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CORRELATIVE ASPECTS OF LANGUAGE SPECIFIC OPERATION AND ARITHMETIC PROCESSING IN BILINGUALS' BRAIN; AN OVERVIEW OF BEHAVIOURAL AND NEUROLOGICAL STUDIES

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ABSTRACT

This study talks about what aspects correlated between the language specific operation and arithmetic processing skills that occur in bilingual people's brains. Some studies toward the behaviour and neurology's aspects are discussed as well as their findings in order to answer the research questions of the study. The discussions reveal that both skills have a positive correlation and that both occur in the brain's left hemisphere; however, the left hemisphere largely participates in automatic language specific operations and simple calculations, while the right hemisphere dominates advanced control processing operations in calculation (e.g. calculus, logarithm) and language information transfer. In addition, studies show that the bilinguals' language dominance does not clearly determine the correlation between the language and arithmetic skills. Further, in order to retain better arithmetic concepts, comprehensive and simultaneous training should be conducted in both languages and in the early stage of language development, especially during bilinguals' critical age of language learning.

Keywords: bilingual, language specific operation, arithmetic processing, language development, language dominance, left hemisphere, right hemisphere

INTRODUCTION

There has been a heated debate as to whether the development of language influences the calculation skill in bilingual cases, as been mentioned by Tamamaki

(1993) that bilinguals have difficulties to solve mathematical problems in their non-dominant language. Baldo and Dronkers (2007, p. 229) suggest the existence of common syntax for both language and arithmetic in which the systems influence the way bilinguals perceive understanding. If the bilingual person has weak syntactic knowledge of a language, it is assumed that the arithmetic skill is also in deficit state. This "common syntax" determines how language and mathematical entities be coded in the mental structure of human brain. However, some argue that these two systems are distinct in a way that each has different process as can be proven in several aphasia *acalculia* cases. Aphasia is an impairment of language due to injury or illness in the brain, whereas *acalculia* is an inability to perform arithmetic calculation and numbering processes.

In the first view, if both language and arithmetic share the common syntactic entities, which suggest the common overlapping area in the brain to be used for both development, one suffering from aphasia must also have a problem with counting and vice versa (Baldo & Dronkers, 2007, p. 230). The other study conducted by Vitali et al. (2003), in contrast, showed significantly different results when several aphasic patients do not lose their ability in calculation. This proof strengthens the second view that recommends separate operational domains. In some other studies, however, types of aphasia determines kinds of *acalculia* which means they may share the same lobe to some extend but not always (Semenza, Dalazer, Bertella, & Grana, 2006, pp. 1-2). These findings arouse questions on the localisation of language and arithmetic skills in human brain whether they share the same section or placed in two distinct specific areas.

The common finding derived from fMRI, er-gMRI, MIT, TEP, and *Intra-Parietal Sulcus* neurological tests points that calculation operation and language development exist mostly in the left hemisphere of the brain, especially in the case of early bilinguals, adding the complication to observe separability of the two entities. Thus, this paper tries to explore some knowledge of the bilinguals' brain processing relevant to language-arithmetic correlation.

Context and Research Problems

Firstly, the writer needs to specify what language intended to be observed in this particular case. It is not the whole or general language of human communication;

rather, the focus is narrowed down to the language of mathematical operation or referred as the language specific operation. Cohen, Dehaene, Chockon, Lehericy, and Naccache (2000) mentions this specific language is used for problem solving in calculation, to interpret numerical and symbolic data into their verbal semantic functions (words). The focused operation is in both exact and approximate arithmetic processes involving mental semantic ability to construct calculation based on abstract concepts. The exact operations comprise simple addition, subtraction, and some simple functions of multiplication and divisions, as for approximate operations include advanced structural operation such as advanced triple digits multiplication, division, logarithm, square cubic, square root, and calculus.

The bilingualism degrees in this observation vary from early simultaneous, consecutive bilinguals into late bilinguals, to compare the different effects of the language acquisition and learning on their arithmetic skill retention. The introduction of Language Arithmetic (La+) should be noted here, referring to the language in which bilinguals learn their first numbering process compared to Language Non-Arithmetic (La-) where bilinguals do not have enough experience to learn number and calculation within this language. Therefore La+ may not be their first language or their dominant language.

To observe the correlation between language specific and arithmetic skills, most researchers use more than one test; the preferable tests are to combine both behavioural psychological assessments with neurological brain test. The comparison of the control group (healthy bilinguals) and aphasic/*acalculic* patients (impaired bilinguals) is to be made to explain the distribution and allocation of brain stimuli regarding its function on language specific and arithmetic entities. Hence, the observation should fulfil answers to these following research problems:

1. To what extent does language specific operation correlate with the arithmetic skill of bilinguals?
2. In which preferable language and in what phase does the relation dominantly occur?

3. What strategy do bilinguals apply to preserve better arithmetic operation retention?

Literature Review and Discussion

The correlation between the language specific operation and arithmetic skill development

The dramatic increase of children's arithmetic skill soon after they acquire language is one significant interest of the linguistic-arithmetic study. Baldo and Dronkers (2007, pp. 229-230) portray this phenomenon as a form of numerical range escalation experienced by the early bilingual children learning arithmetic operation in their first language. In line with this finding, Cohen et al. (2000, p. 1426) explains two possible expansions of arithmetic skill development regarding the language specific skill in: 1) the acquisition of number in its verbal format and 2) the acknowledgement of "non-verbal number " such as the symbolic form of numbers (e.g. Arabic or Latin) alongside the development of language acquisition. These two processes support the basic manipulation of quantity operations in bilingual children minds.

The verbal recognition of numbering and its operations are described in Dehaene, Spelke, Pinel, Stanescu, and Tsivkin (1999)s' tests using "picture naming, word reading, and lexical decision" to examine which part of the brain corresponds to the process. The findings show that both left and right intra-parietal cortices of the brain surface are activated simultaneously and functionally meaning that both share spatial responses as well as controlled attention on the given tasks.

On the other hand, the different performance of the brain activity is shown by another test conducted by Benn, Zheng, Wilkinson, Siegal, & Varley (2012) which separates arithmetic operations into categories of rote-learning and advanced learning. Rote learning consists of simple addition and single digit subtraction operations, while the latter induces more semantically complex operations such as multiplication and division (Benn, Zheng, Wilkinson, Siegal, & Varley, 2012, pp. 2-5). The test shows that there is an interference of "verbal shadowing" involved in the complex mathematical operation. Bilinguals need to perform additional mental imaging retention and language mediation in solving the advanced tasks. This process

is different from the rote learning type because there is no necessity in processing further input into semantic understanding; bilinguals only need a so-called "look-up" automaticity system in their mental dictionaries. The left hemisphere, especially in the Broca area, is proven to be more active in rote arithmetic operations, as for the advanced learning, the right hemisphere, as the expansion of the "superior parietal lobule", takes a larger contribution. The test being used is a conventional versus abstract shape manipulations conducted in three consecutive phases.

In addition, Dehaene et al. (1999)'s observation on exact versus approximate calculation formats provides an outstanding view on the brain activation distinction. Bilinguals perform better whenever they are given exact problems rather than the approximate ones. In the exact operations, bilinguals tend to activate faster their trained skill in word sequences as the representation of language specific emphasis directly linked to automatic language specific association. In the contrary, when dealing with approximate problems, bilinguals store the advanced knowledge in the format of number magnitude making it harder for them to interpret, understand, and link the mathematical problem with its language representation. Dehaene's test with fMRI and Event Related Potentials (ERPs) provide a clear picture of left hemispheric functioning during the exact problem solving; whereas the approximate case is represented by the minimum participation of the Left Hemisphere (LH) and the dominance of the Right hemisphere (RH) parietal lobes.

Language Dominance of Arithmetic Operation

A neurological study by Baldo and Dronkers (2007) proposes the interdependence of language specific and arithmetic operation. Both are mediated by fragmental overlapping within the brain networks. This contention is also supported by Pica, Lemer, Izard, and Dehaene (2004, pp. 500-503) suggesting that some people coming from non-numerical language cultures have difficulties in performing calculation. Moreover, Dahmen, Hartje, Bussing, and Sturm (1982, pp. 146-150) claim that the occurrence of verbal deficiency influences to some extent the arithmetic ability in such a way that both entities are likely to share the correlating general structure named as "common syntax". The understanding of thematic role, as Baldo (2007)

mentions, concludes that the syntax of language specific and arithmetic operation is similar.

However, surprisingly, another study brings quite an opposite argument towards what kind of syntactic interdependence does affect the arithmetic ability. When the proposed interdependence exists, there should be an absolute condition where aphasic patient has to always be *acalculic* and vice versa. The study of several aphasic and/or *acalculic* patients then proves three possible conditions: 1) aphasic patient may be well performed in calculation; 2) *acalculic* patient might have no problem with language interpretation, and 3) associative deficits of both aphasia and *acalculia* which is in line with the first assertion of the shared syntactic role (Basso, Caporali, & Faglioni, 2005, pp. 99-103). Now, the question is in what condition or requirement does the arithmetic operation be influenced by the language specific mode for bilinguals.

Salillas and Wicha (2012) try to untie the above question by a thorough study on electrophysiological and behavioural response tests of Spanish-English for both healthy and aphasic bilinguals. A reaction-time experiment and the Brain Electrical Response test are conducted simultaneously for the participants learning arithmetic in one of their two languages. The Electro-encephalogram records are performed to check the electrical wave functioning as the participants undergo the behavioural tests. The findings point out positive relevance between language proficiency and arithmetic retrieval strategy for both groups. The "multiple mapping" of bilinguals to interpret the same concept for two different productions always occurs in any case.

The other significant finding of this study is related to the language dominance matter. The language in which bilinguals first experience the arithmetic learning (La+) influence strongly to the ability to process and solve numerical operations, even in the case of aphasic/*acalculic* recovery (Salillas & Wicha, 2012, p. 745). La+ does not necessarily be their first language, instead it may be their second language learned at school. The fast activation response of La+ brings an automatic answer needed in the reaction time test. In the case of La- (Language Non-Arithmetic), participants perform a weaker and slower reaction due to an indication of translating the mathematical function into the La+ to be easily solved then trans-

ferring back to the La- to provide the expected answer (Dehaene et al., 1999). Definitely, the second process takes longer time. Thus, the arithmetic accuracy skill is not determined by language dominance nor language proficiency, instead the calculation skill is largely depends on arithmetic networks built during the first encounter with any language introducing the operands.

The continuum of the bilinguals' brain translation processes from La- to La+ back to La- occurs in frontal parietal regions for both hemispheres with the dominant process in the right hemisphere. The mental calculation is supposed to add some extra works for the right lobe since the increase activity is required to translate and transfer information twice as hard as the original version occurring only in La+. The more bilinguals train themselves to solve mental arithmetic problems in La-, it might bring more efficiency in using neural resources; thus, the status of La- is dynamic. A La- can be a La+ when bilinguals continuously operate in the non-arithmetic language.

Arithmetic Memory Networking for Bilinguals

Salillas and Wicha (2012) and Basso et al. (2005) agree that the shaping of potentially strong arithmetic skill is first developed during the early stage of language specific learning. As mentioned earlier, the existence of La+ in the bilinguals' brain is well maintained and preserved in the further production of both verbal and symbolic arithmetic data as long as it is learnt and practiced persistently. As been asserted by Warbuton, Price, Swiburn, and Wise (1999), the early arithmetic learning in the bilingual person acts as a glue towards mathematical operands, solution strategies as well as a language particular so that the stored information can be accessed easier. More controlled process such as translation (from and/or to La-, La+) can be reduced to optimize intuitive self regulating problem solving.

In the monolingual brain networking, there is only a one to one interpretation between an arithmetic concept and its verbal representation (Salillas & Wicha, 2012, pp. 745-746). The case of bilingualism projects different networking designs since bilinguals undergo multiple mappings for one arithmetical concept, adding another cognitive component processing. For non-balanced bilinguals, more complex process will occur when the calculation is presented in their weaker language.

Four operational arithmetic procedures, "identification of independent sub modules, recognition of quantity, operation of non-dedicated calculation, act of translation/interpretation" proposed by Semenza et al. (2006, p. 287) are the common calculation operations experienced by non-balanced bilinguals which may inhibit the information discovery. If one of these four is blocked, it is assumed that a bilingual will find it hard to seek the answer or even to understand the mathematical semantic content.

Lin, Imada, and Kuhl (2012) as well as Ischebeck, Zamarian, Egger, Schocke, and Delazer (2007) through fMRI tests observe the brain activation of bilingual children before and after receiving extensive training. The left hemispheric *gyrus* is likely to be more active and sensitive after eight repetitive tasks and the arithmetical codes remain stable over the experiment. The brain activation investigation indicates that repetition of several stimuli in the early bilinguals profoundly affects the preservation of arithmetic code in the bilinguals' language specific operation format. Ischebeck, Zamarian, Egger, Schocke, and Delazer (2007), furthermore, suggest the balanced training of arithmetic repetitive problem solving in both languages to eliminate the activation of the *fronto*-parietal area which brings a controlled translation tool. In contrary, an extensive training for late bilinguals brings only little pattern changes in the *fronto*-parietal area of the brain which may not preserve memory for a long time.

SOLUTIONS, RECOMMENDATIONS, AND CONCLUSION

To answer the first question on the correlation of language specific operation with arithmetic skill of bilinguals, there are three points worth considering. Firstly, bilingual children develop their arithmetic skill drastically soon after they acquire language. The implication is that there must be a positive correlation between the two cognitive aspects.

Secondly, behavioural and neurological tests prove that both language and number processing occur in the same brain region, which is in the LH. There is a factual overlapping activity in Broca area in most cases of arithmetic operation and/or within language specific modules. However, different patterns of brain acti-

vation appeared by the occurrence of advanced arithmetic functions requiring more control of language specific to interpret and transfer semantic content of the function. In this case, the *fronto*-parietal RH region is highly activated for additional mental imaging and translation.

Furthermore, the LH largely participates in an automatic language specific operation and in simple calculation; whereas the RH dominates advanced control processing operations in calculation (e.g. calculus, logarithm) and language information transfer.

The second research problem concerns the language preference and dominance regarding the correlative aspects of numerical and verbal accesses. The Language Arithmetic (La+) is the absolute requisition for the language and arithmetic function to correlate each other. It is difficult for bilinguals to solve arithmetic problem in the Language non-Arithmetic (La-) as they need to transfer/re-transfer information for comprehension matter. The language dominance of bilinguals does not determine correlation between the two skills of language and arithmetic because the La+ can be acquired during the acquisition or learning of the later language.

The case of movement of La- into La+ is always possible along the learning and extensive training for both early and late bilinguals. However, the pattern will be different; the former will activate the long term memory retention in the LH, while the later induces the activation of the frontal-lobe of RH which may not hold a long term memorisation.

Finally, the researchers' attempt to find effective strategies or treatment to preserve arithmetic skill within the language specific operation comes to a deduction that teaching arithmetic skill in both languages starting from early development of language is seen to be a positive idea. Simultaneous training in both languages is expected to provide better atmosphere to create La+ so that bilinguals can perform automatically as well as develop auto-sensitivity towards symbolic and verbal calculations.

Late bilinguals can also modify their brain activation by intensive regular training. However, if both early and late groups undergo the same process then being

compared, the result of the training is likely to be different. The late bilinguals are apt to stimulate the frontal-parietal lobe of the RH compared to the early bilinguals training that triggers the LH performance. The positive point of the training for the late bilinguals is that the simultaneous conduct of arithmetic problem solving may increase their La- status into partial La+ and to prevent the lost of the arithmetic and language particular skills in their RH.

To conclude, overlapping brain activation in the LH does occur in the case of simple exact mathematical operation with its language specific interpretation. A complementary distribution (distinct RH shift) will present when it comes to advanced approximate calculation applying controlled transfer of information in the interpretation of more sophisticated mathematical problems. In addition, the La+ is the language in which bilinguals encounter their first experience in learning numbering system, thus, they are likely to perform more efficient and automatic compared to the La-. In order to retain better arithmetic concepts, comprehensive and simultaneous training should be conducted in both languages and in the early stage of language development; especially it is best regulated during bilinguals' critical age of language learning. In the aphasia/*acalculia* recovery pattern for late bilinguals, repetitive training on mathematical problem solving will help them regain better memory of numerical functioning although the process is different from the early bilinguals.

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