Does Age Of Acquisition Of A Second Language Have An Effect On Brain Structure/Function Among Multi- And Bilinguals?

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Abstract

While some people may be monolinguistic, the majority of humans learn more than one language in their lifetime. It is reasonable to ask if the age of acquisition (AoA) of a second language (AoA) has any impact on brain structure and functionI. I presented evidence from five different articles to reinforce my claim that AoA of L2 does indeed have a profound impact. I started by displaying results from studies conducted by Bloch et. al, Jasinska, K. K., & Petitto, and Cargnelutti et. al to present the functional differences; contrasting rates and variations of activations in language regions among individuals depending on their AoA of L2. Furthermore, I supported this with research done by Kaiser et. al., where they found that gray matter (GM) in cortical regions associated with language increased with AoA of L2 among multilinguals. These differences can be linked to a suboptimal recruitment of the brain for language learning the later the acquisition of L2 takes place. Lastly, to summarise the consequence of this structural/functional difference I put forth research done by Gullifer et. al,, where they displayed distinct results of reactive performance to a general cognitive task done by groups with different AoA of L2.

Language is a system of functions relating to communication and is an essential part of human cognition. It is one of the earliest skills we attain as infants and use for the rest of our lives. A well-known fact is that multilingualism (people who know more than one language) reflects more robust neural activity in the brain; giving it a “signature” (Kovelman et al., 2008). They also show greater activity in classical left hemispheric tissue as opposed to monolinguals (Jasinska, K. K., & Petitto, L. A., 2013).

In this paper I will be discussing the relation between age of acquisition (AoA) of a second language (L2) and the structural/functional effects in the brain. Various other studies have previously displayed the plasticity of the human brain through reshaping across a lifetime. I will discuss how the neural networks specifically concerning language can be fundamentally different across groups who learned L2 at different ages. Furthermore, I will be providing evidence using multiple relevant articles in order to demonstrate both the different rates/variations of activation and the structural differences in the brain between subjects with different AoA of L2. Presenting the potential malleability of the human brain through training at an early age.

The findings from the studies I will refer to will help explain the variability of language learning abilities in adults and the potential for priming a brain for language learning through early acquisition of a second language. I will also explore the structural differences across groups as a result of their linguistic upbringing. Furthermore, I will show how these functional and structural variabilities may have further implications in some general cognitive processes (eg. control). To begin, I will outline the regions of interest in the brain; focused in language areas.

In Classical language theory, the areas of the brain relevant to language processing are Broca’s region (in the frontal lobe) and Wernicke’s region (in the temporal lobe) both lateralized to the left hemisphere (LH) and their right hemispheric (RH) counterparts. Broca's region is commonly associated with articulation (phonological and syntactic) while Wernicke's region is associated with semantics. These regions are thought to be connected by four different routes (2 dorsal and 2 ventral). The RH counterparts are classically thought to function in the context of prosodic language, and narrative comprehension (Banich, M. T., & Compton, R. J., 2018). As of recent, further research has been conducted in order to determine the extended language network, done through neuroimaging studies (Ferstl, 2008). I will now explore the various ways the function in the aforementioned language regions are different in relation to the AoA of L2, and provide reasons why this phenomenon is observed.

The AoA of L2 is relevant because of the sensitive period hypothesis; defined by a period of time in early childhood where individuals are highly receptive to certain types of stimuli. After this specific age, learning may become challenging (Sagarra, N., 2010). The age of 6 is recognized to be the cut-off. These findings can possibly be explained by the following developmental events that take place around this time: i) The brain is almost adult size (e.g., Giedd et al., 1999); ii) Myelination processes are complete (Nakagawa et al., 1998); iii) Memory is organized similarly to adults and the verbal component takes an importance, with respect to visuo-spatial components (Gathercole et al., 2004). The dissociation between implicit and explicit memory systems also takes place around this age. Where during the sensitive period, children mostly acquire skills through implicit memory i.e 'subconsciously'. The relation between AoA of L2 and neural function was seen very early on (Cargnelutti et. al, 2019).

Before the invention of imaging technology, cognitive findings were made from the presence of disabilities among individuals who suffered from injury in certain cortical regions. Lesions among polyglots who suffer aphasia in only one of the originally mastered languages were found. This showed double dissociation in representation between two languages (Bluhme, H., 1981). Furthermore, simulation of discrete regions in polyglots by electric signals of the neocortex in the dominant hemisphere successfully resulted in selective disruption. This implies that the 'cortical networks responsible for language' use different regions depending on the select language. Going back to our original premise, the AoA of L2 has a significant impact on these cortical networks for different languages. I will outline several journal articles to enforce this claim.

In correspondence, Bloch et. al. (2009) conducted a study discerning the relationship between the AoA of L2 and the variability in activation elicited by narration across three languages within a subject. The goal of their research was to investigate the differences in 'degree' of activation during language specific tasks between earlier and later AoA of L2 among multilinguals. The following questions were entertained: i) Does AoA have an influence on cortical representation of multilingual repertoire?; ii) Is there a critical time period for native like representation of late learned languages?

Their hypothesis was that the AoA of L2 has an effect on the cortical representation of a multilingual repertoire. 44 multilinguals subjects with different AoAs studied, and all them were fluent in 3 languages (L3 was learned after the age of 9). The subjects were divided into four groups: i) simultaneous, growing up in a bilingual family (n = 16); ii) covert simultaneous, growing up in a monolingual family with language different from surrounding (n = 8); Sequential, AoA between 1-5 (n = 8); and iv) Late, AoA after the age of 6 (n= 12).

All their participants had successfully passed the requirements for academic education and had spoken the 3 languages on at least medium proficiency, so that these factors did not impact the results. The experiment was conducted using fMRI on subjects who underwent a silent narration task with the independent variable of language. This task was based on the one done by Kim et. al. (1998), and was specifically chosen in order to simulate the use of language in everyday life. A within-subject analysis of the 3 languages was conducted with focus to classical language areas; Broca's & Wernicke’s. This consisted of the calculation of variation in activation among the languages within each subject.

Their results show that simultaneous bilinguals have an overlap in activation for all three languages and bilateral activation in Wernicke’s area. While covert simultaneous bilinguals exhibited lateralized activation in Wernicke’s area stronger in L1 compared to L2 and L3. The sequential group had comparable levels of activation albeit a bit more focused and left-centered. In contrast, the late group presented a stronger activation for their late learned L2 & L3 with a tendency for bilateral activation in both Broca’s and Wernicke’s regions, along with further activation in the basal ganglia. In the three groups of early multilinguals, several subjects showed no activation at selected thresholds while late multilinguals did in at least one of their three languages. Therefore, It was found that the variation in the number of activated regions (voxel in the image) elicited by the 3 languages in both Broca’s and Wernicke’s areas is related to the AoA.

To delve into further detail, for Broca’s area, the three groups of early multilinguals had 11 subjects with no activation in any of the languages, while others showed activation in one or more. Late multilinguals on the other hand exhibited activation in at least one of their ‘late’ learned languages, displaying that the range of activation is dependent on the AoA of L2. Overall, variation in Broca’s area is directly correlated to the AoA; lowest in the simultaneous group, highest in the late group. The same findings were made in Wernicke’s area, albeit lower across the board. These observations suggest a considerable overlap in the cortical substrate which supports internal speech in different languages. Late multilinguals did tend to show more activity in L2/L3 than in L1 implying their requirement for increased workload in the processing of late-learned languages.

The homogenous activation in “early multilinguals” independent of languages used indicates that early exposure of two languages can result in the formation of a language processing system that is able to handle all languages acquired (including later-learned ones). Therefore, making the brain of these individuals organised in a fundamentally different manner than late multilinguals who show more variability; causing an inhomogeneous activation. This is also supported by linguistic studies that have shown that “passive” exposure to other languages during childhood can lead to an unfocussed form of learning and to a form of competence that can be reactivated at later stages of life.

For further analysis of previous findings regarding AoA and functional representation, I will be discussing the research conducted by Cargnelutti et. al. (2019) very recently, in which they implemented a statistical analysis on previous research in this topic. Their goal was to determine possible contrasting brain representations in relation to the critical period of learning and also visualise functional differences between Simultaneous and Sequential learners of L2. In addition, they included the variable of language proficiency to determine whether it plays a role in the findings related to AoA of L2.

Their research was conducted using numerous papers that had done neuroimaging in relation to AoA of L2, restricting selection to studies that addressed main structural domains, and excluding specific tasks such as emotional components or mathematics. Studies with participants having a higher proficiency in L2 were also excluded. In total, 57 papers were used (53 fMRI, 4 PET). The three AoA of L2 groups were: very early, ages 0-3; early, ages 3-6; and late, after the age of 6. The analysis they implemented was activation based likelihood (ALE) which evaluates whether clustering in a region is higher than the expected under null distribution of a random spatial association (with $P < 0.05$). Their hypotheses were: i) Greater functional activation for the late group; ii) Greater activation for L2; iii) Differences in groups reduce among high proficiency individuals.

The results for the Early group show functional activation in five regions for L1 (eg. the inferior temporal gyrus, the inferior frontal gyrus, etc.). While L2 show activations in four regions (eg. the superior parietal lobule, precentral gyrus, etc.). The late group displays a more robust selection. L1 specifically shows activation in eight regions for (eg. inferior occipital gyrus, middle temporal gyrus, cerebellum, etc). While L2 shows activation of eleven regions(eg. superior posterior-medial frontal gyrus, calcarine gyrus, angular gyrus, cerebellum, insulae, etc). Furthemore, in regards to individuals with high proficiency, for L1, the early group presents activated regions in the middle temporal gyrus and (ii) the posterior-medial frontal gyrus, while the late group presents activated regions in the (i) posterior-medial frontal gyrus; and (ii) the inferior frontal gyrus. For L2, proficient individuals in the early group presents activations in the middle temporal gyrus and (ii) the posterior-medial frontal gyrus, while in the late group activates a much robust set of five regions (eg. the inferior parietal cortex, insulae, etc).

There are no general conjunctions found in L1 between the two groups (early and late), while L2 has one conjunction; the inferior frontal gyrus. The findings display a widespread language network predominantly in the left hemisphere. This network includes classical language areas with additional cortical and subcortical regions to support lingual functions. The parietal lobe especially was activated and indicates a relevance of working memory activation (localised in this region), reflecting on the heightened necessity of bilinguals to reinforce linguistic information with a particular language (control). The lower number of regions activated in very early bilinguals show evidence of the previously mentioned concept of ‘subconscious acquisition’, implying a lower cognitive effort. The recruitment of the left superior frontal gyrus in late bilinguals also shows their greater use of executive control in relation to L2.

The further implications of the findings that very early bilinguals only activate a few regions consistently reinforce the previously shown evidence on their recruitment of a lower variation of regions to perform language tasks. Even in L1 tasks, late bilinguals showed a greater number of activation clusters in language associated areas and control areas. This indicates their internal inhibition of the first language in all lingual contexts, which must be overcome. Furthermore, high proficiency did not significantly decrease the differences between early and late groups as late bilinguals consistently had a wider activation range than early ones; sharing a cluster in only the left inferior frontal gyrus. This reinforces our original claim that AoA specifically plays an important role in functional organisation rather than other underlying variables involved.

To supplement the previous finding of separate regions of activation for language among groups with different AoA of L2, I will disclose the study conducted by Jasinska, K. K., & Petitto, L. A. (2013). In this article, they have shown how very early life experience (0-3 years), and not just before the critical period, can have a profound impact on the brain's functional organization. This is a further in-depth analysis on the difference between simultaneous and sequential learners of L2.

They used FNIRS (a real time recording measure of deoxygenated and oxygenated hemoglobin with 3-4 cm depth in the cortex) to measure activity among 2 groups of participants: simultaneous AoA (0-3 years); and sequential AoA (3-5 years). The participants completed a language specific judgement task in their first language. In this task they were presented sentences of types object-subject, subject-object, plausible and implausible. The hemodynamic (BOLD) response during syntactic processing of these sentences was measured.

The results revealed significant differences between simultaneous and sequential bilinguals with the expected greater activation for the sequential group in the following regions: i) left superior temporal gyrus; ii) right superior temporal gyrus; and iii) dorsolateral prefrontal cortex. This solidifies the idea in findings from previous studies and applies them to two subsections of earlier AoA groups. It shows how linguistic development during not only the critical period but rather a much earlier time in human life (before age 3) can have profound impact on the human brain; which remains into adulthood. This contrasting functional organisation of brains among early AoA groups also coincides with a structural difference.

In the study conducted by Kaiser et. al. (2015), they studied how the AoA of L2 has an impact on gray matter volume. This has implications on neural plasticity and the impact of early life development in construction of cortical regions. They conducted a study using structural MRI among individuals fluent in three languages, where the third language was learned after the age of 9. The simultaneous group had the acquisition of L2 between ages 0-2 while the sequential group AoA of L2 was between 2-5.

The findings show differences in gray matter (GM) volume in the temporal lobe, the inferior and medial frontal regions of both hemispheres, and in the inferior parietal area. These are broadly part of the regions involved in the functional anatomy of language i.e the extended language network (Ferstl, 2007). GM was found to increase with AoA of L2 in the aforementioned regions with exception to the inferior prefrontal cortex. It is well known that both the inferior and the middle temporal gyrus handle various aspects of lexical semantic representation and processing. Their findings suggest a greater recruitment of these regions among individuals with later AoA.

The results support our thesis that the AoA of L2 also persists in the anatomic (structural) makeup of the adult brain. The earlier the second language is learned the more receptive the brain is to learning new languages and incorporating areas more efficiently. The structural changes reflect an explicit learning strategy for linking new words to concepts among later groups, which is implicit for native languages. The thicker cortex in sequential L2 AoA subjects, are analogous to findings in individuals acquiring new motor skills after infancy (Draganski et al., 2004).These differences in brain structure associated with sequential L2 acquisition might reflect on the recruitment of suboptimal neural circuits for language learning. Interestingly, this combined with the increasing variability and activation among later L2 learners provides more proof for the idea that AoA of a second language has a linear relation with the performance in language tasks.

Lastly, it is reasonable to inquisite about the cognitive implications of these structural and functional differences related to AoA. I will be using the recent study conducted by Gullifer et. al. (2018) to address this. They used seed-based Resting State Functional Connectivity (RSFC) to determine the contributions of L2 AoA on cortical connectivity. Their position was that earlier the L2, the stronger the connectivity in frontal cortical regions; leading to better performance in certain cognitive tasks relevant to executive control. The experiment task consisted of a Yes/No selection to a certain pattern of letters; either B followed by X/Y or A followed by X/Y. They recorded the variations in reaction times between A- and B- patterns, measuring the reliance of proactive control as patterns switch. The subjects in the experiment were 28 bilinguals with varying L2 AoA (mean AoA of 7).

The findings show an inverse relation between AoA of L2 and the connectivity in the LIFG and RIFG (Broca's area and right hemispheric analogue). Additionally, participants with early L2 AoA also are shown to have smaller speed advantages for B- trials relative to A- trials. This indicates that proactive control is needed for response inhibition among bilinguals with later AoA, for selection of words in the target language rather than the untargeted one. Furthermore, it is demonstrated that greater connectivity in the frontal regions is associated with reduced proactive control. Thus, early acquisition of two languages in childhood promotes a bilingual neural framework in which greater functional separation of those languages in real time is achieved through reactive inhibitory control. In contrast, the later acquisition of an L2 requires folding a new language system into an already existing left-hemisphere dominant network that is tuned for one language. Therefore requiring the deployment of proactive control measures of language selection, as seen in results found from the selection task.

In summary, I have provided affirmation to the thesis, with evidence from multiple research articles; the relevance of age of acquisition of a second language to the development of a human brain. This includes both a structural and functional disparity in the adult brain among multi- or bilinguals in association with their AoA of L2. Furthermore, I have discussed the possible reasons difference among the groups being the need for more executional control in late AoA subjects, and the priming of neural regions for language production in early AoA subjects. I have also provided evidence of this 'excess control' through results found in a selection task. Hence, I demonstrated the neural plasticity of cortical areas during early childhood, and how life experiences during these times can have an effect on both cortical structure and functional organisation of the brain which last a lifetime.

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