthood and may even be strengthened as these individuals age and continue in their usage of both languages.

Our own data recently found neural correlates that relate to the age of acquisition and perhaps the context in which a language is acquired rather than the usage of two languages (Klein et al, 2013). Strikingly, we found no differences in brain structure (cortical thickness) due to bilingualism in simultaneous bilinguals compared to monolinguals. This suggests that learning two languages from birth, as if natively, does not alter brain structure relative to learning only one language. Also we found that life-long use of two languages into the third decade did not appear to produce measurable differences in brain structure that might be considered advantageous in supporting healthy ageing or staving off age-related decline or dementia onset. In contrast, neuroplastic changes were measurable in relation to age of acquisition in the sequential bilinguals, who learnt their L2 during childhood and also experienced usage of both languages since that time. In these people, the largest changes in brain structure relative to a group of monolingual adults occurred the later in life the L2 was acquired. We observed changes that resulted in both increased and decreased cortical thickness in relation to age of acquisition of the L2. It is not clear which of these is more advantageous. Normal patterns of maturation result in cortical thinning (Sowell et al, 2003), so an area reduced in cortical thickness might be considered to be more specialised or efficient in processing. On the other hand, many studies measuring neuroplastic changes due to new learning in adulthood (e.g. juggling, navigating) report increases in the volume of grey matter, and in these cases, “bigger might be considered better” (Draganski et al., 2004; Maguire et al., 2000). Given normal ageing results in

a loss of bulk or tissue, having a thicker cortex due to later or earlier acquisition of L2 could be seen to be advantageous and delaying of consequential cognitive impairments. This remains to be determined.

Our experience with functional imaging in bilingualism is also supportive of the need for better descriptors and matching of groups for proficiency, experience and environment etc. In the first imaging study of bilinguals that was published in 1994, we reported increased activation of the putamen when native speakers of English spoke their L2 French (Klein et al, 1994). We replicated this effect in a later study in 2006 for bilinguals with English as their L1 and French as an L2 (Klein et al, 2006). We were unable to replicate this activation for another group of bilinguals for which French was the L1 and English the L2 and for a group of bilinguals where Mandarin was their L1 and English was their L2 (Klein et al 1999). We suspect that this difference was not language related, as these effects have been observed in other languages (Abutalebi et al, 2013), but instead due to some uncontrolled difference between the groups of bilinguals studied that related to proficiency or accent control.

We agree with the authors that the field is now poised to address these questions and that in vivo brain imaging technologies make it possible to explore changes in the underlying brain structure of humans. A good understanding of the relationship between structure and function is fundamental to the ability to draw inference from data. While it is clear that group comparisons are instructive, we agree that the inferences drawn from such comparisons are highly limited unless care is taken to address confounds at all stages of the research process from study design to data analysis to interpretation of the results. As we move forward it might be helpful to

develop standardized ways of characterizing language background and proficiency measures, as well as analysis techniques to be shared across laboratories so that greater strides can be made in advancing our understanding.

As Baum and Titone note, there is desperate need for longitudinal studies of bilingualism and ones that study bilinguals across the lifespan. The observation that anatomical features differ across groups of people who differ in background is useful but not sufficient by itself to demonstrate that the feature has caused the change. A persistent question in bilingualism is whether such effects can be causally attributed to such learning, and we agree that stronger evidence for causality will come from longitudinal studies. Moreover, the imaging studies that are out there have not yet integrated information across imaging modalities to understand how anatomical, functional and connectivity characteristics of the brain relate to one another.

As articulated in this review, in future research, sophisticated behavioural investigations combined with brain imaging tools and good characterization of language acquisition histories of participants, will help to shed light on the functional and structural changes associated with bilingualism. It will also be of interest to determine what individual factors are at play in predicting success in language learning and in cognition more generally, and whether there are ways to facilitate language learning and cognition in individuals who experience difficulty. The answers to these questions are likely to be complicated and nuanced and we believe that the brain imaging field should move beyond a localizationist descriptive approach, and apply the same level of complexity of analysis and interpretation to anatomical analyses that have been most recently applied to the study of behavior.

Cognitive neuroscientists are still early in their understanding of how experience with language may influence wiring in the brain, with the field increasingly moving from a static view of the brain in favour of a nervous system that adapts and reorganizes in response to specific cognitive demands, environmental influences, or damage. The time is right for elucidating when windows open and close in the brain for learning language. Cross-sectional and longitudinal neuroimaging studies will reveal the impact of early language experience at different developmental epochs, from childhood through to old age. Such research should open new doors to understanding how brain function is linked to human behaviour and learning.

References

Abutalebi J, Della Rosa PA, Gonzaga AK, Keim R, Costa A, Perani D. (2013). The role of the left putamen in multilingual language production. *Brain Lang.* 125(3):307-15. doi: 10.1016/j.bandl.2012.03.009.

Bialystok, E. (1986). Factors in growth of linguistic awareness. *Child Development, 57*(2), 498-510. doi:10.1111/j.1467-8624.1986.tb00048.x

Bialystok, E., & Craik, F.I.M. (2010). Cognitive and linguistic processing in the bilingual mind. *Current Dir. in Psych. Sci., 19*(1), 19-23.

Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., May, A. (2004). Neuroplasticity: changes in grey matter induced by training. *Nature,427,* 311–312.

Grant MD and Brody JA. (2004). Musical experience and dementia. Hypothesis. *Aging Clin Exp Res.*16(5):403-5.

Klein, D., Zatorre, R. J., Milner, B., Meyer, E., and Evans, A. C. (1994). Left putaminal activation when speaking a second language: Evidence from PET. *Neuroreport*, 5, 2295-2297.

Klein, D., Watkins, K. E., Zatorre, R. J., and Milner, B. (2006). Word and nonword repetition in bilingual subjects: A PET study. *Hum. Brain Map.*, 27, 153-161.

Klein, D; Milner, B; Zatorre, RJ.; Zhao, V; Nikelski, J(1999). Cerebral organization in bilinguals: A PET study of Chinese-English verb generation. *Neuroreport*: 10 (13) 2841–2845

Klein, D., Mok, K., Chen, J-K, and Watkins, K. (2013). Age of language learning shapes brain structure: A cortical thickness study of bilingual and monolingual individuals. *Brain &Lang.,* /doi:pii: S0093-934X(13)00112-0

Kovács, A and Mehler J. (2009). Cognitive gains in 7-month-old bilingual infants. *Proc Nat. Acad. Sci,* 106 (16) 6556–6560, doi: 10.1073/pnas.0811323106

Lee, H., Devlin, J. T., Shakeshaft, L. H., Brennan, A., Glensman, J., Pitcher, K., Crinion J., Mechelli, A., Frackowiak, R. S., Green, D. W., & Price, C. J. (2007). Anatomical traces of vocabulary acquisition in the adolescent brain. *Journal of Neuroscience, 27*(5), 1184-1189.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S. J., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences of the United States of America, 97*(8), 4398-4403. doi:10.1073/pnas.070039597

Mechelli A., Crinion, J. T., Noppeney, U., O'Doherty, J., Asburner, J., Frackowiak, R. S., & Price, C. J. (2004). Structural plasticity in the bilingual brain. *Nature, 431*, 757.

Peal, E., & Lambert, W. E. (1962). The Relation of Bilingualism to Intelligence. *Psychological Monographs, 76*(27), 1-23.

Sowell, ER, Peterson, BS, Thompson, PM, Welcome, SE, Henkenius, AL, Toga, AW. (2003). Mapping cortical change across the human life span. *Nature neuroscience* 6 (3), 309-315

Wilson RS, Mendes de Leon CF, Barnes LL, Schneider JA, Bienias JL, Evans DA, Bennett DA. (2002), Participation in cognitively stimulating activities and risk of incident Alzheimer disease. *Journal of the American Medical Association,* 287:742–748.