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Bilingualism and Cognitive Development:

A Study on the Acquisition of Number Skills

Phd student: Delia Guagnano

Advisor: Prof. Roberto Cubelli

Co-advisors: Dr. Elena Rusconi, Prof. Remo Job

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Contents

Introduction

The question of defining the term “bilingualism” seems to have a very trivial answer. Both lay people and *connoisseurs* define bilinguals simply as people able to speak more than one language. The same term is also used to denote those who communicate naturally and fluently in more than one language in all domains. However, between these two definitions lie worlds. People belonging to one or the other category are indistinctly considered as bilinguals and researchers in the field follow more and more different criteria to define them. Therefore when such jumble of criteria are used faintly, much confusion can be caused.

Such lack of theoretical specificity in defining a unique criterion has led to a series of methodological problems specially in studying the cognitive effects of bilingualism. When wide-ranging criteria (as considering “bilinguals” people particularly skilled in the second language only) are deemed enough to consider an individual as bilingual, then doubts can be raised regarding the real relation between speaking more than one language and its positive effects on cognitive functions. Many experiences, in fact, can exert an influence on the positive development of cognitive abilities such as socio-economic status, IQ, and also other more specific experiences (such as playing video-games or playing musical instruments, Green and Bavelier, 2003; Lamb et al., 1993).

Therefore, it is really necessary to adopt strict criteria whose validity is accepted above all by researchers studying this phenomenon. Few authors have tried to identify the most important criteria, defining true bilinguals. Among all, the age of acquisition (AoA) and the modality of acquisition (MoA) have been regarded, as discriminating people knowing more than one language from people able to communicate naturally and fluently in more than one language in all domains. Learning a second language very early as a vehicle of communication allows one to acquire a “perfect” accent and a complete and correct grammatical knowledge (Fabbro, 2004). When children acquire the second language at school, they have already acquired implicitly the basic features of the first language and, also due to maturational constraints (the so called "critical period"), they apply the same procedural schemes they have acquired for the first language also for the second language (Flege, 1999). Therefore, in addition to the quality of the accent, also the knowledge and the actual use of grammatical structures regarding the second languages are affected. Neville et al., (1992) found that the grammatical knowledge of the first language are represented in the left frontal areas, while its semantic knowledge is represented bilaterally in the posterior areas. When the second language is acquired after 8 years and often following formal method of teaching, both semantic and grammatical knowledge are represented in the posterior areas. Therefore, the age of acquisition can influence the representation and thus the quality of acquisition of the second language.

For this reason, in the present dissertation I will adopt strict criteria to define children as bilinguals: whose who acquired the second language from 1 to 3 years, belonging to mixed bilingual families (parents had different mother-tongues), and whose parents reported to speak both languages at home. Bilingual sample will be carefully controlled regarding the socio-economic status, fluency in the second language, and other general abilities which could, if not properly matched, influence cognitive performance, such as non-verbal reasoning and verbal-working memory. The present research will report three series of studies. The first series of study (Experiments 1-3) will investigate whether bilingual experience influences the ability to enumerate items from 1 to 9: attention will be focused to study how bilingualism can affect different mechanisms involved in this ability. Children's ability to access to the magnitude of numbers combined with the ability to suppress interfering information will be the subject of the second series of studies (Experiments 4-6). Here, it will be considered also a second sample of bilinguals to examine whether the supposed bilingual advantage applies to all types of bilingualism. The third series of studies will use a different and more demanding number task to investigate more deeply the nature of the bilingual advantage, by comparing both groups in solving simple multiplications when high levels of working memory are required.

On the whole, the present research will confirm previous studies, will provide new methodological information in defining bilinguals and emphasizing the role of confounding variables and will extend its results to the mathematical education.

Chapter 1
Dimensions and measurement of Bilingualism

1.1 Introduction

Imagine that you are challenged to enlighten the structure and the functioning of a system made up of hundreds of thousands of units that are bred from a specific set of materials. These units can be also combined into a very high number of ways. Only some of these combinations are correct for your reasons and you can use them to communicate only with those people who share the same combinations of units. If they do not, a different system with different units, materials and thus combinations must be learned. Human language can be conceptualized as one of these complex systems that may share some of their characteristics.

From birth children are continuously exposed to streams of sounds (language specific set of materials), which are used in combination to produce words (units) and then sentences (combinations). It is necessary to wait between 9 months and 1 year to hear a child pronouncing the first lallations; then even before they comprehend the meaning of words, they start to reproduce phonemes, then words and finally sentences. Even before they start to attend school, they develop the ability to comprehend and speak, and during school, they learn to read and speak in a conventional way. As it should be clear by now, parsing all the components of the language system and showing how they combine with each others to produce the human language helps to clarify how complex and, at the same time, amazing is the functioning of this system with such range of components and abilities.

Imagine now how astonishing is the functioning of a mind that masters two of these systems, as it is the case for a bilingual mind and how difficult it will be to give, in just few words, a precise definition of what it takes and means to embed double components (sounds, words, sentences) and double abilities (listen comprehension, speaking, reading and writing), especially when two languages are largely dissimilar.

In the following paragraph I will give a brief overview of all principal dimensions of bilingualism, trying to roughly outline, the main boundaries of a phenomenon that look spreading slowly, at least in Italy, but surely in the following years. Following a research made by ISMU (Rapporto sulle Migrazioni, 2008), a scientific organization promoting studies and research on the multi-ethnic society, 574.133 foreign students attended Italian schools in the school year 2007/2008. Most of these students come from Romania (96.734, the 16,1% of foreign students), from Albania (85.195 equal to the 14,8%), Morocco (76.217, equal to 13,2%), China (27.558, 4,8%), Ecuador (17.813, 3,1%), Tunisia (15.563, 2,7%),Philippine (15.248, 2,6%), India (14.708, 2,5%), Serbia (14.340, 2,5%).

This “statistic picture” helps to describe the Italian multicultural landscape concerning schools, a fact that foreshadows the multicolor dimension of our society.

In addition to the phenomenon of bilingualism coming from immigration, it is also important to count another source of bilingualism which is growing more and more. The number of international private Italian schools is raising quickly: in Roma, Firenze, Genova, Milano, Napoli, Lanciano, Trieste, Bologna, Torino, Vicenza, and Monza are scheduled schools providing for education in English language only. Although these schools are still a chance mainly for children coming from the upper class, its unceasing increase gives witness of the need for the Italian society to raise up children as bilinguals.

1.2 Definition and dimensions of Bilingualism

What it is typically meant by *being bilingual* is often a simplification and only seldom it is thoroughly thought up to deduce a complete definition. The reason is that being bilingual may cover a wide category of concepts, all of which having different emphasis.

Bilingualism is a theme of interest for social psychologists, linguists, sociologists, cognitive psychologists and, not least, politicians and educators. This is probably one of the reasons why a lot of definitions have been formulated but none of them can be considered exhaustive.

When speaking about the broad phenomenon of “languages in contact” or “the use of (at least) two codes on interpersonal and intergroup relations”, it is useful to distinguish between the two principal terms that will be used in the following paragraphs: the term “bilingualism” refers to the state of a linguistic community in which two languages are in contact and are used interchangeably within the community. This term, however, includes also the concept of “bilinguality” or “individual bilingualism” that is the psychological state of an individual who has access to more than one linguistic code as a means of social communication.

Within a cognitive perspective, there are two main positives: on the one hand Bloomfield’s (1935) approach defines bilingualism as “the native–like control of two languages (thus including “perfect bilinguals only”); on the other hand McNamara (1967), suggests that a bilingual is anyone who possesses a minimum competence in one of the four language skills in a foreign language: listening, speaking, reading and writing.

There are many other different definitions: for instance according to the Webster’s dictionary (1961), bilingual is “using two languages especially as spoken with the fluency of a native speaker”; “a person using two languages especially habitually and with control like that of a native speaker”; or simply “the constant oral use of two languages”; Hamers and Blanc (1987) report about bilingualism as “the individual’s capacity to speak a second language while following the concepts and the structures of that language rather than paraphrasing his mother tongue”. There is no intention of reviewing all the definitions that have been proposed so far. Here it should just be stressed that the phenomenon of bilingualism is multidimensional: every definition take into account one or few dimensions depending on the specific interest and competence on the theme which, in addition to these, refer to single dimensions of the phenomenon and raise a lot of theoretical and methodological difficulties because of their intrinsic lack of precision and concrete operationalism. They range from the native-like competence in two languages to a minimal proficiency in the second language: they do not specify what is meant by “native-like” competence whose degree varies along the population, nor by minimal proficiency nor by being able to use concepts and structures of the second language.

According to Hamers and Blanc (1987) six dimensions, at least, can be considered as relevant: relative competence, cognitive organization, age of acquisition, exogeneity, socio-cultural status, and cultural identity. When considering the relationship between the competences in each language, an obvious distinction is made between *balanced bilinguals*, (speakers having the same competence in both languages), and *unbalanced or dominant bilinguals* (speakers whose competence in one of the languages is often their mother tongue and it is higher than their competence in the other language).

Another distinction concerns cognitive functioning. Ervin and Osgood (1954) distinguished between compound and coordinate systems. In a compound system two labels (each belonging to one language systems) can be associated to the same concept (i.e. there would be a single cognitive representation for two translation equivalents), whereas in a coordinate system, translations in the two languages coincide with two different set of associations (separate system of meanings and expressions for each of their languages). Ervin and Osgood (1954) assumed that the cognitive organization of the two languages can depend on the context of acquisition: compound and coordinate bilinguals have respectively fused and separate context of acquisition and language use. While compound bilinguals use either both languages interchangeably inside or outside their home, coordinate bilinguals made use of each language in different settings (e.g. one language exclusively at home and the other at school or at work).

A third and important dimension that may be useful to distinguish among different types of bilinguals is age of acquisition: *childhood bilingualism* refers to the acquisition of the second language (L2) at the same age as the first (L1) in normal development; it differs from *adulthood bilingualism*, where the second language is acquired when many cognitive functions have not yet reached maturity and can influence the quality of the learning of second language (see Hamers and Blanc,1987).

The dimension of *exogeneity*, as opposed to *endogeneity*, refers to the presence of different speech communities in the child’s social environment. A language is called exogenous when it is used as an official language but not in one’s own familiar speech community, as it happens when children attend schools with special linguistic programs, while speaking another language at home (see Hamers and Blanc,1987).

Socio-cultural environment can also influence bilingualism: if socio-cultural context is such that one of the two languages is undervalued in the child's environment, he will develop two different levels of competence for each language (*subtractive bilingualism*). For instance, immigrants children live in places where their home language is different from the language spoken by the community. In such a context they do not receive support for their native language and this situation may mean losing their competence in their first language. In contrast, multicultural communities, whose politics explicitly foresee the use of more than one language in official fields, ensure to maintain higher degree of bilingualism as learning an additional language provides a skill to enhancing individual's opportunities in life. In these communities, which value both languages equally, the type of bilingualism is often called *additive*.

The last dimension relates with *cultural identity:* when bilingual recognize the self as members of the two cultural groups speaking different languages, they are considered *bicultural.*

Of course some of the above mentioned dimensions can overlap: a balanced bilingual is often also bicultural. Consider for example some towns in Alto Adige where the German and Italian communities are mingled and both languages are used in every-day life. This situation both supports either the feeling of *being bicultural* and fosters the opportunity of learning and using both languages in every-day life.

Any definition of bilingualism is thus far from exhaustive and unique but a conceptualization of this phenomenon is anyway necessary when trying to operationalise it and to identify the salient features that have to be quantified in any given research program.

1.3 The measurement of bilinguality

Assessing the degree of bilinguality is a very important issue even for reasons other than research purposes. For instance, to determine the competence of children coming from different linguistic communities, an appropriate educational program can facilitate and ensure special services, when needed, to be successful in school. Moreover, the assessment of the second language is necessary for teachers who have to conduct courses in bilingual classrooms but also for interpreters, diplomats, students and even for pilots.

Importance of determine the bilinguality of workers is also evident in Alto Adige, where a linguistic certification concerning the competence in German language is considered a “passport” to find a job.

In the next paragraph, I will list and describe several methods to assess the degree of bilingualism. A first classification is between reported and observed linguistic behavior. Reported behavior means all knowledge collected by the bilingual speaker herself as reported in questionnaires or interviews about the linguistic knowledge and use. Observed behavior refers to all information about the linguistic performance in the two languages as measured by the tests of competence in the mother tongue and in the second language.

1.3.1 Reported measures

Questionnaires and interviews are useful to collect information about the age of acquisition, where and to whom bilinguals speak their languages and the age of acquisition and use of languages. Among the questionnaires, the one conceived by Hoffmann (1934), *the Hoffmann Bilingual Schedule*, has been considered a model for its way of collecting information about language background. It contains items reading and writing and on the active language use in speaking (“which language do you speak with your mother?”) and listening (“which languages does your father speak to your mother?”). Further, it provides information on the age and context of acquisition of both languages, their past and present use, their number, the degree of literacy. The output, *the bilingual score*, is obtained by assigning a score for each factor/question. The validity of the questionnaire is often questioned because of the importance given on some factors influencing language acquisition: when questionnaires consider length of residence as index of second language acquisition, doubts can be raised about the validity of such criterion. Length of residence assumes a relative importance when amount of time spent in extra-scholastic contexts is not determined. Consider the case of immigrant bilinguals who , although living in foreign countries for many years, outside the context of work, form and belong to communities of immigrants. Therefore, if other variables are not properly considered, the amount of time spent in a foreign country cannot be considered a clear index of the proficiency in L2. Another criticism concerns the lack of distinction between knowledge and actual use of the second language, which allows assessing separately the competence and the performance. Knowing one language does not necessarily imply its proper and real use. This is an important issue specially in areas where politics overtly suggests to use more than one language. If we ask which language a child uses with her father we should also ask how well the father knows that language. Parents could choose to speak to their children in a language that they don't use. For example in Sweden, teachers tell immigrant's parents to speak Swedish to their children even if their Swedish is rather poor. This aspect should be considered also in using questionnaires and interviews. People or parents are asked to evaluate their performance: the differential scores between the self-evaluations of proficiency in both languages are considered good predictors of the degree of bilingual competence. However this way to evaluate proficiency seems to be reliable with balanced bilinguals only. When indeed, dominant bilinguals are asked to judge their proficiency, the reliability seems to be lower. For these reasons, the use of questionnaires is often combined with an observed measure of proficiency.

1.3.2 Observed measures

A way to get an "objective" measure of linguistic proficiency is to evaluate the performance by means of tests. The usefulness of these tests depends on the specific linguistic aspect under investigation. Indeed, "objective" does not mean "exhaustive". Thus each of the following tests cannot be considered sufficient to provide exhaustive evaluations of proficiency and their value are often questioned especially when it is not combined with other measurements.

The most frequently used technique for measuring bilingualism is to take measures of the bilingual's two languages and compare them. This technique, as it will be clear in the next chapter, is useful to differentiate between the proficiency in both languages. This is an important aspect, because bilingualism cannot be evaluated only assessing the proficiency of L2 and comparing it with that of other speakers but it should be also evaluated in relation to the proficiency achieved in L1.

1.3.2.1 Tests of competence in L1

Competence in the native language is a problematic construct because it entails different abilities (speaking, listening comprehension, reading, and writing) and the level of competence degree can differ between skills. However, researchers typically measure competence in L1 by focusing on only one. One of the most frequently used tests attempting to measure this broad ability (from 2 to over 90 years old) is the Peabody Vocabulary Test (Dunn, 1959), whose assumption is that language competence can be measured through the study of either oral language or receptive vocabulary. To administer the PPVT, the examiner presents a series of pages that contains four black-and-white pictures. Each picture is numbered. Then, the examiner says a word and the examinee will identify the number of the picture that best corresponds to the word. It is specially used in school-age children, because it can estimate the child's scholastic aptitude, revealing high or low verbal abilities and identifying possible learning disabilities (Breen and Siewert, 1983). Therefore, it is a useful tool for teachers who must set their teaching at an appropriate level to be easily acquired by scholars. Further, it can be used also as a screening for foreign students whose intention is to attend schools and universities in foreign languages. A further test used to evaluate the language competence in the mother tongue is the Reynell's syntactic complexity test (see Hamers and Blanc, 1987), which measures only one aspect of language like many other with other language tests included in traditional test batteries (e.g. WISC-R).

Therefore, the use of any of these measures is tightly dependent upon the contingent target of researchers or teachers.

1.3.2.2 Tests of Competence in the second language

The methodology used to evaluate the competence in the second language is, as for the first language, problematic. Several tests are used and none of them can be considered exhaustive in itself. Among these, the most used to evaluate different linguistic skills is a timed-test, called in different ways depending on the language of interest. For example, the one used to evaluate the competence of the German language is called Fit in Deutsch, Toefl in English it is called, Delf in French. These tests last about 60 minutes and are composed of four parts: the *oral comprehension* part requires participants to understand brief conversations staged in every-day settings and on the phone; the *written comprehension* part is based on the understanding of short and visual advertisements and brief phrases; the *written production* that consists of writing a brief piece based on instructions, such as writing a letter or an e-mail; the *oral conversation* requires the candidate to actively interact, both formulating and answering questions, with a friend. Such test seems especially useful when various degrees of proficiency must be identified but it can be misleading when used to distinguish between balanced bilinguals from very good second language learners. When second language learners are particularly skillful, their high scores can be interpreted as a clear index of bilingualism. However they learn a foreign language in formal contexts through the use of these exercises but their use of language is very poor.

1.3.3 Behavioral Measures

Comparing the proficiency between the first and second language instead of contrasting second language skills against fixed levels of proficiency (as it happens for the tests mentioned above) can be a choice. Assuming that any task requires a certain level of linguistic competence, a true bilingual should show the same level of competence in both languages. When linguistic competence (using the same test) is reported to be different for the same speakers, a lower degree of competence must be acknowledged. Tests typically used in bilingualism research are the following: reaction times measures; completion and word-detection tests; verbal association tests; interlingual verbal flexibility; use of interlingual ambiguity.

Reaction times measures are mostly used in experimental psychology. The assumption underlying this measure is that differences in reaction times between the two languages can be indirect indicators of qualitative differences in mental linguistic functioning. The speed of reacting to stimuli is used as a tool in several tasks: in reacting to instructions; in producing words; in reading; in reaction to words presented in isolation; in lexical decision tasks; in grammatical judgment tasks. Taking into account the speed of processing stimuli allows to highlight the degree of automaticity of languages. When one begins to learn whatever skill he often hesitates in producing words or actions; as then he develops that skill, he becomes faster in reacting automatically. Apart from tasks previously mentioned, reaction times are also used in experimental protocols requiring verbal decoding and encoding operations: for example a participant is asked to react to oral instructions in both languages by pressing one or the other key; if the reaction time to the same instruction is similar for one and the other language then speakers are classified as balanced bilinguals. For instance, Lambert, Havelka and Gardner (1954) instructed participants to press a given key with instructions appearing randomly on the screen in either one or the other language and recorded the speed of response. A similar way is to measure reaction times for recognizing a word presented on the screen. In verbal encoding tasks participants are asked to respond verbally in one or the other language to non-verbal stimuli (pictorially objects: Ervin, 1961) or colors (Hamers, 1973). Obviously these techniques cannot be considered as unique in measuring bilinguality for many reasons: stimuli (pictures or words) could not have the same cultural value and the same frequency of use in both languages. In addition, the words in the two languages may differ from the beginning phoneme and differences in reaction times could be an expressions of difference in speed of pronouncing a specific phoneme rather than different speed of processing between L1 and L2.

Verbal decoding and encoding as measured by speed of reading aloud in both languages are however considered a good predictor of bilingual competence (Macnamara, 1969).

In *completion and word detection tasks,* participants produce as many words as possible in both languages starting in a given letter. The number of words produced in one language compared with the number of words produced in the other language is considered an indicator of bilinguality.

In *word detection tasks* participants are asked to recognize as many words as possible in a string of non-sense syllables in both languages. For instance a participant can be asked to identify how many French and English words he can recognize in the string DANSOODENT (see Hamers and Blanc, 1967).

The *Verbal Association Test* requires participants to give as many associations as possible in response to a certain stimulus word in the same language and in the other language. This technique is based on the assumption that the more a speaker becomes competent in the second language, the more likely he or she can provide a high number of associations in L2 (see Hamers and Blanc, 1967).

Interlingual verbal flexibility refers indeed to the ability of bilinguals to manage two languages simultaneously, for example in tests measuring the speed of translation or the ability to switch from one language to the other without translating (see Hamers and Blanc, 1967). However, clinical data suggest that this is not a good measure of the degree of bilingual competence because these tests call upon an ability which is different from the linguistic competence. Indeed Paradis (1980) reported cases of bilingual patients affected by aphasia who maintained translation abilities.

Another behavioral test used for this purpose is the *Interlingual ambiguity test* which consists in a list of cross language ambiguous words that have to be read aloud. The underlying hypothesis is that the more balanced a bilingual is, the less he or she will classify the words as belonging to one language and not to the other thus obtaining about equal scores for each language. Though this test seems to correlate with other measures of bilingual competence, it shows clear-cut limits. For instance, all tested languages should have several items of the lexicon in common and ambiguous words should not have different frequency of use in each spoken language (see Hamers and Blanc, 1967).

Judging the grammaticality of single sentences is another task: if the learner's grammaticality judgments match that of native speakers, they may be considered to possess a similar mental construct. However the use of this test is also questioned because it does not clarify also why the participant has accepted or rejected that as correct sentence. For this reason, the use of such test is often supplemented by a similar one where participants have to decide which, among many, is the correct grammatical form of a given sentence. Another example of use of reaction times is the Sentence Matching Paradigm (Crain and Fodor, 1987; Freedman and Forster, 1985) which consists of the presentation of two sentences; some pairs are grammatical or not. Participants are asked to say whether the sentences are the same or not. Pairs that are both grammatical usually take a shorter time to be judged while pairs consisting of a grammatical and an ungrammatical sentence take longer. If these differences in speed are reliable, researchers infer that learners show a sensitivity to ungrammaticality, and therefore to language-specific constraints.

Lexical decision tasks are also used to roughly distinguish between bilinguals and non bilinguals. De Bot, Cox, Ralston, Schaufeli, and Weltens (1995) presented a prime word (through the use of earphones) and then a second word: the participant had to decide whether the latter is related to the former. The time taken to decide is recorded and it is an index of the relation between the deep meaning representation and the phonological representation. Latency for words related with to the prime are shorter than latency for trials where the prime and the target are unrelated.

By and large none of these measures can be considered an exhaustive way to assess bilingual competence. These measures have the advantage of being simple, easy to use and useful to make comparison between two languages at a time.

However, when using these behavioral measures other issues must be taken into account: first of all, individual variation in working memory can influence the performance regardless of the degree of linguistic competence and comprehension abilities. Other factors affecting the reliability of these tests are the frequency of word use and the difference in proficiency level among participants. It seems therefore necessary that the use of these measures should be combined with other kind of measures.

1.3.4 Measures of cognitive and affective correlates of bilingualism

Several studies suggest that there is a correlation between bilinguality and the development of cognition. This issue and its history will be examined in more detail in the next chapter. Here it will be just stressed that researchers reported both cognitive advantages and disadvantages. Bilingualism seems to exert positive effects on tasks requiring control of attention: bilinguals are more accurate in judging the grammaticality of sentences when attention must be focused at specific features of the sentences (Bialystok et al., 1986); and are faster in the Attentional Network Task (Costa et al., 2007) and in the Simon task (Bialystok et al., 2005). The negative effects of bilingualism concern tasks requiring speech production: bilinguals seem to be slower in picture naming when the lexicon needs to be accessed (Ivanova and Costa, 2007), to produce more tip of the tongue occurrences (Gollan and Silverberg, 2001), to exhibit lower rates of retrieval in verbal fluency tasks (Gollan, Montoya, and Werner, 2002).

There is also an affective correlate of bilingualism which refers to the relationship between a bilingual individual and his or her two languages. Personal value about the languages can influence in fact attitudes or motivation to lean it. The most commonly used techniques of these measures are Lickert-type evaluation scales such as those developed by Gardner and Lambert (1972).

1.4 Conclusion

In this chapter I attempted to describe and review critically some of the problems connected with the definition and measurement of bilingualism. The importance of bilingualism research lies in its multidimensional character involving, at the same time, a personal psychological state of the individual and a social situation of interpersonal and collective level. These two main dimensions can occur independently from each other and determine different types of bilingualism: a situation of *languages in contact* happens at the societal level without necessarily implying the bilinguality of any member of that society (an example can be found in certain areas in the territory of AltoAdige where even though bilingualism is nudged by politics and society, bilinguality is still confined mainly to the German-speaking population). Conversely, individuals can be bilingual even without the existence of a societal bilingualism as it is for immigrant bilinguals or children attending special schools.

Chapter 2
Cognitive Effects Of Bilingualism

2.1 Introduction

About 2300 years ago, Aristotle wrote: "*It is a very difficult task, in any respect, to form a solid opinion on the mind (psyche, soul) ... It seems as though everything the soul experiences occurs only in association with a body... joy, as well as love and hate; in all of these cases something happens in the body as well... If this is the case, then these properties possess something material even in their very essence... And that is, after all, the reason why the physicist is responsible for the investigation of the soul" (De Anima).*

These words are still valid today, since the relation between physical and psychological events remains one of the most fascinating issue to be addressed. A review of all theories attempted would be off-site in this chapter. However, it is necessary to mention that during the twentieth century, at least, two main equally false pretences were put forward: the materialist theories argued that mind does not exist and only brains and bodies should be investigated; and dualist theories claimed that mind and brain exist independently from each other because both of them are composed of separate type of "substance". Of course, between them there are different other theories which, as well as the materialist and dualist ones, lacked in explaining how brain and mind work.

The introduction of the new machines like neuroimaging techniques (fMRI, PET, TMS, MEG) and the development of new paradigms in cognitive psychology, has helped not only to enlighten how brain mechanisms and mental processes work but specially, how brain and mind are, somehow, related. Whether the nature of this relation is causal or not, is not the purpose of the present chapter, here both behavioral and neuroimaging studies will be reported providing evidences on the fact that experiences and learning can influence both brains and minds.

2.2 Experiences-driven plasticity

For a long time, it was believed that as we age, the connections in the brain became fixed. When Wiesel and Hubel in 1965, with their studies on the influence of visual experiences on the development of visual cortex, suggested the idea that our brain can be shaped by learning and experience, they introduced a new way of thinking about its functioning. Successively, Rauschecker (1995) demonstrated that the functioning of visual structures is strongly affected by early deprivation and that extensive cross-modal reorganizations in the deprived system would follow.

Since those initial works, a number of studies using a range of tasks and techniques highlighted the striking ability of the brain to rapidly rewiring itself by forming new connections between neurons and dropping inefficient ones. This discovery dismantled, in a sense, the idea that genetics was the main influencing factor during brain development, suggesting that also environment plays a fundamental role in neuroplasticity.
Several conclusions can be drawn from these later studies, such as that functional and structural changes take place in cerebral cortex after injuries such as after trauma or strokes suggesting that new forms of rehabilitative interventions can help to remodel damaged brains. For instance early blind subjects activate early visual areas during Braille reading tactile discrimination tasks and spatially encoded auditory processing to a larger extent than do sighted individuals (Wittenberg, et al., 2004). Other examples of brain plasticity concern the recovery of language in aphasic patients: Gazzaniga et al., (1996) reported on a split brain patient who was unable to speak even if his right hemisphere could understand both spoken and written language. Fourteen years after his surgery this patient was able to name approximately 25% of the stimuli, 1 year later he could name about 60% of such stimuli.

Rehabilitation is not the only desirable consequence of brain’s plasticity. Neural plasticity permits the adaptation of the brain to environmental factors that cannot be anticipated by genetic programming. Experience and education can thus exert an influence on brain development. Several studies report evidence in favor of experience-driven plasticity. For instance plastic changes occur in musician brains. Gaser and Schlaug (2003) found that musicians practicing at least for 1 hour per day have a higher gray matter volume (in motor regions) than intermediate amateur musicians. This is not the unique example: London taxi drivers have been found to have a larger hippocampus (in the posterior region) than London bus drivers (Maguire, et al., 2006). It is likely because this region is specialized in acquiring and using complex spatial information in order to navigate efficiently. Taxi drivers navigate around London whereas bus drivers follow a limited set of routes.

Further, Karni, et al., (1998) showed that a few minutes of daily practice of a sequential finger opposition task induced large, incremental performance gains over a few weeks of training, which was associated with changes in cortical motor representations within the primary motor cortex.

Changes are also evident in purely behavioral research. Playing with video games seems to lead to several improvements in visual attention, and visual-motor coordination (Green and Bavelier, 2003): when asked to respond to visual stimuli, video game players show faster RTs and diminished attentional costs (Greenfield et al., 1994). In addition, Gopher et al., (1994) showed that cadets trained on a video game performed better than their untrained peers on measures of flight performance. They outperformed their peers in distributing attention over space and time. This suggests that such videogame-induced increases in visual attention may have real-world practical implications.

The most surprising consequence of neuroplasticity is that brain activity is typically associated with a given function can move to a different location as consequence of experience, brain damage or recovery. For instance playing an instrument requires many skills: from reading a complex symbolic system (musical notes) to translating their meaning into precise successions of motor activities relying on multisensory feedback; perceiving and identifying acoustic stimuli (tones) and memorizing long musical sequences. Practicing these skills seems to confer to musicians enhanced performance in a wide range of more general skills: prosodic (Lamb et al., 1993) and pronunciation (Norton et al., 2005) abilities, phonological awareness (Peynirircioglu, 2002), reading and mathematical skills (Overy, 2003).

Environment can be also associated with negative effects on cognitive functioning: low socio-economic levels seem to correlate with lower language development and executive functions. Language achievements indeed, sharply differ as a function of the socio economic status (SES). For instance, Hart and Risely (1995) found that the average vocabulary size of 3-year-old children from professional families was more than twice as large as for those on welfare. Several studies have also reported SES differences in Prefrontal/Executive function: Lipina et al. (2005) reported that infants from lower SES families are, on average, less advanced in the working memory and inhibitory control abilities needed to perform the 'A not B' test.

Bilingualism is perhaps one of the most well-known examples of such contradictory effects of learning and experience because it is, at the same time, a boosting and a hampering experience. More and more researches are trying to shed light on the specific advantages and disadvantages brought about by this so tangled skill because of its intrinsic importance to contemporary society.

Further, contrary to other abilities such as playing videogames or musical instruments, being able to speak more than one language often comes as a compulsory necessity, not a luxury or an optional. Many educational curricula include linguistic programs and many companies and institutes seek for improving career development by encouraging mobility to and from foreign countries. Nowadays, speaking fluently foreign languages is an essential prerequisite to pursue successful professional careers.

In the following paragraph I will report and analyze the long and complex story of studies on the cognitive effects of bilingualism starting from a description of the early studies on the relation between bilingualism and intelligence until the most recent studies about the effects of bilingualism on general cognitive functioning.

2.3 Historical Perspective on the Studies of the Cognitive effects of Bilingualism

2.3.1 Early studies: 1920s to 1950s

Over time, as few other spheres of cognitive science, bilingualism has attracted unceasing interest for its valuable consequences for society, educators, parents and for children. Unfortunately, research on this topic has been unfairly overstepped by superficial and hurried twists. (Baker, 1993). Thereby, especially in absence of clear-cut effects, the interpretation of results has been "dressed up" differently depending on why people were interested in it. The history on the effects of bilingualism on cognition can be split into two main ages.

Cerebral confusion, split personality, spiritual deprivation, language handicap are just few ways in which bilinguals were described between 1920s and 1960s. These expressions came from a wide range of experts who proposed many ideas on how acquisition of a second language takes place. For instance, someone suggested the image of two balloons in mind, one holding a language and the other the second language with no communication between them Other experts suggested the analogy of a weighing scale, claiming that the more one learns of one language, the less knowledge he can hold on the other language. Juggling two languages would thus throw one or both languages "out of balance" (Baker, 1993).

Research in this period took side on these misconceptions and confirmed the idea that learning two languages results in mental confusion. Baker (1993) for example, claimed that learning a second language halves intellectual growth. In fact a wide number of studies concerned the relation between bilingualism and intelligence: for instance Saer (1923) compared the performance of four groups: a rural monolingual group, a rural bilingual group, an urban monolingual and an urban bilingual group. Stanford-Binet tests, rhythm, vocabulary and composition tests were given to each component of these groups.

Monolingual and bilingual rural university students showed a difference in favor of monolinguals on the group intelligence test, while there were no differences between monolingual and bilingual university students living in urban areas. Despite these contradictory results, Saer strongly concluded the bilingualism resulted in lower intelligence, disregarding the equal performance achieved by monolinguals and bilinguals living in urban areas. He just commented the finding claiming that bilinguals in urban areas managed to resolve the "emotional" conflict between the use of English and Welsh! The presumed bilingual's inferiority however was indeed evident in the group of rural bilinguals but not in the urban group. If bilingualism was the cause of lower IQ, this upshot should be clearly visible even in the comparison between monolinguals and bilinguals living in the urban areas.

This critique provides an example of the weaknesses of typical researches on bilingualism during this historical period. Children who were considered bilinguals did not differ from the American normative population only in the knowledge and usage of a second language. Being bilingual involved social dimensions which were encompassed by the languages they spoke. They were in fact immigrants and their performance should have been viewed within the context of the social history surrounding the debate over the changes that the American society was undergoing in the early 1900s. At that time, there was an intense social debate over the quality of the new immigrants coming from southern and eastern of Europe. Suffice to report that the president of MIT, Francis Walker, expressed his opinion in these terms:

> "*These immigrants are beaten men from beaten races, representing the worst failures in the struggle of existence. Europe is allowing its slums and its most stagnant reservoirs of degraded peasantry to be drained off upon our soil (Quoted in Ayres, 1909, p.103").*

The interpretation of these studies was thus influenced by the social atmosphere that the America society breathed in this period. Hasty interpretations were therefore put forward and accepted even though variables of evident paramount importance, such as socio-economic status were not properly controlled.

In fact in 1930 McCarthy alerted that bilingualism was most likely confounded with low socio-economic status, since she found that more than a half of bilingual sample of children enrolled in the research of that period belonged to unskilled labor occupational families. Nearly at the same time, Fukuda (1925) pointed out that high-scoring English-speaking children were mostly in the occupational and executive classes. Yet, McCarthy findings were neglected.

A second limit is that bilingual children were administered verbal tests of intelligence such as the Stanford-Binet test. Doubts were indeed raised concerning the reliability of those scores. Some researchers wondered whether their insufficient mastery of English could handicap them on verbal subscales of this test. For instance Mitchell (1937) found that Hispanic children obtained higher IQ's on a non-verbal test when the instructions were given in Spanish than when they were given in English. The same result was confirmed by Darcy (1945) with a different design: she selected one hundred six monolinguals (American monolinguals) and one hundred six bilinguals (Italian-American bilinguals) to whom were administered two intelligence scales: a verbal (Stanford Binet Scale, Form L) and a non-verbal test (Atkins Object-fitting Test, Form A). Bilinguals scored significantly lower than monolinguals in the verbal intelligence scale, whereas their performance on the non-verbal intelligence scale was significantly higher suggesting that the language in which verbal intelligence tests are built can strongly influence performance when they are administered to children having low proficiency in that language.

Nevertheless, such results were not sufficient to successfully counter the devastating theories on the causal relation between bilinguals and intelligence. Environmental psychologists sustained that proficiency in two languages retarded cognitive growth and only led to mental confusion. Macnamara (1966) claimed that since proficiency in a second language implied a loss in proficiency in one's own first language, the lower intelligence of bilingual children was a consequence of this "balance effect". There were also those who, among the hereditarian psychologists such as Lewin Terman (1919) and Florence Goodenough (1934), argued that intelligence was innate, and that these immigrant bilinguals descended from intellectually and genetically inferior people!

Furthermore, other studies claimed that bilinguals showed worse performance in some verbal abilities: poor vocabulary (Barke and Perry-William, 1938), deficient articulation (Carrow, 1957), lower standards on written composition and more grammatical errors

(Harris, 1948). Of course, these results were, once again, the consequence of low second-language proficiency in children considered bilinguals.

A third methodological concern associated with these studies was the way children were considered as bilinguals, that is whether subjects were in fact fluent in both languages. Brunner (1929) for instance, proposed that bilinguals be defined by the foreignness of their parents. In other studies indeed, bilinguals were assessed through family names or place of residence (Darcy, 1953).

To summarize, toward the end of the 1950s, research on the cognitive effects of bilingualism tended to show that bilingual performed lower than their monolinguals peers on measures of intelligence. On non-verbal abilities, however, some studies showed that bilinguals actually outperformed monolinguals but these results were not consistent across studies. Peal and Lambert's (1962) study, assuring a careful selection of bilinguals and a control of the socio-economic status, marked a breakpoint and, at the same time, a benchmark for later studies (see below).

2.3.2 Later studies: after 1960s

One of the earliest contributors to the second age of research on bilingualism is Leopold (1961). He noticed that his bilingual daughter Hildegard could render the same story freely in both languages. She efficiently stored new names for objects she already knew in the other language. Starting from these observations, Leopold proposed that bilingualism could lead to a *"looseness of the link between the phonetic word and its meaning".*

These suggestions inspired a different approach in the field: instead of studying the effect of bilingualism on general intelligence, the development of specific abilities of cognitive functions was monitored in relation with the degree of bilingualism.

In Peal and Lambert's (1962) study, all 10-year-old children were selected from the same school and were defined as bilinguals only after behavioral and subjective measures were acquired: (1) the relative proportion of words provided in a word association task in L1 and L2; (2) the relative proportion of words in L1 and L2 detected in a series of letters;

(3) the proportion of words recognized in L2 form a subset of stimuli chosen in the Peabody Picture Vocabulary Test and (4) subjective auto-evaluations about speaking, understanding, reading, and writing in L2. Children whose scores were unbalanced between L1 and L2 were considered monolinguals otherwise, if they performed equally well in both languages, they were considered bilinguals.

This study was a first attempt to overcome the main limits of previous research: attention was paid to proficiency in both languages, trying to consider as bilinguals only children having comparable proficiency in L1 and L2. Children were asked to perform subtests of the Thurstone Primary Mental Abilities test (Thurstone and Thurstone, 1954); Raven's Colored Matrices (Raven, 1956); and Lavoie-Larendeau Group Test of General Intelligence (Lavoie and Laurendeau, 1960).

Despite previous results, when controlled for differences in gender, age, and socio-economic status, in Peal and Lambert's (1962) study bilinguals showed significant better performances than monolinguals in both verbal and non-verbal abilities. The bilingual advantage was particularly evident in tasks requiring mental manipulation and reorganization of visual stimuli (symbolic flexibility) rather than on perceptual abilities.

This study had a strong influence on the field for two reasons. First, these positive results questioned several studies whose findings were completely opposed; second, given the care used in subject selection procedures (balanced bilinguals and SES), this study was viewed as a methodological breakpoint.

Criticisms were also promptly put forward: Macnamara (1966), for example, criticized the process of subject selection arguing that they could have introduced a bias in favor of the bilingual group because the bilingual sample included only children who scored above a certain level in the English Peabody Picture Vocabulary Test, a test used to measure intelligence. On the whole, however, this study offered a valuable methodological contribution and stimulated new and controlled research into the field.

After Peal and Lambert's (1962) seminal study, several researches replicated the bilingual advantage in a number of cognitive abilities such as concept formation (Liedtke and Nelson, 1968), metalinguistic awareness (Cummins, 1978), flexibility (Balkan, 1970), lateral thinking skills and creativity (Torrance, Wu, Gowan, and Alliotti, 1970), and the use of language to monitor cognitive performance (Bain and Yu, 1980). Among these heterogeneous abilities, data on metalinguistic awareness were consistent across studies. For instance, Ianco-Worrall (1972) showed that bilinguals outperformed monolinguals in the ability to compare words along semantic rather than phonetic dimensions. Cummins (1978) found that two different groups of bilinguals outranked monolinguals, above all in the capacity to evaluate tautological and contradictory sentences. El Salvador, Galambos (1982) showed that bilingual capacity to note syntactic errors was higher than that of their monolingual peers. Ben-Zeev (1977) asked to Hebrew-English balanced bilinguals to perform a symbol substitution task, measuring the capacity of children to replace words in a sentence according to the experimental instructions. For example, he asked to substitute the word “I” with the word “spaghetti” in the sentence “I am cold”. Children should be able to rapidly pronounce “Spaghetti am cold” (which is grammatically wrong but correct for the rules of the game) instead of the grammatically correct sentence: “Spaghetti are cold”. In essence, they were asked to perform the task while violating the grammatical linguistic rules and showing control over the automatic production of correct sentences. In such task, requiring awareness and attention to linguistic features, bilinguals outperformed their monolingual peers.

It was then argued (Bialystok and Ryan, 1985) that metalinguistic awareness is built on two abilities. The *analysis of representational structures*, is the ability to build mental representation and to access linguistic knowledge. This process is responsible to restructuring and recoding conceptual representations into symbols.

A*ttentional control* is the ability to direct attention to specific features depending on the task demands. According to Bialystok and Ryan’s (1985) model, bilinguals should show the same performance of their peers in the former ability, and better performances in the latter. Children were therefore asked to perform a sentence grammaticality task. Bialystok and Ryan distorted semantically some sentences making their meaning anomalous and asked to monolinguals and bilinguals to judge these sentences on a grammaticality basis. They argued that judging the grammaticality of these anomalous sentences would be more difficult than when this judgment is applied to meaningful sentences, since more control of attention over linguistic the processing is needed to solve the task. They actually found that bilinguals outperformed monolinguals in judging these sentences and confirmed the predictions of their model. However, Bialystok and Ryan model did not explain the origin of the bilingual advantage in attentional control. At that time there was no model sufficiently clear in describing the functioning of the bilingual system and how its characteristics relate to gains in cognitive functioning. A model that seems most useful in explaining these aspects of bilingual cognitive processes is the Inhibitory Control (IC) model.

2.4 Inhibitory control model (IC): from lexical access to executive functions advantages of Bilingualism.

The structure of the linguistic system is very complex as it connects syntactic structures, semantic intents and phonological outcomes. Imagine now bilinguals who possess and use regularly two of these linguistic systems: how do they manage to use only one of these languages? It is clear that bilinguals, unlike monolinguals, face the problem of producing words in one language while avoiding interference from the other language. To address the issue of how bilinguals manage to select between languages, it would be useful to know how words are represented in the bilingual lexico-semantic system.

Several theories addressed the question on the nature of the bilingual lexico-semantic system but only few of them have made predictions on how balanced bilingual are successful at using one linguistic system at a time. For instance, Ervin and Osgood (1954) proposed the concept mediation hypothesis: when bilinguals acquire their two languages in the same environment they create a compound system. If this is the case, how can they produce a word in L2 when its meaning is also expressed in its equivalent word in L1? Weinreich (1953) and Potter, So, Von Eckhardt and Feldman (1984) proposed that bilinguals could build a direct link from a word in L2 to its equivalent in L1, suggesting that accessing to word meanings in L2 is mediated by L1 representations. Again, if the access to semantic system of L2 representations is via L1, how is it possible for bilinguals to avoid L1 productions when words have to be produced in L2?

In 1994, Kroll and Stewart proposed a revised hierarchical model integrating both theories: they suggested that translations equivalents are linked both via concept-mediation and through direct associative links. Although this model can explain how translations occur, it did not solve the problem of how, in switching between languages, bilinguals succeed in avoiding naming the word to be translated.

Macnamara and Kushnir (1971) proposed that one or the other language system (or subsystem) can be switched either on or off, thus allowing to translate without necessarily naming the language to be ignored. However other works (Grainger, 1993; Guttentag et al., 1984; Hermans et al.,1998) suggest that both languages are always active because bilingual performances can be influenced by some features of the alternative language (for exceptions see Grosjean, 1997). This evidence was confirmed using cross-language tasks, including priming (Gollan et al., 1997), Stroop interference (Brauer, 1998), homograph recognition (Dijkstra et al., 1999) and picture naming (Hermans et al.,1998). More recent proposals suggest that in order to speak one language, its levels of activation must exceed that of the other language (Paradis, 1984). Of course bilinguals can face at least two types of situations: they can speak only one of the languages they know or they can mix their languages in situations where the use of both languages is allowed. The ability to regulate the use of this "language control function" has, following David Green's model (1998), much in common with the model of action proposed by Norman and Shallice (1986). David Green's model proposes that language is a form of communicative action, thus supposing a correspondence between the mechanisms of action control actions (when competing cues have to be ignored) and the mechanisms used by selecting languages and lexical items.

When performing actions, individuals identify the object that is the goal of the action (e.g., a glass), as it happens in speech when bilinguals specify the language to be used. Following Norman and Shallice's (1986) model, behavior is controlled by two different systems: the system responsible for routine (automatic) actions such as driving, which exerts direct control over behavior, through a process called contention scheduling. This process works by the use of schemas, containing detailed action sequences and it can control behavior. In novel tasks, where automatic control is not enough, contention scheduling is modulated by a system called supervisory attentional system (SAS), whose task is either to modify existing schemas or build new ones.

According to David Green's proposal, in performing *language actions*, the bilingual lexico-semantic system can be regulated by a conceptualiser, whose task is to store conceptual representations (long-term memory) that are chosen in response to the specific goal of the communicative intention; *language actions* are regulated by the SAS, a component of the language system (lexico-semantic system) and a set of language schemas (e.g., word production schemas or translation schemas). Language schemas can modulate the outputs from the lexico-semantic system either by regulating the activations of representations or by inhibiting outputs from the system. This works until the goal of a *language action* is completed and is inhibited by another language schema or until the SAS has changed its goal.

Now, consider you are performing a language task, such as producing a word in L2, how does the system would decide which is the right lemma to be associated to the right lexical concept? The IC model suggests that after the lemmas have been activated, inhibitory control suppresses those lemmas that present incorrect language tags.

In brief, the IC model assumes that to successfully perform a language task, the SAS acts as a devise influencing the activation of language task schemas that compete to control the outputs, by activating and inhibiting tags at the lemma level. Therefore, by selecting and coordinating language task schemas into a sort of control circuit, bilinguals can differentially modulate a word's mental representation of meaning and lexicon. Some data are consistent with the hypothesis that the more dominant a language is, the more active suppression will be required: for instance, in a PET study, Price Green, et al., (1999) showed an increased activation in the supramarginal gyrus of the parietal cortex (a brain area activated also in non linguistic tasks requiring attention) in tasks involving a switch between languages. Jackon et al., (2001) found also an increase over parietal cortices in an ERP component associated with response selection as it is in the Stroop task. Data coming from bilingual aphasics support these evidences for an involvement of attentional control in language tasks. An example is a study made by Fabbro, Skrap, and Aglioti, (2000) who found that lesions in the left prefrontal lobes were associated with pathological switching between languages. In a fMRI study made by Hernandez et al. (2001), increased activity in the dorsolateral prefrontal cortex for switching condition was found in early Spanish-English bilinguals. Surprisingly, rTMS (repetitive transcranial magnetic stimulation) applied on the left prefrontal cortex of two bilinguals (as a treatment for depression) induced in these subjects language switching (Holtzheimer, Fawaz, Wilson, and Avery, 2005)!

Strong evidence was brought about by Rodriguez-Fornells et al. (2002) who compared the neural correlates of language selection in a group of early bilinguals (Catalan-Spanish) and a group of monolingual (Spanish) using both event-related potentials (ERPs) and fMRI. In a task where participants had to read Spanish words intermixed with pseudo-words, they found an activation of left anterior prefrontal region in the bilingual group only.

Bilinguals would therefore need a control mechanism able to orient attention to the required language system and, at the same time, to ignore the alternative language system. In some bilingual contexts, such as it happens in the territory of Alto Adige where Italian and German are used interchangeably, on a daily basis, the exercise of attentional control over one or the other language is really frequent: bilinguals must shift attention to the other language when the interlocutor speak in that language and, in few seconds, they have to suppress the alternative language and control attention to the language that is relevant in that moment. Therefore, after having recognized and monitored the "language context", he must perform efficient switching between languages and fluent conversations.

Following the IC model, Ellen Bialystok studies propose that the linguistic and cognitive system engaged in regulating "competing" languages can be handled by general cognitive processes, mostly involving executive functions (attention, inhibition, switching and monitoring abilities). The early and continuous exercise of these skills could alter the normal development of the executive functions in bilinguals who use their languages on a daily basis. The next paragraph will describe the most important contributions in enlightening the bilingual's advantages in the attentional domain.

2.5 Cognitive control and bilingual advantage

2.5.1 Metalinguistic tasks: linguistic bilingual advantage

The processing framework provided by Bialystok as a mean to explain the results of the bilingual advantage in metalinguistic development, suggested that tasks requiring high demands for control of attention are solved better by bilinguals than monolinguals; whereas tasks involving high demands for analysis of representation are solved equally well by either groups. Within this framework, Ellen Bialystok and her colleagues found bilingual advantages in many subcategories of metalinguistic tasks: in counting words in sentences; symbol substitution; sun-moon problem (Piaget, 1929); use of novel names in sentences; word-referent problems; judgments on grammaticality of anomalous sentences and phonemes segmentation. Awareness of the segmentational processes that isolate words in utterances is one among the many metalinguistic abilities. Usually this ability is studied by asking children to count the number of words in a sentence or to define the concept of a word. Bialystok (1986a) compared the performance of English monolinguals and bilingual French-English in counting the number of words in a sentence when it appeared in its canonic form or when words were mixed to produce a string without any meaning. This task was solved easily when words were mixed but it was difficult when sentences were intact. Meaningful sentences interfered with the children's the ability to enumerate the words in the sentences. However, bilinguals suffered from less interference than monolinguals.

In a symbol substitution task, children were told to substitute words in sentences, making up meaningless sentences. For instance, they were asked to substitute the word *we* with the word *spaghetti*, which produced the following sentence: "*Spaghetti are good children*". Bilinguals showed to be less tied to familiar meaning of words and more willing to accept that the meaning of a word was just a convention. The same result was achieved by asking children to solve the classical sun-moon problem (Piaget, 1929). The experimenter asked:" Suppose you were making up names for things, could you then call the sun "the moon" and the moon "the sun"? Even in this case, bilinguals were better than monolinguals at understanding that they can arbitrarily change names for things (Bialystok, 1988). A similar task was employed by Feldman and Shen (1971) who taught groups of monolinguals and Spanish-English bilinguals new names for things: the new names were either the real names for objects or nonsense words. Monolinguals and bilinguals were equally successfully in using the new or nonsense names but only the bilingual group were able to actually use nonsense names in linguistic contexts.

Edwards and Christophersen (1988) investigated how levels of literacy influenced performance on a segmentation task, a referential arbitrariness task and simple grammaticality judgments. They found that higher levels of literacy but not bilingualism were related with higher performance on a segmentation task; in the referential arbitrariness task the level of bilingualism was positively correlated with performance; neither literacy nor bilingualism was significantly related to children's ability to judge the grammaticality of sentences.

This latter task, grammaticality judgment tasks have been widely used as a prototype to measure syntactic awareness. Galambos and Hakuta (1988) compared longitudinally monolinguals and bilinguals in a standard task (children were asked to judge and then correct the syntactic structures of sentences) and in a second task, where they had to judge for the ambiguity of sentences and then paraphrasing their possible interpretation: Galambos and Hakuta did find a bilingual advantage, but only for older children.

A further component of metalinguistic task is phonological awareness that is the ability to discriminate the sounds that make up words. This skill is considered very important because it has been associated with achievement in learning to read, hence with literacy. Advantages were not consistent among studies. Bialystok, Majumder, and Martin (2000) asked 5, 6, 7 years-old children to perform a phoneme substitution task: they had to replace the first sound in a word with the first sound from another word to produce a new one (i.e.: *cat* can be modified to *mat* by substituting the first sound of *mop*).No differences were found between groups. According to Bialystok et al. (2000), bilinguals show better performance only in tasks requiring high levels of attention, when a misleading piece of information has to be ignored.

Although data were not always consistent with such processing framework suggested by Bialystok, several studies have investigated other aspects of the bilingual cognitive function. The most important question that was not sufficiently addressed in the processing framework proposed by Ellen Bialystok is why bilinguals should show any advantage. That is, what is the mechanism is responsible for that gains in the bilingual cognitive system.

2.5.2 Attentional tasks: non linguistic bilingual advantage

According to the IC model proposed by David Green, bilingual lexical access might involve some kind of control mechanisms (Costa, 2005) because bilinguals need to decide which language they want to use. To communicate successfully, they should select only lexical representations of the intended language; otherwise communication will be confused (especially when the interlocutor knows only one language). Two questions seem important for this issue: if mechanisms that permit bilinguals to focus only on one language involve attention, are they the same mechanisms that are used in general cognitive functioning or are they specific to language? If they are general control mechanisms, may the continuous involvement of such mechanisms in bilinguals influence general cognitive functioning? Answers to these questions can be addressed by investigating whether bilinguals exhibit a general advantage in mechanisms of attentional control. If, in accessing to linguistic representations, bilinguals use mechanisms of attentional control which are not specific for language, and if its continuous involvement has in impact on the general cognitive functioning, differences between bilinguals and monolinguals should be found in non-verbal tasks requiring control of attention.

A first attempt to answer these questions is to investigate the development of these processes in different domains such as the number domain. Although the literacy and numeracy may appear separate from cognitive domains, according to Bialystok and Codd (1997), acquisition of their basic concepts shares common processes. In both cases, indeed, children acquire arbitrary symbols (numbers and letters) that stand for referents (quantities and sounds). Following, these symbols are ordered in conventional sequence (counting and alphabet) that is learned as a basis for more complex abilities (arithmetic and reading). A way to investigate the development of cardinality concepts within this framework is to measure bilingual performance in tasks containing misleading information (Bialystok and Codd, 1997). Thirty-eight monolinguals (twenty 4-years old and eighteen 5-years old) and fifty-nine bilinguals (twenty 7-years old and thirty-two 5- years old) were asked to perform two tasks. During the sharing task, participants were told to share a quantity of items and determine the quantity in each set of items. Two stuffed animals, Huey and Dewey Duck, were shown to children: they were told that Huey and Dewey Duck wanted to share the blocks and children would help them in the process of dividing the blocks giving one to each duck in turn. When the blocks were evenly shared, children were asked whether the Huey and Dewey had the same number of blocks and counting how many block each duck had got. The second task was supposed to require attentional control: it was called Tower task. Children were shown pairs of blocks towers made by Lego and Duplo blocks. All blocks had the same color and structure but a Lego block was half the size of a Duplo block, therefore, two towers of blocks built with Lego blocks would be half the size of a tower built with Duplo blocks. Children were shown a pair of towers and were told that each block was an apartment and even if some apartments are large and other are small, just one family could live in each of them. Children had to count the blocks and choose the tower having more families in. Different pairs of towers were shown: two of the items were corresponding pairs (the taller tower also had more blocks); two other items were non corresponding pairs (the Lego tower had more blocks but the Duplo tower was taller). These latter items contained conflicting information: if children relied on the perceptual cue to answer, they would not give the correct response. Therefore, to solve this task, they should count the blocks and, at the same time, ignore the distracting information given by the height of towers in non corresponding items. Whereas no difference was found between groups in the sharing task, bilinguals seemed to perform better than monolinguals in the task requiring attentional control (non corresponding items of the tower task).

A different way to investigate the issue may be to test bilinguals and monolinguals on tasks that explicitly require the involvement of executive functions. A classical executive functions test is the Dimensional change card sort (Zelazo and Frye, 1997). In this task, children are shown cards containing pictures (i.e.: a red rabbit and a blue boat). They are asked to sort by color cards containing red boats and blue rabbits. Then the experimenter gives them a new rule to sort the same cards (i.e. by shape) and children must sort the card by this new dimension.

The second phase of this task, when children have to resort the same cards by a different rule, is very difficult to perform for children until 4 or 5 years old. According to the Cognitive Complexity and Control theory (CCC), executive functioning is needed to successfully solve this task: children need to understand the purpose of the first sorting rule and after having applied this knowledge, they have to ignore the rule, thus reconsidering the cards under a new dimension (the new rule). Bialystok (1999) administered the test to a sample of 60 children: 30 English monolinguals and 30 Cantonese-English bilinguals and found that bilinguals outperformed monolinguals. However, Young and Lust, (2004) using the same test, did not replicate Bialystok's (1999) finding: no difference was found between groups) A few years later, in 2005 Bialystok and Shapero addressed the same issue using the reversing ambiguous figures, a test that, according to some authors presupposes some sort of attentional mechanisms. For instance, Meng and Tong (2004) proposed that selective attention is responsible for the ability to reverse figures as compared to other abilities involved in bistable perception; Tsal and Kolbert (1985) showed ambiguous figure to participants and asked them to maintain the same interpretation. After that, they presented a mask appearing for 50 ms and a letter placed in the focal area responsible for one or the other interpretation. Participants had to indentify the letter. They found that the identification of the letter was faster when the letter was placed in the focal area that was relevant for interpretation being maintained by the subject. They thus suggested that attention could be responsible to perform this test. The reversibility of meaning requires the ability to direct attention to the stimulus in a different way and suppress its original interpretation. Rock, Gopnik and Hall (1994) found that children between 3 and 5 years old failed in performing this test. Bialystok and Shapero (2005) showed to six years old monolingual and bilingual children four pictures: two figure-ground figures (vases-face and saxophone-woman) and two content meaning figures (duck-rabbit and rat-man). Results showed that bilinguals did not differ from monolinguals in the duck-rabbit (which is considered the easiest) and in the saxophone-woman figure (which is considered the most difficult). Bilinguals instead over performed their monolingual peers in the vases-face and in the rat-man figures. These tasks suggested, that bilingual children were more successful, although not consistently, than their peers in solving these tasks are important they contribute to the extend research on bilingualism beyond the verbal domain of this research to non-verbal domains.

However, two questions must be raised at their peaks: such three tests overtly involve different attentional abilities, so which is the specific mechanism that is putatively boosted by the bilingual experience? Could these results be indeed expressions of differences in the socio-economic status rather than dependent upon bilingualism? None of these three studies adopted specific measures to determine the socio-economic status of children. This is an important issue since much research (Mezzacappa, 2004) suggest that environmental factors may exert influence both on global cognitive functioning such as IQ, or school achievement and also on more basic processes such as alerting and executive functions.

The role of the caregiver has been found to be important in influencing the early maturation of the hypothalamic-pituitary-adrenal (HPA) axis. Cortisol, secreted by HPA axis, is essential for brain development and also for areas of the medial and dorsolateral prefrontal regions considered important for attentional mechanisms (Gunnar and Donzella, 2002; Lupien, King, Meaney and McEven, 2001) For instance, Lupien et al.(2001) found that 6 years old children from lower socio-economic backgrounds have higher levels of basal cortisol and poorer attention than their peers belonging to advantaged backgrounds.

Two studies (Young and Lust, 2004; Costa et al.,2007) have indeed investigated more deeply the effect of bilingualism on a range of specific executive abilities The Attentional Network task (ANT) a task developed by Fan et colleagues (2002) is a set of abilities that have been widely used in research for studying the development of attention. The Ant task is composed by three different attentional network: executive control, alerting and orienting abilities. Participants are simply to say whether a central arrow (target stimulus) points to the right or to the left. However this arrow is presented along with other arrows pointing to the same or different direction than the central arrow. All these arrows point to the same direction as the central arrow (corresponding trial), responses are usually faster than in trials where the arrows point to the opposite direction than the central arrow (non corresponding trials). To successfully solve the task, participants have to ignore the conflicting information given by the arrows placed on the right or left of the target arrow. This is supposed to involve executive functioning. In addition, to study the alerting network, there were trials with a cue presented before the target stimulus.

Typically, reaction times are faster when a cue precedes the target stimulus than when it does not. The third mechanism studied by the Ant task is the orienting network: a cue placed on the right or the left in the screen signals the position where the target stimulus would appear: performance is faster when the cue signals the position of the target than when it does not. In 2004, Young and Lust administered a modified version of this test to 13 English monolingual and 13 Korean-English bilingual children (mean age:4,8), and found that the percentage of accuracy in bilinguals was significantly higher than that of monolinguals across all tasks. However, reaction times analysis did not show any difference between groups. The Ant task was also employed with a large number (100 participants for each group) of monolingual and bilingual adults by Costa, and colleagues (2007): they found that the group of bilinguals were overall faster than monolinguals in all three tasks. In addition, they found that bilinguals suffered from a smaller switching cost than monolinguals. Specifically, when participants had to switch from congruent to incongruent trials, both groups showed the same performance. However, bilinguals exhibited a smaller cost in switching from incongruent to congruent trials.

Another way to test the hypothesis of the bilingual's advantage is to test bilinguals of different ages on a same task and see whether performances between monolinguals and bilinguals differ across age. A task that can be addressed for this purpose to both children and adults is the Simon task (Lu and Proctor,1995), a measure that, to be performed accurately, requires executive control. In the Simon task, participants are told to learn a rule, that is to associate a color to a response key ("if the circle is red, press the right key, if the circle is green press the left key"). Stimuli appear on the right or left side of the screen and participants are instructed to respond as soon as possible. Although the position of the stimulus on the screen (on the right or left side on the screen) is irrelevant to perform the task, reaction times slow down when the position of the stimulus and the correct key are non corresponding. For example, when a red circle appears on the left side of the screen and participants have been instructed to respond to red with right key, reaction times are slower. In corresponding trials, when indeed, the red circle appear on the right side of the screen, and participants respond pressing the right key, performances are faster. In the non-corresponding trials, the conflict between information given by the position of the stimulus (although irrelevant) and the position of the key, causes a slowing in reaction times.

The magnitude of the Simon effect has been shown to enhance with age. If control processes are involved in this task and if its magnitude increases with age, will bilinguals exhibit a smaller Simon effect than their monolingual peers, at any age? Bialystok and colleagues (2004) employed the Simon task in a study where participants were forty: 20 were younger adults (from 30 to 54 years) and 20 were older adults (from 60 to 88 years old). In each group half of participants were monolinguals and half bilinguals. The authors predicted that younger bilingual adults would show a smaller Simon effect than their peers. Moreover in older ages, bilingualism should attenuate the age related decline in inhibitory processes. Indeed, they found that bilinguals outperformed their peers showing a smaller Simon effect in both groups. However the study presents some methodological problems: groups of participants were too small (10 participants); the number of trials (14) for each condition was meager, and not for least, reaction times were unusually large for the monolingual groups: the magnitude of the Simon effect was 40 ms for the younger bilinguals and 535 ms for their monolingual peers! A similar pattern of results was present in the older groups: bilinguals exhibited a 748 ms of Simon effect and monolinguals 1713 ms! For instance, Van der Lubbe, and Verleger (2002) investigating the relation between aging and the magnitude of the Simon effect, found that the magnitude of this effect in the younger groups was 20 ms and 48 ms for the olders adults. In a further study Bialystok and colleagues (2005) employed the Simon task in a MEG study. Although there was no difference between corresponding and non-corresponding trials across between language groups, they found that the two language groups used different brain areas to solve the Simon task; in corresponding trials, while bilinguals activated anterior cingulate, superior frontal and inferior frontal regions, monolinguals mostly activated middle frontal regions. Importantly, all left-hemisphere regions were that activated in bilingual participants were close to language areas in the inferior frontal cortex. These findings, according with Green's model, suggest that the experience of managing two languages could enhance control processes in the left frontal areas allowing to use these areas for inhibitory non-verbal processes.

The same task was used more recently in a study where participants were 5-years monolingual and bilingual children (Martin-Rhee and Bialystok, 2008). This study was aimed at exploring the development of two type of inhibitory control. In a first study, they asked children to perform three different versions of the Simon task: in the immediate task (canonical version) children were asked to press the key as soon as possible; in a second version, children were told not to press the key until a cue appeared (800 ms) on the screen; in the third version they had to wait for longer (1000 ms). Martin-Rhee's rationale was that inserting a delay between stimulus presentation and response, the need for inhibitory control should be weakened. Bilinguals would outperform monolinguals in the immediate response task, showing a reduced Simon effect than their monolingual peers in the short delay version of the Simon effect and show no Simon effect in the long delay task. Results did show that bilinguals outperformed monolinguals only in the immediate version of the Simon task but no reduction of the effect was found in the other two tasks. However, the main finding was not replicated by Morton and Harper (2007), who compared the two language groups only after they performed an accurate selection of participants: in addition to language use and SES (measured by making a composite measure of the total family income and level of academic achievement) they gathered information about country of origin, occupation, and level of education of parents.

2.5.3 Recent explanations on the bilingual advantage

On the whole, these findings were not clear-cut in establishing differences between bilingual and monolingual cognitive functioning.

Colzato et al. (2008) offered a new mechanism for the re-interpretation of the supposed bilingual advantage: they assumed that there can be two mechanisms to select words in one or the other language. Bialystok model (1985) and Green's model (1996) assume that a word can be selected by inhibiting its distractor. This process, called active inhibition, presupposes that target and distractor compete for selection and that selection of the words to be used occurs only after the competing word has been inhibited. If bilinguals use the mechanism of active inhibition, they should show advantages in the Stop Signal task (Logan and Cowan, 1984).

As in any test a stimulus is presented and a response must be executed. The stimulus can be followed by a stop signal indicating the immediate abortion of the response. Several versions of this task have been used to investigate the efficiency in inhibiting cognitive processes. Colzato's version of this task was that she told to participants to respond to the direction of a green arrow with right or left keys. The stop signal was a sudden change of the arrow's colour. Performance between groups was identical, suggesting that bilinguals are no better inhibitors than monolinguals. Since this task could not be sufficiently sensitive to detect differences in the bilingual functioning, they administered an inhibition of return (IOR, Klein, 2000) task. In this task, the location of a target is cued by a flash (that may appear at the location where the target will be). Cues that appear at short stimulus onset asynchronies (SOAs) improve the performance, whereas those cues occurring at larger SOAs impair the performance. During short SOAs, cues automatically attract attention to their location thus providing an advantage in solving the task. When cues appear at long SOAs, inhibitory mechanisms responsible to suppress the previous location might be involved. Their prediction was that performance between groups will be identical at short SOAs but it will differ (in favour of bilinguals) at longer SOAs. Both groups showed similar performance in the two shorter SOAs, but actually bilinguals seemed to be disadvantaged at longer SOAs! The authors explained these results by suggesting that bilinguals could be able to build distinct representations for cues and target leading to more inhibition of the cue and its features: as consequence, repetition of location produces more negative consequences in bilinguals than in monolinguals.

Another process that can be involved in selecting words is called reactive inhibition. It is assumed that it does not involve direct inhibition of distractor, but indeed support, by strengthening, the word to be selected. A task that enables the study of reactive inhibition employ the attentional blink paradigm (Raymond et al., 1992): when participants are shown a rapid sequence of stimuli at the same place on the screen, they often fail to recognize another target occurring in this rapid sequence, if it occurs between 100-500 ms after the first one. It is widely assumed that the first target occupies a larger part of attentional resources that prevents the second target to be effectively detected. Colzato et al. (2008) predicted that if bilinguals produce stronger reactive inhibition, they should show worse performance in the attentional blink task, because they would support more strongly the first target and thus exert a higher cost in detecting the second target: this prediction was totally confirmed thus suggesting that for bilinguals it was more difficult to process the second target while they were still processing the first one. These data could likely reflect the fact that bilinguals engage more resources in selecting a target rather than inhibiting a distractor. The experience of bilingualism might, for these authors, improve the ability to select relevant information, that is reactive inhibition, rather than actively inhibiting the competitor information.

Although a growing number of studies have supported the idea that the experience of bilingualism could be favorable for the development of cognitive functioning, data coming from these research does not offer an unitary and coherent view. Some studies showed advantages for bilinguals and other studies did not replicate the same findings even when using the same task. Moreover a comparison among all studies is not possible because many methodological aspects differ from each other: participant's selection procedures, tasks, and designs. However, two effects can be taken as constant in these studies: bilinguals performance is overall faster in tasks involving conflict resolution that is bilinguals are faster in both corresponding and non corresponding trials and that they are faster when both corresponding and non correspondent trials are presented in mixed blocks.

This result, initially underestimated, can indeed be an index of the influence of bilingualism on cognitive abilities others than the inhibition of distracting information.

If bilinguals need to control their two linguistic representations, focusing on the relevant language and ignoring the other one, bilinguals should be better only in non corresponding trials: why, indeed they excel in corresponding trials too? A possibility could be that bilingualism aids also the monitoring processes. Bilinguals could be better at dealing with tasks involving different types of trials which can or not imply conflict. The ability to perform these in mixed tasks can entail monitoring processes as it could happen when they need to choose the appropriate language to use. This hypothesis could be directly tested by varying the percentage of corresponding and non corresponding trials. Costa and colleagues (2009) asked participants to perform different version of a flanker task: in some cases the percentage of one type of trials was very low (i.e.: 8% of trials were correspondent) and thus the involvement of monitoring processes is very low because the majority of trials are corresponding; in other cases the percentage of corresponding and non corresponding trials are quite similar and demand for monitoring processes is very high. Their prediction was that if bilinguals are better in monitoring processes, they would show an advantage in cases where the percentage of corresponding and non-corresponding trials was quite similar. In fact, bilinguals showed a clear smaller effect than monolinguals in tasks with high demands of monitoring processes (a similar finding was also shown by Bialystok, 2007).

This latter study, in addition to the study of Colzato et al. (2008), provides a new insight to this field by proposing that conflict resolution could play a minor role than one can expect in bilingual functioning. This would imply that the process of lexicalization, that is the process allowing bilinguals to select one or the other word, could it not the only process responsible of the bilingual advantage. Before selecting the right word, bilinguals need to decide which language they should use in that specific context, and select the most appropriate language schema (Green, 1998) to successfully monitor the language context.

2.6 Lexical Access and bilingual disadvantages

When asked to produce words, for instance in tasks requiring naming pictures, monolinguals might first identify the object depicted in the picture, access the correct conceptual representation of that object and retrieve its right lexical representation. According to some model of speech production (e.g., Caramazza,1997), when conceptual representations are accessed, this activation causes the simultaneous activation of disparate lexical representations that are semantically related to the concept. Then a mechanism of selection is needed to activate the correct lexical representation that will be produced.

Translating a conceptual information into speech productions is called *lexical access*. Image how complicate it will be accessing lexical representations when an individual possesses two lexical systems, as it is the case for bilinguals. In addition to the activation of semantically related representations within one language, activation spreads also to lexical representations of the other language. It is clear that accessing to the correct lexical representation is more difficult for individuals who possess more than one linguistic representation. The complexity of bilingual lexical access leads some authors to suggest that bilinguals could be disadvantaged in tasks requiring speech production (Ivanova, Costa, 2008; Gollan, Silverberg, 2001; Gollan et al., 2002).

For instance, Kohnert et al., (1998) have found that bilinguals scored below the norms on the Boston Naming test, a measure of object naming from line drawings used to examine children with learning disabilities or brain-injured adults. The same finding was replicated by many other studies (e.g. Roberts et al., 2002). Portocarrero et al., (2007) for instance, measured performances of college students (either bilinguals or monolinguasl) in English vocabulary and verbal fluency. Despite bilinguals' arrival in the U.S. occurred at a relatively young age, bilinguals had lower receptive and expressive vocabularies and semantic fluency scores than their peers.

Vocabulary size is a very important measure especially for children's cognitive development: because knowledge of vocabulary poses a basis for developing a higher understanding of language. Bilaystok and Feng (2008) measured the performance of bilinguals and monolinguals children (from 5 to 9 years old) on a standardized version of the Peabody Picture Vocabulary test. The lowest scores were associated with the bilingual sample in all bilingual groups and thus it was constant throughout age. Pearson, Fernandez and Oller (1993) found that also pre-school bilinguals had a vocabulary size that was half that of their monolingual peers, when total vocabulary (L1+L2) was measured, however it equaled that of their monolingual peers (Genesee and Nicoladis, 1995)

In addition to vocabulary size, disadvantages are also found in accessing lexical representations, or lexical retrieval. In verbal fluency tasks, participant are asked to produce as many words belonging to a given semantic (animals, fruits or vegetables) or phonemic (words beginning with F, A, or S) category, in 60 seconds. In a study by Gollan et al., (2002), Spanish-English bilinguals produced fewer correct responses in verbal fluency tasks. Rosselli et al., (2000) found similar results when tested both groups in two semantic fluency tasks.

Bilingual disadvantages in lexical access are also evident with reaction times measures in picture naming tasks. Gollan et al. (2005) asked English monolinguals and English-Spanish bilinguals who learned both languages early, to classify and name pictures. On picture naming tasks bilinguals were slower and produced more errors than monolinguals. Even after participants repeated the task for three times, bilinguals still showed a disadvantage. However, when they had to classify pictures bilinguals performed as well as monolinguals. This result is striking, since reaction times for bilinguals were slower in picture naming but not in picture classification, suggesting that lexical access is where bilinguals are disadvantaged. Disadvantages have been confirmed in a study made by Ivanova and Costa (2008): they found that Spanish-Catalan bilinguals were slower than Spanish monolinguals both when they were assessed in their first and their second language. Gollan et al., (2007) found that slower naming was constant with age.

Bilinguals report also more tip-of-the-tongue states (TOTs), that are experiences made by individuals who fail in retrieving well-known words. Individuals usually report they know well that word and that they feel to be recalling the word in that moment; sometimes they can also report some feature of that word: its initial sound, categories, colors, etc.

This finding has been confirmed in different types of bilinguals: Hebrew-English (Gollan and Silverberg, 2001); Spanish-English, Tagalog-English bilinguals and, as for data on lexical access, TOTs were reported even in bilinguals' s dominant language (Gollan and Acenas, 2004). They obtained the same result when the comparison between groups involved only bilinguals who rated their English with high scores, suggesting that differences between groups were not determined by language ability or lack of familiarity with targets. Two accounts can describe the bilingual disadvantage: the weaker links and the cross-language interference accounts.

The weaker links model predicts that bilinguals possesses weaker lexical connections because, differently from monolinguals who speak only one language at any time, bilinguals speak each language half of the time and thus their connections are less strong that connections of monolinguals. Cross-language interference instead, assumes that these patterns arise from cross-language competitions at the retrieval stage. Despite these different explanations, for both models, lexical access seems to be the key component to explain the bilingual disadvantages.

2.7 Conclusion

Research into this field indicates that the constant use of two languages may exert two main effects on the development and functioning of cognitive functions. The direction of these two effects is opposite: whereas bilinguals seem to show better performances in tasks requiring attentional mechanisms, they exhibit consistent disadvantages on tasks requiring lexical access. Such opposite findings cannot be attributable to different samples because some studies (Bialystok, Craik and Luk, 2009) replicated both findings within the same sample.

Although opposite, these effects seem to share the same origin: the lexicalization process. Whenever bilinguals need to produce a word in one or the other language, they face the problem of selecting the right lexical item according to the language they need to use. Selecting the right word is obviously more complex in individuals who possess two linguistic representations within the same mind: bilinguals, as monolinguals, need to select the right word within the same language (avoiding semantic related words) but also, unlike monolinguals, selecting the right word for the language they are planning to use in that context. Knowledge about precise mechanisms involved in this selection are still under debate.

Interestingly, recent data from these parallel studies on the cognitive effects of bilingualism (Costa et al., 2009; Finkbeiner et al. 2006) converge into the idea that both advantages and disadvantages may arise from bilingual speech production to enhance the activation of the target (Colzato et al. 2008; Costa et al.2009) rather than inhibiting the target to be ignored (see Bialystok, 2008).

Future work will surely attempt to clarify these aspects of theories on bilingual cognitive functioning and give more decisive contributions to the field.

Chapter 3
Relation Between Numbers And Language

3.1 Language and thought

By making meaningful sounds with our mouths, we can circulate complex ideas between different minds. And we can do so, thanks to our linguistic ability. When a specific language is shared by the members of a community, information can be conveyed with incredible power. This is communication. Anyone can benefit from information coming from people with particular skills or experiences. Throughout language, people can also work in team and realize wonderful enterprises. Language is thus, the most powerful tool that we could ever possess: considerations on its invaluable role and for its effects on our thoughts and cognition have inspired several theories. Piaget (1962b) considered language and the conventional nature of words (i.e. the arbitrariness of the link between a particular sound form and its referent) as a crucial social factor for the development of concepts and logical reasoning. Vygotsky (1964) emphasized the role of conceptual and semiotic aspects on intellectual development: he claimed that once children realize that any object has its proper name, each object become for children a problem situation that can be solved by naming the object. When the link between words and objects is lacking, children should ask adults to solve that situation problem. These theories were derived from two linguistic hypotheses proposed by Benjamin Lee Whorf, in 1920s and 1930s, who believed that language plays a role in thoughts and perception. The stronger version of his hypothesis, called linguistic determinism, maintains that thought and behavior casually depends on the structures shaped by language. A weaker reformulation of Whorf's hypothesis, named linguistic relativism, postulates that thought and language can be linked, but such relationship is not necessarily causal. Nowadays most scientists reject both hypotheses; among these Steven Pinker (1994) claims in his book: *"Eskimos speak differently so they* *must think differently. How do we know that they think differently? Just listen to the way they speak!".*

Many cognitive scientists (e.g., Pinker, 1994) found that the strong version of the Whorfian hypothesis is not reasonable because countless works demonstrate that several forms of thought and perception are already present in pre-verbal infants and animals. Such findings, however, cannot rule out that language can influence certain aspects of thoughts and cognitive processes. The issue can be especially interesting in the field of numerical cognition. The following paragraphs will describe the principal findings concerning the role that the acquisition of the first language and then of bilingualism can exert on the development of number skills.

3.2 Language and numbers

3.2.1 Numerical systems among cultures

Useful insights on this issue can be provided by cultures whose use of numerical concepts is limited to few linguistic expressions. Is the development of numerical skills also limited in such cultures? In 2004, Peter Gordon studied the Pirahã, an Amazonian tribe that uses only three concepts to refer to numerosities: one, two and many. Given such a limited range of expressions for numbers, Gordon investigated on how they refer to larger and exact numerosities. One possibility could be that they make a recursive use of these expressions (e.g., two-and-one meaning three; two-and two meaning four) or they could use counting strategies by means of fingers or body parts. Gordon's expectations were disconfirmed, since he found out that they sometimes use the word for one also to refer to other small numerosities like two or three, whereas they use the word for two to denote larger numerosities. That is, within the same conversation, the same word could be used for identifying different numerosities. Further, their numerical competence was accurate until 2 or 4 items but tended to become much less precise with increasing numerosities. Similar findings have been also replicated by Pica and colleagues (2004) who studied the Mundurukù, another Amazonian tribe whose language possesses number words only for numerosities from 1 to 5. Similarly to Gordon, these authors found that, above 5, Mundurukù relied on approximate expressions like “some” or “many” and they did not use words to identify exact numbers. These data confirmed that numerical approximation is their basic numerical competence and its presence is independent from the acquisition of language. Above all, such limited counting systems lacking of a lexicon to refer to exact numerosities is present with numerical abilities that were already found in pre-verbal infants and animals. It seems therefore that a system for exact number names shouldn’t be a prerequisite for possessing core numerical concepts but could be extremely helpful when attempting to make exact counting or calculations.

3.2.2 Language and numbers: bilingual studies and the Triple Code Model

A seminal study on this issue was carried out by Spelke and Tsivkin (2001), who investigated whether language plays a role in the development of exact and approximate number representations. They trained bilinguals with different set of number facts. Each participant learned, in one or the other language, one set of exact “familiar” large number addition facts (e.g., adding either 54 or 64 to each of a set of two digit numbers); exact “novel” addition facts (additions in base 6 and base 8); approximate number facts (approximate cube roots and approximate base 2 logs of a set of large numbers). Two days after, participants were tested in each language on all number facts. They were also tested in some numerical facts in which they had not been tested previously (exact large additions containing different numbers than those contained in the trained problems; cube roots which involved new numbers than those of the trained problems). When bilinguals were asked to report exact answers to trained large addition facts, they retrieved those facts more effectively in the language of training, whereas they exhibited the same performance both in the trained and non trained language in reporting approximate answers to large number facts. These results support the notion that while exact large facts are language-dependent representations, approximate large facts are stored and retrieved in language-independent representations. Interestingly Spelke and Tsivkin (2001) also investigated whether these findings extended to numerical facts inserted in fictitious histories or geography lessons as compared to non-numerical facts about common objects. In line with their previous results participants showed that, even in non-numerical contexts, large number representations are language-specific (since they were retrieved more efficiently in the language of training) while facts involving objects are retrieved with equal efficiency independently from the language in which they were trained. This research provided evidence that language is not only a medium of communication but is a tool for representing specific categories of information, such as exact large representation facts.

Therefore, bilingual children who learn arithmetic in one language may be disadvantaged when asked to do arithmetic in another language, however when they learn anew arithmetic in a second language they should be, at least as efficient as monolinguals in retrieving arithmetic facts. In addition and more crucially, Spelke and Tsivkin (2001) found that effects of language on storing and manipulating mental representation can vary between different fields and also within the same field: for instance, a child attending classrooms in his second language may be disadvantaged in retrieving exact and large arithmetic facts but should show a similar performance as children attending monolingual classrooms when asked to retrieve approximate numerical facts or non numerical information (common objects). The results of this research also suggest that language plays a role only in number tasks requiring access to precise and large number representations, that are required in more advanced stages of mathematical learning.

Such data are consistent with the "Triple Code Model" (Dehaene and Cohen, 1995, 1997), which postulates that arithmetic facts (especially additions and multiplications) are stored in a verbal code that facilitates their encoding and retrieval. According to this model, these arithmetic facts are stored in language-related left-lateralized brain circuits, having their core node in the left angular gyrus and resting on inferior frontal regions during active retrieval. Approximate number representations are instead independent from language and stored in the inferior parietal lobes bilaterally. In a study focusing on the neural correlates of arithmetic learning (Delazer, et. al., 2003), participants were first trained on a set of multiplications; then they were tested in an fMRI session, in which both trained and non-trained problems were presented. Participants showed a greater activation of the left intraparietal sulcus (IPS) for non-trained problems, suggesting that calculation was more quantity-based and less automatic in the untrained multiplications, and activation in the left inferior frontal gyrus (LIFG), which may indicate greater working memory demands to solve untrained problems. Trained problems activated the left angular gyrus (AG) which, consistently with the assumptions made by the Triple Code Model, could be the result of switching from quantity-based representations (untrained problems) to automatic memory retrieval.

A further fMRI study (Venkatraman, et al., 2006) employed two unfamiliar arithmetic tasks to investigate this issue: base-7 additions involving exact number representations and a percentage value estimation tasks involving approximations. English-Chinese bilinguals were trained in both of these tasks: half of the participants were trained in the approximate task in English and the exact task in Chinese and half of the participants the received the opposite combination. When participants switched their languages, activation was found in the frontal and parietal circuits for both trained and untrained tasks. For the task involving 7-base exact additions, language related areas were activated for language switching; whereas when languages were switched during the percentage estimation task, greater activation was found in the bilateral posterior parietal cortex (region which support visual-spatial attention and non-verbal processing). As postulated by Dehaene and Cohen (1994), approximate and exact number representations seem to rely to distinct cerebral mechanisms. While approximate number representations are not dependent upon language, exact number representations seem to rely on language processes.

3.3 Bilingualism and number skills

3.3.1 Bilinguals and arithmetic performance: early studies

Few studies investigated language switching during arithmetic computations. Some of them studied whether bilinguals have a language preference for making calculations (see Mestre et al.,1993); whether this language coincides with their mother tongue or with the language in which they were educated (see Mestre et al.,1993); also whether bilinguals perform calculations differently from monolinguals in terms of response times and errors (see Mestre et al., 1993). First insights into this field were brought by anecdotes or self-report of bilinguals claiming that they usually change their language when a calculation must be done. Kolers (1968) for instance, mentioned the case of one of his colleagues who, even though he moved from France to United Stated during childhood, still used to perform arithmetic in French. This is consistent with later studies (e.g. Bernardo, 2001) showing that bilinguals do not tend to perform arithmetic in their first language in any case, but in the language in which arithmetic was first learnt. The above mentioned results by Spelke and Tsivkin (2001) also supported this intuition because when they trained bilinguals to learn new exact number facts in one language, they retrieved those facts more efficiently in the language of training rather than in the untrained language.

Language switching was also considered the reason why bilinguals were less efficient than monolinguals in performing arithmetic. For instance, Marsh and Maki (1976) demonstrated experimentally those differences by asking bilinguals to solve arithmetic facts (additions with different number of operands) in the preferred and non preferred languages. They found that switching between languages when solving arithmetic problems slowed down reaction times. Further they also found that bilinguals are slower than monolinguals in performing calculations. They interpreted this latter finding by assuming that maintaining two linguistic codes active in memory hampers arithmetic performances.

A few years later Edith Magiste (1980) found poorer arithmetic performances of bilinguals as compared to monolinguals even when language was not overtly required to perform the task: participants were in fact asked to write down their answers for each calculation. Although she did not demonstrate the involvement of language in performing all of the four arithmetical operations (addition, subtractions, multiplications and divisions) she assumed that bilinguals performed slower and less accurately than monolinguals (in more complex operations) because language is required to solve such problems. Magiste proposed two explanations: she first proposed, in accordance with Ervin (1961), that bilinguals manage two language systems to perform arithmetic: the time taken to choose between the two alternatives is responsible for their longer reaction times as compared with monolinguals. She also suggested an alternative hypothesis based on the different strength of memory traces, in accordance with the model proposed by Hitch (1978): since monolinguals have number representations just for one language they practice only that language and strengthen its representations; bilinguals, instead practice two languages when retrieving numbers, thus their representations strengths are weaker and need more time to be retrieved.

Contrary to the Triple Code model, which assume that arithmetic facts are stored only in the language in which they are taught, both of these explanations assume that bilinguals possess one number representation for each language and that differences in reaction times are due to either an inhibition of the alternative number representation or the use of a less experienced linguistic retrieval route in bilinguals than in monolinguals.

More recent studies have adopted a different view: arithmetic performance is not even associated with language processes. Solving arithmetic operations seems to require the involvement of non-linguistic cognitive processes (Bull, Scerif, 2001), such as working memory or executive functions (Bialystok, 2007; see below). The next paragraph will give a brief overview of the principal cognitive processes associated with numerical tasks.

3.4 Cognition and Mathematics

Performance in numerical task can be influenced by many factors. Among these, some cognitive factors may be correlated with mathematical performance whereas others can predict later mathematical achievements. The relation between specific cognitive abilities and mathematics has a special importance not only for the basic understanding of how mathematical competencies are developed, but also for its possible implementation in educational strategies. It would be extremely useful for teachers to know in advance which of their students might need special attention or might benefit from particular learning strategies.

A substantial body of studies has found the involvement of working memory or some subcomponents of executive functions in numerical tasks. For instance, Bull, Espy and Wiebe (2008) studied the cognitive functioning of preschool children (about 4 years old) and were able to predict their academic achievement during their third year in primary education (i.e. when they were about 7 years old). Children were tested on a battery of cognitive measures, reading and mathematical abilities. At the first and third year of primary education, growth curves analyses revealed that higher performances in digit span and executive functions were good predictors of math and reading achievement. Above all, visual-spatial short-term memory span and working memory predicted mathematical achievement whereas executive functions predicted general learning irrespectively of domains.

Many other studies show that cognitive skills are associated with the mathematical domain: for instance the relative efficiency in using the phonological system seems to account for differences in arithmetical performance (e.g., Furst and Hitch, 2000; Gathercole and Pickering, 2000; Gathercole et al., 2004; Geary et al., 1991; Siegel and Ryan, 1989; Swanson and Sachse-Lee, 2001); the phonological loop has been considered responsible for encoding and retaining verbal codes used in counting or maintaining interim solutions. Visual-spatial working memory correlates with early counting ability (Kyttala et al., 2003) and defective visual-spatial skills can strongly affect number skills in several ways: inversions or reversal of numbers, misalignment of column digits, but also aspects of numerical processing such as number magnitude, estimation, spatial information (Dehaene, 1997; Dehaene et al., 1999).

Mathematical skills are also associated with executive functions: preschool children (Espy et al., 2004), 7-years and 11-years old children (Bull and Scerif, 2001; St Clair-

Thompson et al., 2006) showed that inhibitory abilities are predictive of mathematical achievement.

Other cognitive factors could, in addition to the influence of education and specific learning experiences, influence mathematical performance. Many researchers investigated cross-cultural differences in mathematical education and achievement (Stevenson et al., 1993; Stevenson et al., 1990). The most frequent finding is that Asian children consistently outperform their North-American peers in arithmetic even when education and IQ (e.g., Geary, Bow-Thomas, Fan, Siegler, 1996) are kept constant. Importantly, this advantage is specific for the number domain since performance does not differ in other cognitive domains like spatial attention or science (Beaton et al., 1966). It seems to arise from differences in educational systems (e.g., greater focus on mathematics instruction, or from socio-cultural factors such as special care of parents for skill development). This difference persists even in adulthood: when Chinese and American university students were compared on simple additions (LeFevre and Liu, 1997), the Chinese group showed faster RTs and used more efficient strategies. In contrast, Geary et al., (1997), found that arithmetic competence of elderly Chinese and American participants (60 to 80 years old) did not differ, which confirmed that such cross-cultural differences may be due to education and social influences rather than to biological factors. Importantly, Campbell and Liu (2001) found that when Canadian participants of Chinese origin, Canadian participants of non-Asian origin and Chinese participants educated in China where compared in solving arithmetic problems, the Chinese educated in China outperformed the other two groups in complex arithmetic. For simple arithmetic both Chinese groups outperformed the Canadian sample, suggesting once again that educational and extracurricular experiences should account for the differences found in simple arithmetic.

Chapter 4
Bilingualism and Mathematics

4.1 Rationale of the research

On November 22th 2005, the European Commission (EU) adopted a Slovak proverb as a guide for educational policies: *"The more languages you know, the more of a person you are"*.

In fact, increasing pressure has been devoted to boost levels of multilingualism across EU. The importance of knowing more than one language has also crossed the ocean: Dyane Adam, Canadian Commissioner of Official Languages expressed the concept with these words: *"Linguistic duality is everybody's business. It can only succeed in Canada if the majority accepts the reasons for it and fully supports it. Bilingualism in the 1970s was aimed at institutional change, but now it can be considered a personal and collective asset in an era of globalization. To give young people a chance to be bilingual is to give them a tremendous opportunity for cultural enrichment and help them participate in the new knowledge and information economy."*

Besides its invaluable role for one's own and social enrichment, bilingualism is also a *cognitive experience.* For cognitive experience, I'm referring to the growing bulk of research on its effects on general cognitive functions (see chapter 2 for a review). These findings, even if not always replicated, seem to suggest that bilinguals are advantaged on some components of executive functions and that they experience disadvantages on tasks requiring lexical access. However only one study (Bialystok and Codd, 1997), investigated whether these cognitive effects can actually extend to the real world, and to education in particular: if so, teachers might benefit from knowing in advance possible problems/advantages that bilinguals can experience on some areas.

Bialystok et. al. (1997) attempted to extend the supposed bilingual advantage in metalinguistic tasks to quantity processing. Similarly to the written language domain, where understanding the link between phonemes and letters is crucial for an accurate acquisition of literacy (Bialystok, 1991), Bialystok et al. (1997) tried to apply this framework to the number domain, by assuming that understanding the relation between numerical symbols and the concept of cardinality is a precursor of more complex numerical abilities. They asked to both monolingual and bilingual children to count objects in situations where both processes were required: in some situations children are required to simply count (i.e. to rely on an understanding of the concept "how many"), whereas in other situations they are asked to direct their attention to the counting problem while ignoring some salient perceptual features. They found that, similarly to linguistic studies, bilingual children were more efficient than monolinguals at performing number tasks under attentional load conditions. Results of this work are really interesting because, establishing the role that different educational programs or experiences, like raising a child as bilingual, can exert on mathematical development, can provide useful insights to education and policy.

In the present project I chose to investigate more deeply the possible influence of the experience of bilingualism on number domain, by comparing the performance of monolingual and bilingual children on a set of simple number skills such as counting set of dots, comparing the numerical magnitude of Arabic digits, verifying simple additions and verifying the results of multiplications.

Mastering these elementary skills, besides being a pervasive requirement of everyday life, constitute an important need for individuals living in modern societies.

4.2 Definition and problems concerning with bilingual studies and cognitive development

Bilingualism is a multifaceted phenomenon. Its quality and degree depend upon many variables both at the social and at the individual level that are very difficult to isolate for research purposes. Bilingualism can be at the same time prerogative of upper classes (when parents choose to enroll their children in special bilingual programs) but also a prerogative of lower classes (when parents decide to move in a foreign country in search for a job or a better quality of life). In either case, socio-economic status (SES) is a variable of great importance, especially if the aim is to study the cognitive development of bilingual children.

SES has been widely studied in developmental psychology and it has been shown to influence performance of both adults and children in a wide range of reasoning, linguistic, perceptual and memory tests (see Coscarelli et al. 2008). Many criticisms have been directed to studies on bilingualism, especially those employing children as participants. Peal and Lambert's (1962) study (one of the first studies showing that bilingual children are advantaged in some cognitive tasks), was strongly criticized because their bilingual sample was composed by children who were enrolled by their parents into special schools. These bilinguals could thus represent a special sample of the bilingual population and their cognitive advantage could be explained by SES than by their being bilinguals. Thus, the attempt to generalize the results of this study to the entire bilingual population could be far-fetched.

On the other hand, also studies which considered only immigrant bilinguals could be subject to critiques. The so-called "bilingual paradox" refers to the fact that, in absence of any particular familiar situations, children belonging to immigrant families record better achievement at school and manifest fewer behavioral problems than children belonging to non-immigrant families having the same or higher socio-economic status. Following Balboni et al. (2008) such results could be attributed to different levels of motivation and ambition to obtain social success. In this latter case, SES provides for a positive influence on children's personality and their school success but, clearly and once again, these results cannot be consequences of their being bilingual. Of course, such "immigrant paradox" phenomenon may strongly depend upon the social and political context lying in the host country. When these families move to foreign countries, their expectations for a better life are very high: if the level of their expectations is gradually matched by their social and economic improvement, their growing confidence could exert some effects on processes of acculturation. An examination of the socio-cultural and political surroundings of the bilingual phenomenon being assessed can help to prevent potential methodological and research validity problems.

A substantial part of the most recent American studies on the issue claims that bilingualism is related with cognitive gains in bilingual immigrants. Bilingual samples from different ethnic groups and who acquired their second language at different ages are routinely compared with American-speaking monolinguals. For the reasons outlined above, I instead picked bilingual participants from a local (i.e. not immigrant) bilingual sample, in addition to matching its SES with that of the monolingual group.

4.2.1 Bilingualism in Alto Adige: historical and local context

I decided to consider as target sample, bilinguals belonging to the territory of Alto Adige, whose bilingualism is not a prerogative of either upper or lower social classes. Such wide-spread opportunities to acquire a second language in Alto Adige are the result of both historical and geographical factors. According to the latest population census, which took place in 2001, three main linguistic groups can be identified in the territory: 69, 15% of the population speaks German as their first language, 26,47% speak Italian as their first language, and the 4, 37% speak Ladino. The German-speaking population is distributed almost evenly in Alto-Adige, while the Italian-speaking population is mostly condensed in the greater cities (like Bolzano, Laives, Salorno and Bronzolo).

The coexistence of both German and Italian languages is due to the fact that this territory officially belonged to Austria until 1920, when it was annexed to Italy on condition, subscribed by Vittorio Emanuele III, that local traditions would be maintained and respected. Agreement notwithstanding, under Mussolini’s dictatorship a strong Italianization was imposed. Italian became the official language spoken in all public offices and justice courts; journals, associations and German trade unions were abolished, all streets and places were renamed in Italian.

However, the German population tried hardly to protect their social identity, to the point that when Italian was promulgated as main and unique language to be used in schools, elementary schools in German language were secretly run in the Bolzano area (the so-called *Katakombenschulen*, catacomb-schools). Due to these adverse historical and political events, Italian and German populations were viewed as exclusive, and learning both languages was strongly opposed by political and cultural institutions. After a dozen years of fighting, in 1960 the Austrian chancellor Bruno Kreisky, brought such problem to the ONU's attention and the Italian government instituted a special Commission for studying and trying to tackle the Alto-Adige issue. In 1969 a Statute was approved, whose aim was, among others, to protect the linguistic identities present in the territory. Recently, many efforts have been devoted not only to recognize and protect these linguistic identities, but also to integrate both cultures and languages. Bilingualism is nowadays viewed as both the means and the direct result of social integration between local populations, and thus the diffusion of bilingualism is encouraged and language training made available to all citizens, regardless of their first language or social class.

Despite these laudable efforts, however, the opportunity to learn a second language is strongly dependent on geographical location. For instance in the Alto-Adige urban areas, the use of the Italian language ranges between 40% and 70%, thus there are many opportunities to learn Italian for the German-speaking, whereas Italians have fewer opportunities to learn German outside school. Learning German both at school and outside is instead possible in the valleys close to Bressanone, Vipiteno and Brunico, where the Italian population constitutes 40% of the inhabitants. For this reason (i.e. a substantial symmetry between languages), we focused the research on Italian-German bilinguals in one of these areas: the city of Brunico.

Further, to ensure that the bilingual sample was a representative sample of such socio-political reality we included only children belonging to Alto-Adige's mixed families, whereby one parent had Italian and the other had German as mother-tongues. Such criterion enabled the inclusion of only those children who had been raised in bilingual context, had learnt their second language no later than the age of 3 years, and it was learnt in an informal way, that is it was experienced in the family's every-day life. In other words such conservative criterion allowed us to include "authentic" (they acquire both languages in non-formal contexts), balanced (same level of fluency in the two languages), and simultaneous (both languages were acquired at the same age) bilinguals.

Such efforts were also devoted to avoid a possible confound which could arise in studying the relation between bilingualism and the number field. By considering as bilingual sample immigrant bilinguals only (for sure, easier to enroll), we might have unfairly advantaged such sample in the number field: researches clearly found that different cultures, and different parental number input can positively influence the development of number abilities. Therefore, possible of advantages in number skills could be related to cultural factors instead of being correlated with the experience of bilingualism (Geary et al., 1996).

4.3 Bilingual experience and enumeration ability

4.3.1 The development of the enumeration ability

My first experiment was aimed to explore possible correlations between the ability to count and the bilingual experience. Among the basic number abilities, counting is considered really important since it is one of the first number abilities that children are asked to learn. For many, it constitutes the bridge between core numerical understanding and the mathematical tools provided by culture.

Very early in their lives, children learn names for numbers and their correct order; they also learn to coordinate the production of counting words with identification of objects, with each object being counted only once. John Locke maintained that number names are necessary to acquire ideas of large quantity of numbers; he thought that the concept of numerosity is built from the basic idea of "one": the repetition of this idea in mind would lead to the idea of larger numerosities (Butterworth, 1999).

Number names enable two-year-old children to track large numerosities and perform the first arithmetical operations by adding or subtracting one object from sets of numerosities. Gelman and Gallistel (1978) proposed that three basic skills are required to learn to count. When children between two and five years, assign only one number word to each object, they show an understanding of the *one-to-one principle*. They also learn to use the same set of number words across different counts (*stable order principle*) even when the counting order of number words is not always identical (in early stages children can count sets of objects using a different sequence of number words: e.g. “One, two, four, six” and repeat this sequence any time they count). Children demonstrate to know the *cardinal principle* when they assign that the final number word of the sequence to the cardinality of the set (e.g. “one, two, three, four. Four chocolates!”). Further, Gelman et al. (1978) suggested two other principles: the *“order irrelevance principle”* means that they can start counting from any of the objects in the set and the *“abstractness principle”* meaning that any item, regardless of its physical properties, can be counted.

When learning first arithmetical operations, knowledge of counting is very important: consider a child who is learning to add two small numerosities: the correct result can be worked out by adding the two sets together and counting the numerosity of that union.

Procedures of counting used in the earlier stage of arithmetic learning are often employed by teachers and consequently by children, who can use their fingers or devices like the abacus, to solve simple additions or subtractions. Such procedures are of three types. At first, children tend to use the *Counting all* strategy: when solving 2 + 3 they will, by using their fingers, count “one, two” and represent the first numerosity on one hand and then, counting “one, two, three”, and representing the second numerosity on the other hand. This procedure allow them to visualize all sets and sum up by counting all the items they can see.

A second procedure is the *Counting on from the first addend.* After time they realize that is not necessary to count even the first addend but they can start from the second addend. For instance, when solving 2 + 3, children will start from two and using a hand will count three objects “three, four and five!”.

The third procedure is *Counting on from the larger addend* which allows to solve the operations quickly and more efficiently. When using this procedure to solve 2+3, children will start from 3, then count two items. Usually, a shift to this procedure occurs at the beginning of school, around 5 or 6 years of age. Therefore, when they start school the ability to count is, although not entirely advantaged, widely developed. The mastery of the word sequence of numbers enables them to use such ability in different number contexts, both in situations where a only counting is required but also when counting is used as backup strategy (e.g., in the first stages of arithmetic learning, when more efficient strategy are not completely developed).

In more advanced grades, like the fourth and fifth grades, children's performance already in such ability approaches to the adult's performance: typically, as shown in the figure below (fig.4.1) subjects are very efficient and accurate in enumerating items from 1 to 4 but they gradually become less efficient in dealing with higher number of objects.

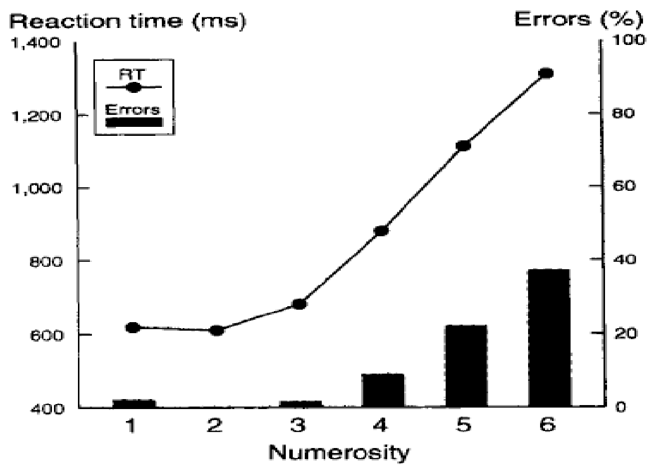


Figure 4.1: Typical Enumeration Performance: RTs and errors rates as a function of the number of items to enumerate (figure taken from Dehaene and Cohen, 1994)

Flat performances among 1 and 4 suggest that quantities beyond four are estimated at a glance, with more laborious processes needed for greater numerosities. Several authors claim that the ability to enumerate different numbers of items requires a quick perception of the number of items until 4. Such mechanism is, according to many, as effortless as perceiving colors or shapes. It is also thought to be a component of the innate core number knowledge (Butterworth, 1999; Dehaene and Spelke, 2004).

The mechanism allowing to quantify larger numerosities can be explained by two processes: estimation refers to a fast modality (although approximate) of quantifying sets of items, whereas counting refers to the verbal mechanism of estimating numerosities by assigning a label to each numerosity. In presence of numerosities greater than four, the use of estimating or counting processes may depend upon task requirements. If the answer has to be performed very quickly, estimation would be used more likely than counting; whereas if the answer need to be accurate counting is most probably the right processes to be used but reaction times would then be longer.

4.3.2 Enumeration task and bilingualism: Experiments 1, 2,3

4.3.2.1 Experiment 1

Experiment 1 was aimed at exploring possible relations between the experience of bilingualism and the ability to count. If such experience exerts any effect on the enumeration ability, differences between monolinguals and bilinguals should become evident in the enumeration range as opposed to the counting range. More precisely, 10-years old bilinguals would be expected to perform as well as their monolingual peers in enumerating dots in the subitizing range, whose ability seems to coincide with the innate core of numerical knowledge shared with infants and animals, but underperform in the counting range, which supposedly rests on the use of verbal labels.

4.3.2.2 Participants

Forty-eight 10-year-old children (fourth grades students) participated in the experiment: half of them were Italian-German bilinguals. Among 25 girls, 10 were Italian speakers and 15 girls were bilinguals; among the 23 boys 9 were bilinguals and 14 were Italian speakers. All children attended public schools in the territory of Alto-Adige.

All parents were asked to fill a questionnaire allowing us to collect information about the age and the context of acquisition of the second language (see APPENDIX A). Children were considered bilinguals when three conditions were simultaneously fulfilled:

the German language was acquired no later than 3 years of age; each parent had a different mother tongue (one parent had Italian as first language and the other had German as first language); parents reported to speak both languages at home and in extra-scholastic contexts. Children whose parents had a different mother tongue but who did not report to use both languages at home, children who did not confirm the information reported by their parents regarding the use of languages at home, and children who attended nurseries in German language but whose parents had the same mother tongue were not included either the monolingual or the bilingual group, and were thus excluded from analyses. To further validate our criterion we administered a category fluency test in German language to both groups: an ANOVA having Semantic Fluency (animals; fruits; colors) as within factor and Language Groups (monolinguals; bilinguals) found a significant main effect of Language Groups [$F(1,47) = 18.44$, $MSE = 339.17$, $p < .0001$] confirming that bilinguals reported a significant higher number of words in German language.

Both groups had also a similar socio-economic status, which was measures by considering the parents' years of education: an independent t-test found no significant differences between groups ($p > .40$; monolinguals: 13.06; bilinguals: 12.18).

In addition, both groups showed no significant differences for other general cognitive processes. Verbal working memory ($p > .14$) as administered through the Listening Span Test (Palladino, 2004) showed that monolinguals had a mean score of 21.16 (SD:3.48) and bilinguals had a mean score of 19.87 (SD:2.45). Non-verbal reasoning ($p > .59$) administered though Raven Progressive Matrices (Raven, 1947) reported that monolinguals scored 31.79 (SD:3.21) and bilinguals scored 32.25 (SD:2.69).

4.3.2.3 Tasks and procedures

Before performing the enumeration task, participants were asked to read the instructions and to perform a training of practice. During this training made of 9 trials (one stimulus for each numerosity), participants learned to keep pressed the space-key while they were counting and, once they finished to count, they were asked to release that key and using the same hand, to press the key corresponding with the number of dots counted. This procedure was used to ensure a more precise data collection, because it ideally allows us to separate the time participants use to count, from the time it take them to reach and press the specific response key. Otherwise, if such release procedure would not been used, the latency of reaction time would have been a composite and inseparable sum of both processes and the time needed to count would likely be confused with the time needed to reach one of the nine keys.

Instructions were both written on the screen and explained by the experimenter. Then the training began: once the space-key was being pressed, a fixation point appeared on the screen and after 500 ms a series of random dots (with numerosities ranging from 1 to 9) appeared for 5000 ms. If participants did not release the button and press the "number" key, stimuli disappeared and the trial was considered incorrect. Stimuli comprised nine sets of black dots (2.1 cm of diameter each) randomly distributed around the center of a blank screen (white background). The spatial position of dots was randomized to prevent the use of grouping strategies and therefore a spurious 'subitizing' performance for the stimuli containing 6, 7, 8, and 9 dots (see e.g. Mandler and Shebo, 1982).

After the training session, a series of 72 experimental trials started, in which each of the 9 stimuli was presented in random order for 8 times.

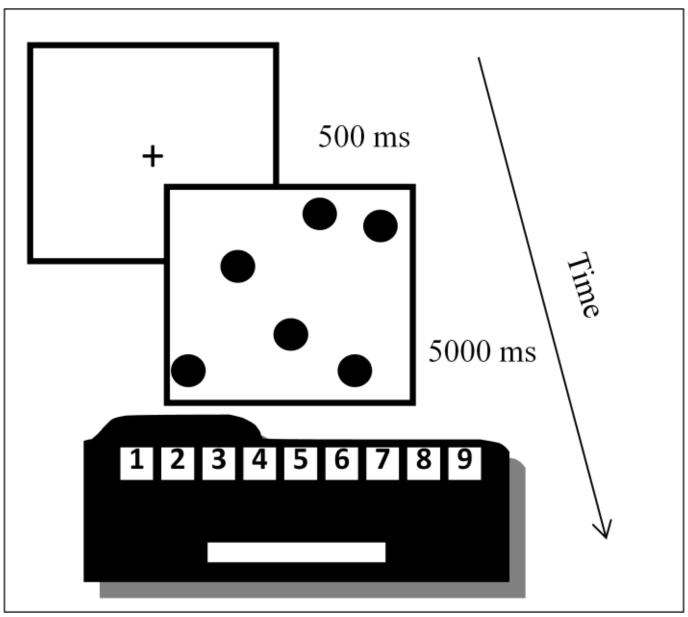
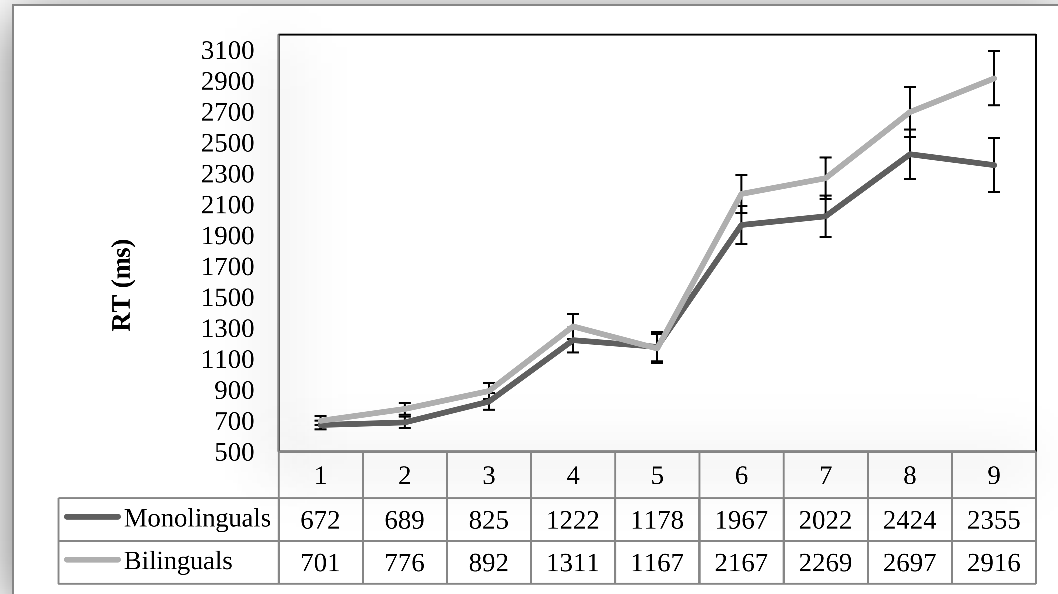


Figure 2. Enumeration task: procedure used in Experiments 1-3

4.4.2.4 Results

A mixed ANOVA having Number of Dots (1 to 9) as within subjects factor and Language Group (monolinguals; bilinguals) as between subjects factor found a significant main effect of Number of Dots [F(1,48)= 176.30, *MS* =2.96, p< .01] suggesting that for all the participants reaction times differed depending on the number of dots to be enumerated. The main effect of the factor Language Group was not significant (p>.12). Moreover crucially, a significant interaction between the Number of Dots and the Language Groups was statistically significant [F(8,368)=2,2, *MS*=3.7, p<.02]. Such analysis showed that bilinguals were significantly slower than monolinguals in enumerating dots in the counting range but did not differ in the subitizing range. The same mixed ANOVA performed on the number of errors did not reveal any significant effects (all ps>.79).

Another ANOVA having Range (subitizing; counting) as within factor and Language Groups as between factor (monolinguals; bilinguals) was performed as to investigate more specifically whether bilinguals differed in the ability to count. The interaction between Range and Language Groups was not significant but showed a trend [F(1,46)=3.42, p<.07] in the expected direction. When performing two separate independent t-tests to investigate the ability to count and to subitize between groups, t-tests confirmed the same trend: difference between monolinguals and bilinguals were far from significance in the subitizing range (p>.43) whereas they were close to be statistically significant in counting higher quantity of dots [t(46)= 1.75, p<.08; monolingual mean: 2191,95 ms; bilingual mean: 2512,34 ms].



	1	2	3	4	5	6	7	8	9
Monolinguals	672	689	825	1222	1178	1967	2022	2424	2355
Bilinguals	701	776	892	1311	1167	2167	2269	2697	2916

Figure 3. Enumeration task: results of Experiment 1

4.4.3.1 Experiment 2: longitudinal study

One year later, we tested again 19 of the children who participated in the previous experiment. Among these, 9 were bilinguals and 10 were monolinguals. In the bilingual sample there were 7 girls, in the monolingual sample there were 6 girls.

4.4.3.2 Tasks and procedures

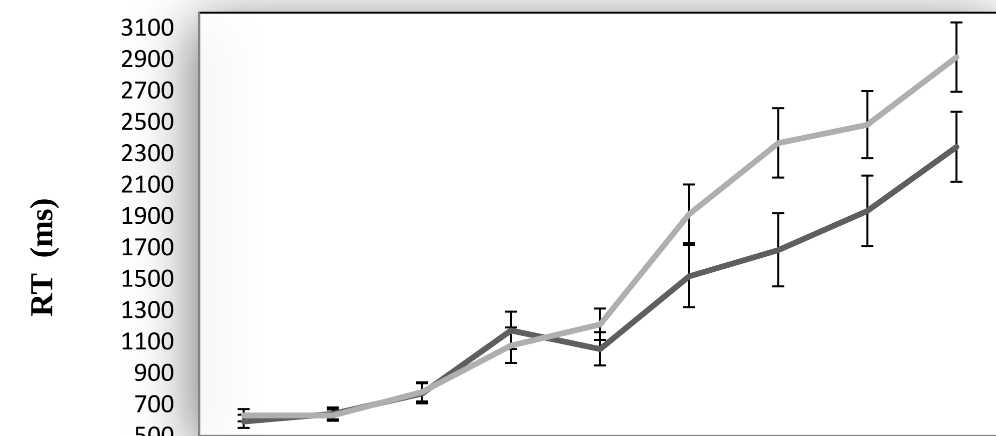
Tasks and procedures were identical to the Experiment 1.

4.4.3.3 Results

An ANOVA having Number of Dots as within subjects factor (1 to 9) and Language Groups (monolinguals; bilinguals) as between subjects factor, confirmed the results of the previous experiment: a significant interaction between the Number of Dots to be counted and the Language Groups [F(8,136)= 2.91, p<.004] confirmed that bilinguals are slower than monolinguals in enumerating dots but in the counting range only.

A further ANOVA analysis having Range (subitizing; counting) as within subjects factor and language groups as between subjects factor (monolinguals; bilinguals) detected a significant interaction between Range and Language Groups [F(1,17)= 6.01, p<.02]. Additionally, two independent t-tests were then performed and confirmed that performance in the two groups did not differ in the subitizing range [t(18)=0.48, p<.62; monolingual mean was 846,39 ms (SD=151.88) and bilingual mean was 886, 37 (SD= 211,68)] whereas it was significantly different in the counting range [t(17)=2,32, p<.03; monolingual mean was 1798,33 (SD= 473,94) and bilingual mean was 2378.41 (SD= 596,62)].

As for Experiment 1, the analysis of errors did not found any significant effects (all ps<.79).



	1	2	3	4	5	6	7	8	9
Monolinguals	592	643	771	1172	1054	1518	1685	1934	2343
Bilinguals	631	631	780	1077	1211	1915	2367	2483	2914

Figure 4. Enumeration task: results of Experiment 2

4.4.4.1 Experiment 3

Experiments 1 and 2 suggested that monolinguals and bilinguals differ in their ability to enumerate items in the counting range but not in the subitizing range. However, counting is not the unique strategy that subjects can use to enumerate. Although participants were instructed to count and stimuli were built as to avoid to set up patterns of items by using visual strategies, a fault might be pointed out.

Stimuli in the previous experiments were presented by repeating the same pattern of dots (e.g. seven dots) for 8 times. Although stimuli were presented randomly, children could have memorized the pattern of dots instead of counting actively the items. To avert the use of alternative strategies instead of counting, 8 different patterns were presented for each number of dots, as to force children to use the counting strategy.

4.4.4.2 Participants

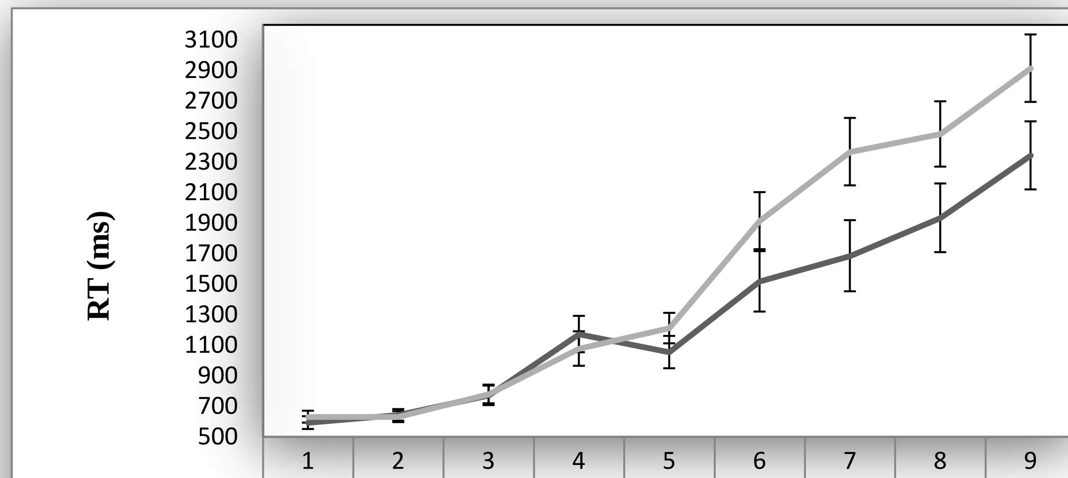
Since 60 of the 84 parents were for re-test their children once again, 30 children participated in the experiment. Participants were fourth and fifth grade children: among the fourth grade children 5 were monolinguals and 8 were bilinguals; among the fifth grades ones 10 were monolinguals and 7 were bilinguals. Fifteen children were Italian-speaking children and 15 were bilinguals. All children participated were enrolled in the previous experiments. Among monolinguals 7 were girls and 8 were boys; among bilinguals 12 were girls and 3 were boys.

4.4.4.3 Tasks and procedures

Task and procedures were identical to the previous experiments except for stimuli. As for the previous ones, here 72 stimuli were presented during the experiment but each set of stimuli had a different pattern. That is, each number of dots to be counted (from 1 to 9) appeared 9 times but we created 9 different patterns of dots for each set of dots.

4.4.4.4 Results

A mixed ANOVA analysis having Range (subitizing; counting) as within subjects factor and Language Groups as between subjects factor (monolinguals; bilinguals) found a significant interaction between Range and Group [F(1,28)= 4.82, p< .03; the monolingual and bilingual mean in the subitizing range was respectively 994 ms and 1077 ms while their mean in the counting range was 2402 ms for the former group and 2798 ms for latter group]. A main effect of Language Groups approached significance [F(1,28)=3,73, p<.06]. Two independent t-tests were performed as to confirm that both groups performed similarly in the subitizing range [t(28)= 1,08, p>.28] but bilinguals were significantly slower in the counting range [t (28)=2,11, p<.04].



	1	2	3	4	5	6	7	8	9
Monolinguals	592	643	771	1172	1054	1518	1685	1934	2343
Bilinguals	631	631	780	1077	1211	1915	2367	2483	2914

Figure 5. Enumeration task: result of Experiment 3

4.4.4.5 Discussion

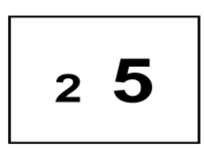
Experiments 1, 2, 3 showed that bilingual children are slower in enumerating dots in the counting range. The fact that bilinguals were significantly slower in this range only, was highly interesting since it suggests, once again and in a new domain, that bilinguals are hampered in tasks involving language.

In the second chapter we described the negative effect of bilingualism in tasks requiring lexical access: such disadvantage was explained by assuming that when the lexical form of a concept has to be accessed, bilinguals face a more complex problem than monolinguals, since they possess two lexical forms for each concept. Thus for highly proficient bilinguals, additional time is required to access the appropriate lexical form to be used in a given linguistic context. In addition, our results suggest that this problem arises also when participants are not explicitly asked to use one of their languages and are thus in agreement with Ivanova et al. (2008) study, where the bilingual disadvantage appeared also when participants were allowed to use their preferred language.

Finally, the range of numerosities employed in our design ruled out any possibility to interpret results by evoking the different linguistic forms in Italian and in German. In Italian, indeed, number words are pronounced by starting from the tens whereas German number words are pronounced by starting with the units. However, numerosities in our task ranged from 1 item to 9 items: in such range both languages do not differ in the morphological structure of the number names.

For similar reasons we did not consider as bilinguals a sample of immigrants children because such sample would be not homogeneous as for their first language and because possible differences in their numerical language systems could have mitigated expected differences between the groups.

4.4.5 Bilingual experience and number magnitude access: Experiments 4, 5, 6



4.4.5.1 Experiment 4

The ability to compare the magnitude of different numbers is an essential skill and its acquisition plays an important role throughout all mathematical training. Many studies suggest that a primitive sense of number magnitude is shared with infants and animals (Starkey et al, 1990; Rugani et al., 2009).

During school, children learn to use more sophisticated tools enabling them to develop and expand these natural gifts. One of such tools is of course language, which enables to recognize and mentally manipulate large exact numerosities. Number words, through counting abilities, enable children to name larger numerosities and during childhood to develop more complex strategies in solving arithmetic operations.

However children can also learn to associate numerosities with Arabic symbols, useful tools that provide them a way to develop more and more complex mathematical abilities (arithmetic, algebra, geometry, etc.). One of the simplest number skills is the ability to judge the magnitude of numerical symbols. People are asked to select the larger or smaller numbers between two digits. In 1967, Moyer and Landauer found that the time required to make a judgment depends on the numerical distance between the two digits presented (distance effect). Studies on comparison between numbers show that this skill is mastered by pre-school children and that by the age of 5, children show patterns similar to those of adults. Siegler and Robinson (1982) suggest that as a first step, they categorize numbers as "small" or "large", then they start to discriminate between numbers from 1 to 5, a differentiation which gradually extends to larger numbers (6 to 9).

The ability to compare the numerical magnitude of numbers is required in many contexts requiring number skills and it is even used in contexts where other cognitive processes are simultaneously required. Imagine when a carry or borrowing calculation has to be performed: while adding or subtracting numbers and thus automatically accessing their numerical value, interim results have to be retained (to prevent them to interfere to the task at hand) and maintained until calculations (tens or units) is performed. Such mental efforts involve components of executive functions.

Accessing and working with numerical magnitude in presence of interfering information is precisely the subject of this experiment. As mentioned in many parts of the present dissertation, the efficiency of executive functions and its ability to counteract or prevent interfering information has been positively correlated with the experience of bilingualism. According with those studies, bilinguals should perform conflict task more efficiently than monolinguals, since bilingual executive system should be more “trained” to filter out irrelevant information than the monolingual one.

However, as previously pointed out, there are many experiences that can influence the development of the executive system, and in the present dissertation we focused our attention on some possible confounding factors. First, SES has been doubly controlled: by selecting a type of bilingualism whose development is not a prerequisite of certain social classes and by statistically controlling for the presence of casual differences between groups.

In this experiment a classical version of the Stroop task and a numerical version of it (Number Stroop) were administered to monolinguals and bilinguals. Recent works report that bilinguals show to be advantaged in Stroop-like tasks (e.g. Stroop picture naming task, Martin-Rhee et al., 2008): the classical version of the Stroop task was thus performed and it was followed by a numerical version of the Stroop task, where the ability to inhibit interfering information was associated with a comparison task.

Further, since the age of our sample did not allow us to investigate such ability in more complex tasks like carrying or borrowing calculations, we investigated the development of selective attention to certain numerical characteristics with different degree of difficulty through the distance effect (Moyer et al., 1967). Such effect as mentioned above, refers to the fact that, when comparing the numerical magnitude of two numbers, reaction times decrease as the difference between numbers increases, suggesting that the greater is the numerical distance between numbers, the easier is to solve the task.

4.4.5.2 Participants

We enrolled the same children participating to Experiment 1.

4.4.5.3 Task and procedures

<u>Classical version of the Stroop test:</u> reaction times (RTs) were recorded for each child in three conditions: the baseline reading condition consisted of reading words (e.g. rosso written with black ink); the baseline naming condition consisted of naming colors (on colored circles); the interference condition, in which they named the ink of color words with words being the name of a different color (e.g., the word green was written with red

ink). For each child the Stroop effect was calculated by subtracting from the sum of reaction times in the interference condition (E3) the average of the sum of RTs in the two (E1 for the word reading condition ; E2 for the color naming condition) baseline conditions (Stroop effect = E3- (E1+E2)/2).

Number Stroop task: Children sat in front of a 17-inch computer screen and were asked to compare the numerical magnitude of two digits. Before performing this task, they were asked to read the instructions, which were followed by 9 trials of practice.

Stimuli, consisting of pairs of single digits ranging from 1 to 9, were showed simultaneously on the right and left side of the screen. All stimuli were built in Arial style and had two different dimensions. For congruent and non-congruent trials one digit was 2,57 cm of height and 1,61 cm of width and the other stimulus was 3,15 cm of height and 2,09 of width. In neutral trials half of the trials contained both digits having the former dimensions (2,57 cm of height and 1,61 cm of width) and in the other part of trials digits had both the latter dimension (3,15 cm of height and 2,09 cm of width).
A fixation point was shown on a blank screen for 500 ms, after which a pair of digits was shown for 5000 ms. If participants did not respond until 5000 ms, the trial ended and was considered as an error.

In congruent trials the number with the greater numerical value was also of that of larger physical size; neutral trials contained a pair of digits having the same physical size; and non-congruent trials the number having the greater numerical value had a smaller physical size compared with the other digit. The initial training contained 9 trials: 3 trials for each condition. The experiment contained 54 trials, 17 for each condition.

Participants had to respond by pressing “q” or “p” on the keyboard with their left and right index respectively. If the larger number appeared at the left of the screen, they had to press the “q” key; if the larger number appeared on the right side, they pressed the “p” key. The two digits had always different numerical values and the numerical distance between the numbers to be compared could range from 1 to 7 numbers (e.g., 1-2;1-3;1-4;1-5;1-6; 1-7;1-8). Interference was manipulated by introducing three conditions: congruent, neutral and non-congruent trials.

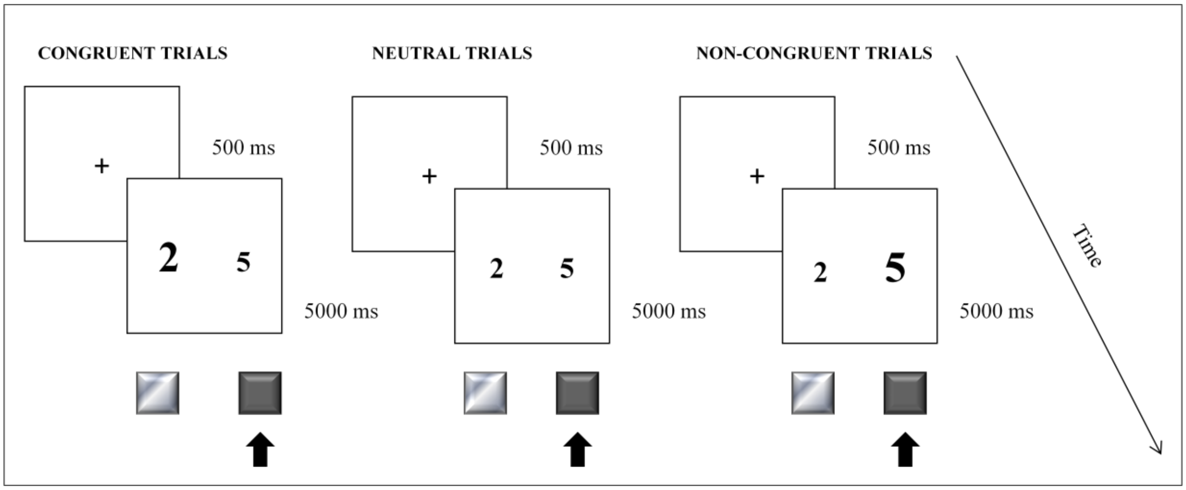


Figure 6. Number Stroop task: procedure.

4.4.5.4 Results

An independent t-test having the Stroop effect as dependent variable and the Language Groups as grouping variable showed no significant differences t(16)=.42, p=.67. For monolinguals the mean was 18.01 seconds (SD=6.26) and bilinguals performance was 18.85 seconds (SD=7.42).

A mixed ANOVA having two within subjects factors and a between subjects factor was performed. The within subjects factors were Congruency (congruent trials; neutral trials; non-congruent trials) and Numerical Distance (low numerical distance: 1-2; medium numerical distance: 3-4; high numerical distance: 5-7). The between subjects factor was Language Groups (monolinguals; bilinguals). The main effects of Congruency [F(2,92)=62,3,p<.01] and Numerical Distance [F(2,92)=31,1, p<.01] were significant, whereas their interactions with the group factor were not significant (Congruency and Language Groups: F(2,92)=1,86 p>.16); Numerical Distance and Language Groups: F(2,92)=1.4, p>.24). Also the main effect of Language Groups was not significant [F(1,46)=.09, p>.76]. The three way interaction (Language groups; Congruency; Numerical Distance) was also not significant [F(4,184)=0,90, p>.46].

The same ANOVA performed considering as dependent variable the number of errors showed no statistically significant effects involving the factor Language Groups (all ps >.18).

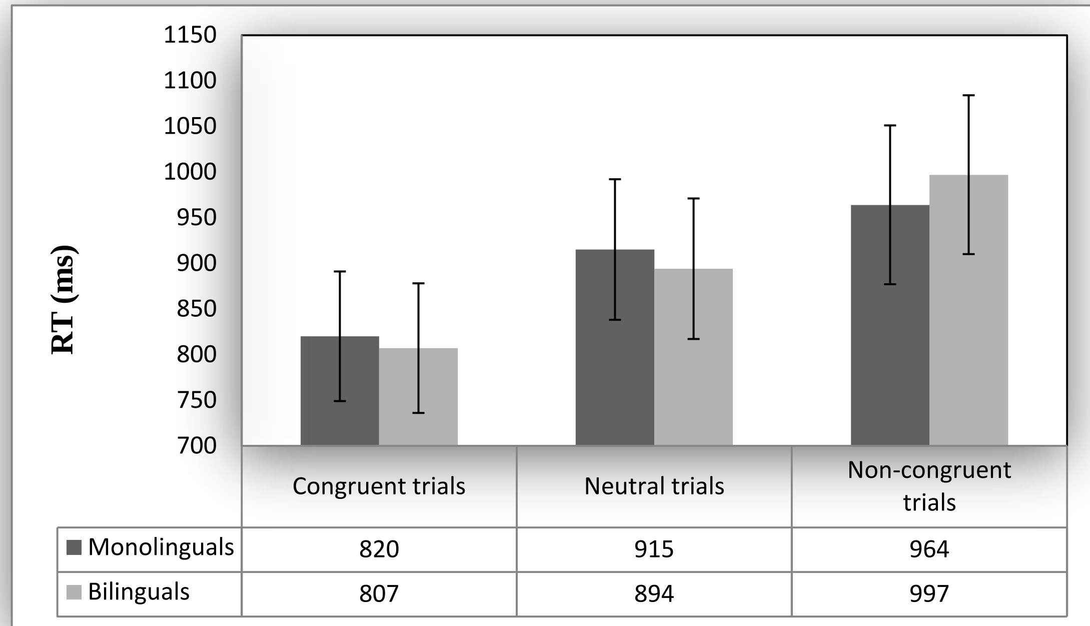


Figure 7. Number Stroop Task: results of Experiment 4.

4.4.6.1 Experiment 5

The lack of any significant interaction between groups in the numerical Stroop and in the classical version of the Stroop test is confusing when compared with the growing body of research on this domain. Our result may have two explanations: first, the bilingual advantage does not show up in all types of bilingualism; second, previous studies did not take into consideration intervening variables, like SES, carefully enough. In the following study, we enrolled a third sample of children: immigrant bilinguals. We compared the performance of such sample with the previous ones to investigate whether these children show indeed such advantage.

Further, in selecting the immigrant sample, we took care of the age of these children: we excluded from analyses children who attended the fourth year of primary school but started to attend it later than their peers. When immigrants come into foreign countries, it often happens that due to language problems or because they immigrate when their child is already grown up to attend school, children lose some years of school and must start it later. This fact is a obvious problem for this branch of research, since the finding that reaction times decrease with age (specially in a developmental context) is a well-known phenomenon in the cognition field. Further, some studies on this issue have claimed for a bilingual advantage even in absence of significant interactions between language groups and the Stroop conditions but they took into consideration significant difference in overall reaction times (Yung and Lust, 2004).

4.4.6.2 Participants

We enrolled the same children participating to Experiment 1 and we introduced a third group of 10-year-old bilingual children attending the same schools and living in the same cities. This additional sample was made up of children whose second language was Italian and who had learnt it at school, since they spoke another language at home. Parents of these children were all immigrants who did not speak Italian at home but Chinese, Ukrainian, Albanian, Arab, Moroccan or Russian. Thus these children spoke their first and second languages in separate contexts (Italian at school and their first language at home) and had different proficiency of such languages. Further, they were also exposed to the German language.

4.4.6.3 Task and procedures

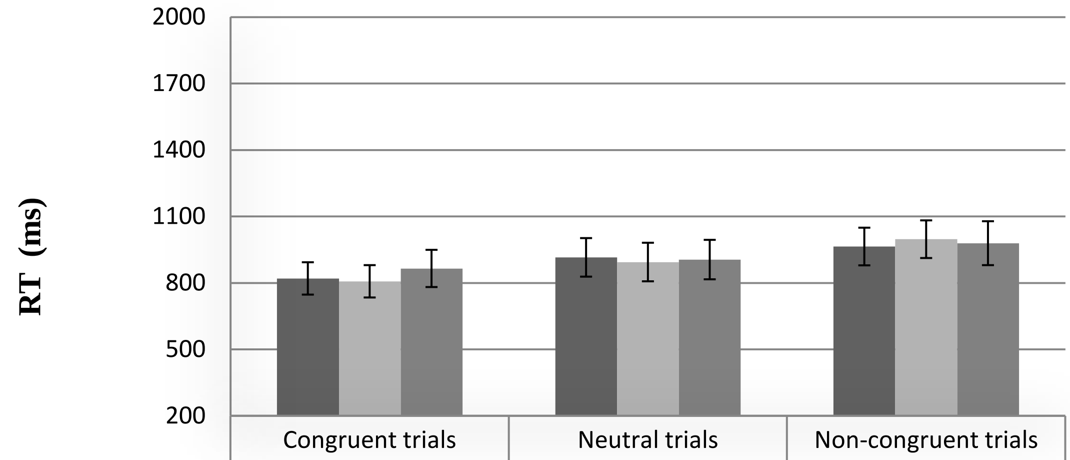
Tasks and procedures were identical to Experiment 4. The immigrant bilingual sample was composed by 27 10 years old children. Data coming from 9 immigrant children were excluded from the analyses because, though they attended the fourth year, they were older than their peers (11 or 12 years old)

Twenty-two immigrant bilinguals having Italian as second language were compared with 24 monolinguals and 24 Alto-Adige bilinguals. For reasons related to their condition of immigrants, this groups had a significant lower SES than the other two groups ($p<.01$).

Non-verbal reasoning (Raven, 1947) was administered to this sample and their performance was compared with that of the other two groups. An independent t-test having the Raven's score as dependent variable and the language groups as grouping variable showed that immigrant bilinguals did not perform differently from monolinguals in non-verbal reasoning abilities: [$t(44)=1.12$; $p=.26$], immigrant bilingual mean score was 30 ($SD=3.76$) and monolingual mean score was 31 ($SD=3.21$); immigrant bilinguals had also a similar performance to that of Alto-Adige bilinguals [$t(44)= 1.68$; $p=.09$] whose mean score was 32 ($SD=2.69$).

4.4.6.4 Results

Analyses were computed by comparing performance between the three groups of children (monolinguals; Alto-Adige bilinguals; immigrant bilinguals) in the numerical Stroop task. A mixed ANOVA was performed having Language Group as between subjects factor and Congruency (congruent; neutral; non-congruent) and Numerical Distance (low numerical distance; medium numerical distance; high numerical distance) as within subjects factors. The main effects of Congruency [$F(2,134)=76.47$, $p< .0001$] and Distance [$F(2,134)=52.42$, $p<.0001$] were significant. The interaction between Language Group and Congruency [$F(4,134)=1.92$, $p>.10$] and the interaction between groups and numerical distance effect [$F(4,36)=.86$, $p<.48$] were not significant. The same lack of significant interactions held true in the classical version of the Stroop test (all $ps>.80$), where the monolingual mean Stroop effect was 18.10 ms ($SD=6.87$); the mean effect for Alto-Adige bilinguals was 18.21 ms ($SD=6.98$) and that for immigrant bilingual was 18.51 ms ($SD=10.10$).



	Congruent trials	Neutral trials	Non-congruent trials
Monolinguals	820	915	964
Alto-Adige bilinguals	807	894	997
Immigrants bilinguals	865	905	979

Figure 7. Numbers Stroop Task: Results of Experiment 5.

4.4.7.1 Experiment 6: longitudinal study

One year later 29 of these 70 children were tested again: 10 were monolinguals, 9 were Alto-Adige bilinguals and 10 were immigrant bilinguals. If the bilingual advantage is given by the everyday exercise in selecting one language and inhibiting the other one, such advantage could increase, if present, or be evident, if it did not existed before, in time.

4.4.7.2 Tasks and procedures

Tasks and procedures were identical to the Experiments 4 and 5.

4.4.7.3 Results

A two way ANOVA having Session (session 1; session 2), Congruency (congruent; neutral; non-congruent) as within factors and Language Groups as between factor (monolinguals; Alto-Adige bilinguals; immigrants bilinguals) confirmed results found in the experiments above. Statistically significant results were only showed in the main effect of

Session: participants were significantly faster [$F(1,26)=11.50$, $p<.002$] in session 2 (mean: 710, SE= 50.44) rather than in the session 1 (mean: 858, SE= 74.35) but no significant interaction was found between the Session factor and between Language Groups [$F(2,26)=.70$. $p>.50$]: in session 2, monolinguals were overall 164 ms faster than in Session 1; Alto-Adige bilinguals were 202 ms faster and immigrant bilinguals were 78 ms faster than in session 1. The main effect of Congruency [$F(2,52)=222.77$, $p<.0001$] and its interaction with Session were also significant [$F(2,52)=55.2$, $p<.0001$] showing that the ability to deal with interference or facilitation information improves with age; however the triple interaction between congruency, session and language groups was not significant [$F(4,52)=1.86$, $p>.13$] showing that, although the mastering of control processes seems to improve with age, no evident difference between groups, based on their level of bilingualism was found one year later.

The analysis of errors confirmed the same findings: the interaction between Congruency and Language Groups was far from significance ($p>.54$)

4.4.7.4 Discussion

Experiment 4 showed that bilingual performance in both the numerical and the classical version of the Stroop task does not differ from monolingual performance. So far, published studies on cognitive control task have not always confirmed Bialystok's findings (e.g. Morton et al., 2007). These results are not surprising for many reasons: such bilingual advantage is not consistent among studies, for instance when investigating the latency of the Simon effect (see chapter 2) such advantage is not always present.

However, if not present in its classical form, Bialystok (2006) found that more demanding versions of the same paradigm (e.g., by using arrows instead of squares) can be more sensitive measures in enlightening the supposed bilingual advantage. In this study, Bialystok (2006) asked to bilinguals and videogame players to perform two version of the Simon task. During this task participants are asked to associate the color of a square with a response; that is they are asked to press the right key whether the square is red, and they are asked to press the left key if the square is green. Usually, when the red square appears on the right side of the screen (correspondent condition), they are faster to respond than when the red square appears on the left side (non-correspondent condition). The spatial position of stimuli on the screen, seems to interfere, although irrelevant, with the task. Tipically, non correspondent trials are supposed to be subserved by control processes. In addition to this version, Bialystok (2006) showed also a modified and more demanding version of this task: she substituted squares with arrows pointing towards right or left, as to increase the requirement of control processes in the non–correspondent trials.

Both versions contained two more conditions: in high switch conditions, among the succession of trials, she controlled for the order of presentation of the correspondent trials. When a correspondent trial (or non-correspondent) was followed by a correspondent trial, the task required less attentional resources than when a correspondent trial was followed by a non-correspondent one. The high and low switch differed in the number of switches (e.g. non-correspondent –correspondent) present in the task.

She introduced the high and low conditions to investigate the effect of increasing monitoring and response switching performances. She found that bilinguals outperformed videogames players in the high switch conditions in both versions of the task (a similar finding was also reported by Costa et al., 2008 in the ANT task).

The results of the present experiment did not show any significant interactions between bilingualism and the Stroop effect, not even in the most challenging condition (i.e. with lower numerical distances). A possible explanation could be that, unlike the modified versions of the Simon task employed by Bialystok and colleagues, it is not clear whether numerical distance, in association with the interference processes, necessitates more executive demands.

Also the interaction between the congruency factor and language groups was not significant. In fact, as far as we know, Morton and Sarah (2007) and Namazi and Thordardottir (http://www.bilingualism.bangor.ac.uk/conference/Namazi%20and%20Thordardottier.pdf) showed a complete absence of any bilingual advantage in a more controlled sample. Morton et. al. (2007) compared the performance of bilinguals and monolinguals in a Simon task. In his participants selection procedure, he carefully controlled SES by creating a composite measure of the level of education, academic achievement, and parental occupation. Namazi et al. (available online) indeed considered children as bilinguals only whether children were exposed to English and French 40-60% of the time prior to age 3.

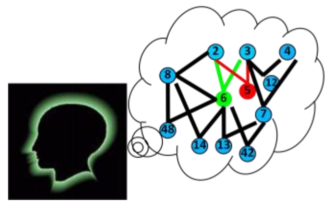
We carefully controlled our selection procedure even in Experiment 5, where a fresh bilingual group was included. However, since the supposed bilingual advantage is often confounded with an overall faster speed of processing (Yang and Lust, 2004) and being speed of processing faster with age, we excluded immigrant children who were attending the fourth year but were older (these children started school later for reasons related with their condition of immigrants). In fact, Experiment 6 showed that the ability to deal with competing information increases with age: when we tested the same children one year later, all participants showed faster RTs and smaller Stroop effect. Yet, no interaction with bilingualism could be detected.

In sum, these results did not confirm Bialystok's claims; they confirmed instead less frequent (and less popular) but more controlled findings produced by Morton et. al. (2007) and Namazi (available online), in which, by strictly matching both groups for SES and by operationalizing bilingualism with stricter criteria as we did, found no differences between groups.

Since the above set of findings cannot be conclusive to establish whether bilinguals (or certain types of bilingualism) show such advantage in numerical tasks, we tried to analyse this issue from a different point of view. Although factors such as SES and the definition and type of bilingualism can be important factors to boost or mitigate the presence of this advantage, an impressive number of studies found, even if not consistently, such bilingual advantage.

In our third set of studies, the same selection procedure was employed as used in our previous experiments. It was tested whether more complex and resource demanding number skills are influenced by the bilingual experience. It is indeed possible that dealing with interfering information in number magnitude comparisons with single-digit targets is a too simple task for 10-year-old (Experiment 4 and 5) and 11-year-old (experiment 6) children. The same samples were therefore tested in simple arithmetic.

4.4.8 Bilingual experience and arithmetic performance: Experiments 7, 8, 9



4.4.8.1 Experiment 7

Experiment 7 was conceived to study whether bilingual performance differs from monolingual performance in simple arithmetic. As far as we know, no studies comparing the performance of these two groups were performed with children. Marsh et al. (1976) and Magiste (1980) found that bilinguals are worse at solving arithmetic problems. Both of them explain such finding by pointing to the presence of a double language representation, since a more demanding situation of either managing two linguistic number representations or less frequent use of either number lexicon for a bilingual, could slow down bilinguals' performance.

However, as already mentioned in this chapter, many studies and self reports suggest that simple arithmetic is stored in long-term-memory (LTM) and only in the language in which arithmetic has been taught. If that was true, differences between monolinguals and bilinguals should not be originated by the need of managing two different linguistic representations of number. Recent works have also hugely improved the knowledge on how simple arithmetic is solved, and pointed out that working memory plays a critical role (Lemaire, et al., 1996; Ashcraft et al., 1992) in both producing and verifying arithmetic operations.

The following experiments will attempt to clarify such issue by combining findings and protocols from the number field with results hailing from bilingual research. Experiment 7 will investigate whether bilinguals and monolinguals perform differently on simple arithmetic and Experiments 8 and 9 will study whether differences found in the first test are due to working-memory demands by studying the same sample of participants in two new number tasks involving the same stimuli but different working-memory resources: a verification in the context of possible associative confusion effects and number matching tasks in the context of automatic associative effects.

4.4.8.2 Participants

We enrolled the same children participating to Experiment 1.

4.4.8.3 Tasks and procedures

Children sat in front of a 17-inch computer screen: they read the instructions and were asked to perform 6 trials of practice, after which they moved on to the actual experiment comprising a total of 80 trials. For all stimuli Arial was used as font style and 1,15 cm x 4 cm was the size of stimuli.

Their task was to verify the correctness of multiplication problems: after a central fixation cross, which remained on the screen for 500 ms, a simple multiplication (operations whose operands are single digits), with a proposed result appeared in the centre of the screen for 5000 ms. If the result was correct, they were asked to press the "q" key, if the result was wrong, they were asked to press the "p" key. 40 out of the 80 trials required a 'correct' answer and the remaining 40 required a 'wrong' answer; among the 40 wrong trials, half contained a result numerically close to the correct one (e.g. 4x2=9), and the remaining trials contained results "numerically far" from the correct answer (e.g. 4x2= 11).

As Ashcraft pointed out (1992) in his network retrieval model, each association of problem-answer may be represented in terms of strength of association. Once a problem is presented, the time required to retrieve depends on the way in which the problem is stored: in verifying whether the result of an operation is correct or not, activation spread to the correct answer but also to its "neighbors". For instance, in verifying the correctness of 4x2=9 or 4x2=11, activation is stronger for the first result (9) than for the latter result (11) because 9 is numerically closer to the correct answer (8). The retrieval mechanism would thus need more working memory resources to reject 9 than 11. If bilinguals possessed more advanced working memory and control mechanisms, they would show a specific advantage in those trials requiring a 'wrong' response when the proposed result was numerically close to the correct answer.

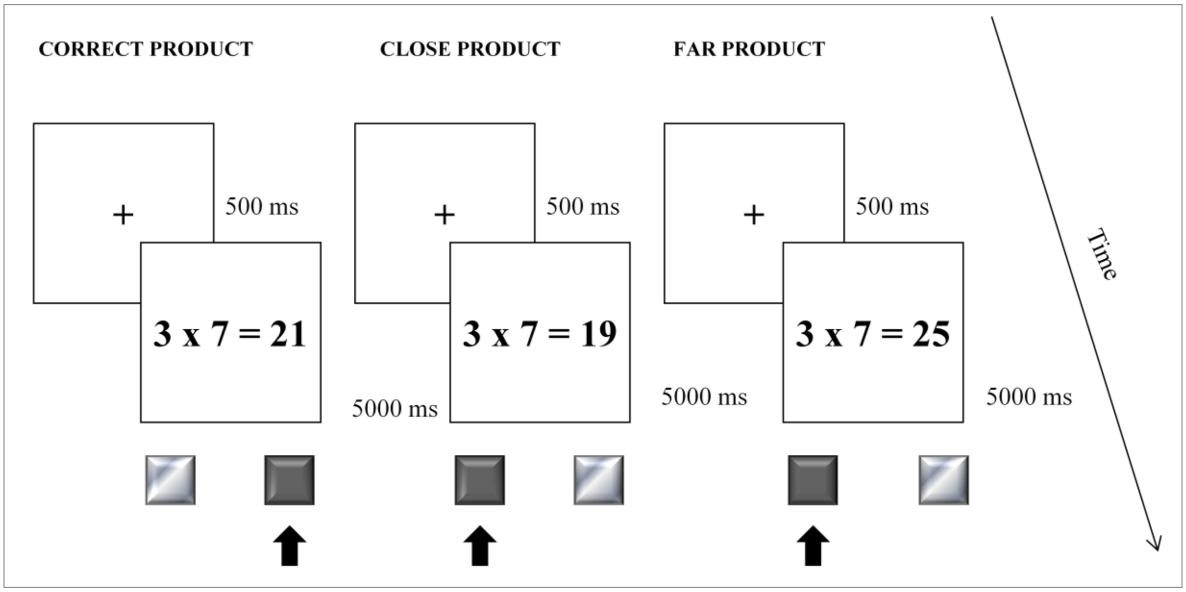


Figure 8. Multiplication task: procedure.

4.4.8.4 Results

A mixed ANOVA having Condition (correct; wrong-numerically close; wrong-numerically far) as within subjects factor and Language Groups as a between subjects factor (monolinguals; bilinguals) was performed to investigate whether accurately matched bilinguals performed multiplications differently from monolinguals. Numerically close and far wrong trials were introduced as a first attempt to investigate whether bilingual performance is affected by resource-demanding trials.

The analysis showed a significant main effect of Language Groups [F(1,46)=4,91, p<.03] reporting that bilinguals were significantly faster (mean RTs:1544 ms, SE=83) than monolinguals (mean RTs:1807 ms; SE = 83). Further the main effect of conditions was significant [F(2,92)=22,41,p<.01], For the whole sample of participants, mean RTs for trials requiring a 'correct' answer was 1532 ms (SE=55), while mean RTs for trials requiring a 'wrong' answer with a proposed results that was far from the correct one, was 1750 ms (SE = 67), and for those having a result numerically close to the correct one was 1746 ms (SE=66). Importantly for the purpose of this study, the interaction between conditions and the language groups was also significant [F(2,92)=4,13, p<.01]: trials with a correct result were responded faster by bilinguals (1437 ms, SE=78) than by monolinguals (1627 ms, SE=78) as well as wrong trials. RTs mean for numerically close wrong trials in bilinguals was 1556 ms (SE=95,16) and 1943 ms (SE=93) (SE=93) for monolinguals whereas RTs for numerically far wrong trials was 1639 ms (SES=93) for bilinguals and 1852 (SES=93) for monolinguals. Three independent t-tests were performed as to investigate more accurately bilinguals performance. The first independent t-test having Correct trials as test variable and Language Groups as grouping variable was not significant [t(46)=1.71,p>.09] as it was not significant, using the same t-test, the analysis performed by employing the Numerically Far Wrong Trials [t(46)=1,61, p>.11]. However, the independent t-test having numerically close wrong trials as test variable and Language Groups as grouping variable showed that bilinguals were significant faster than their monolinguals peers in solving this task [t(46)=2,87, p<.006]. Such latter result suggested that bilinguals overcome monolinguals in tasks requiring more working memory demands.

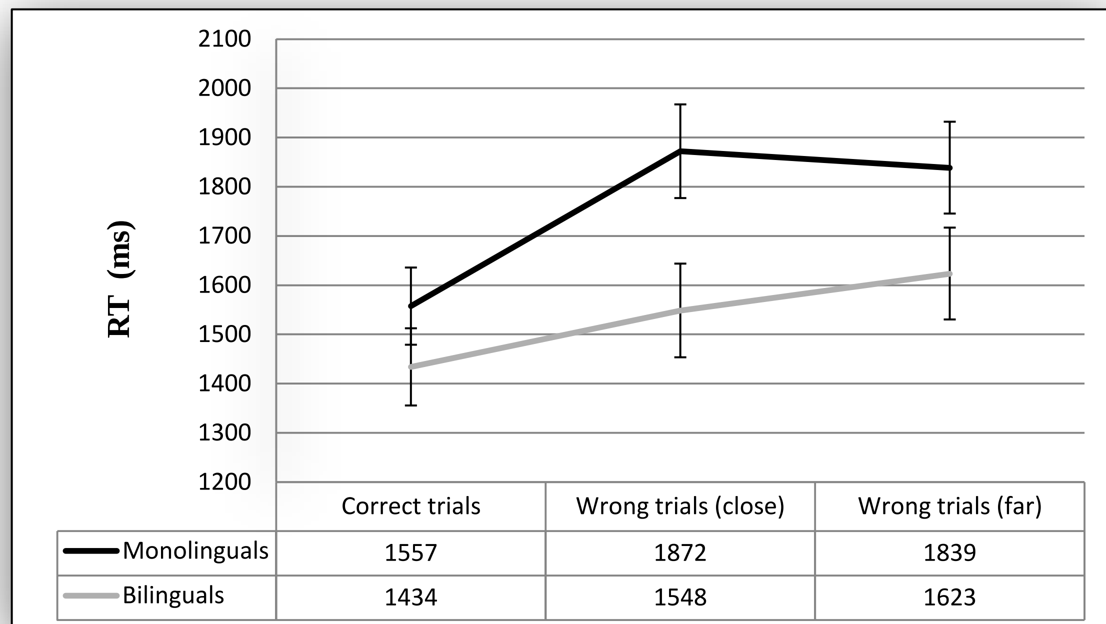


Figure 8. Multiplication Task: results of Experiment 7

4.4.9 Experiment 8

4.4.9.1 Participants

Forty-four out of forty-eight of children who had participated in the Experiment 7 took part in this experiment. Four children (three monolinguals and 1 bilingual) were discarded from the analyses because their accuracy was lower than 50 %.

4.4.9.2 Tasks and procedures

All participants performed both a verification task and a number matching task. Stimuli were built in Arial font and their dimension was 1,15 cm x 4 cm.

The verification task consisted in the presentation of simple additions with a proposed result. Participants had to verify its correctness and press the "q" key if the result was correct, and the "p" key if the result was wrong. 40 trials contained the correct results (Correct) and 40 trials contained a wrong result. Within the 40 wrong trials, 20 trials contained a wrong result that was correct for the corresponding multiplication problem (Lure: 4+2 = 8) and the remaining 20 trials contained an arithmetically unrelated result (Wrong: 4+2 = 10). Lure trials were here introduced to investigate children's ability to inhibit interfering information (the correct result from a multiplication) when a simple arithmetic problem had to be solved.

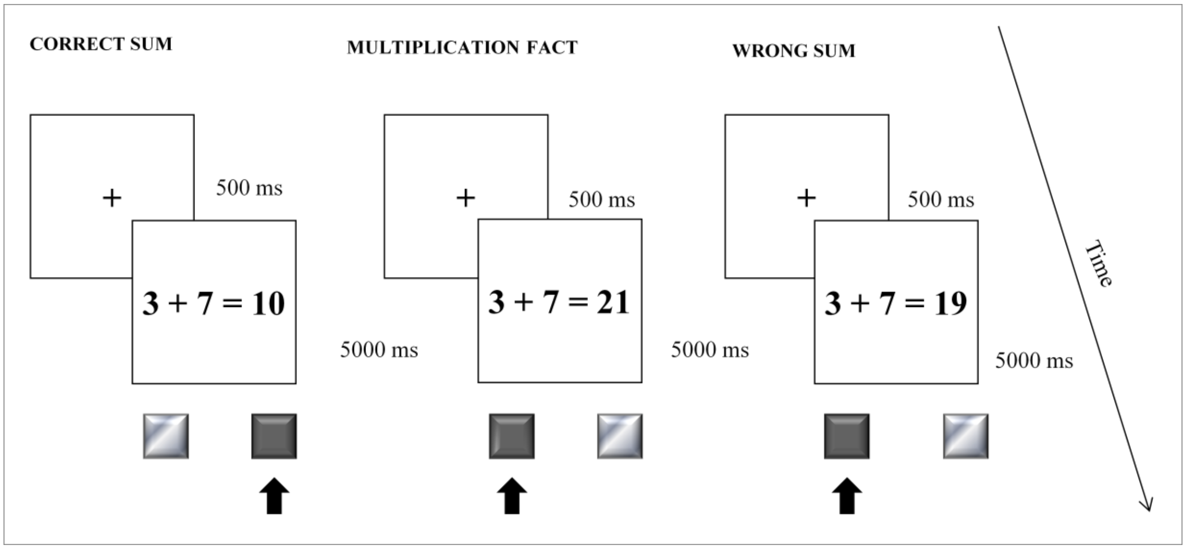


Figure 9. Verification task: procedure

While some studies found that verification tasks require working memory resources to be solved (Lemaire et al. 1996; Aschcraft et al.1992), number matching tasks, which revealed the arithmetic interference effect, do not require such resources (Rusconi et al. 2004). In a typical number matching task, participants are presented two numbers as a cue and the task consists of deciding if a probe (one- or two-digit numerical target) was present in the preceding cue. In the current version of the task participants had to press the “q” key if the latter digits was already presented and the “p” key whether the latter key was new.

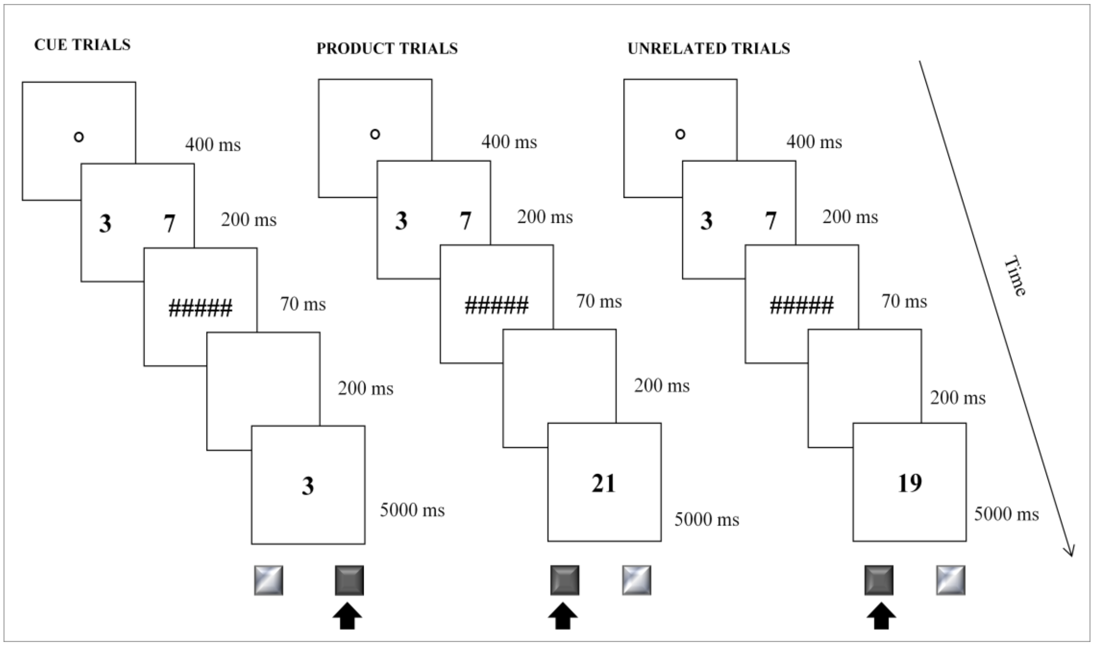


Figure 10. Number Matching task: procedure

The experiment comprised 40 trials which required a positive answer (Correct), 20 trials where the probe number was not present in the cue (Wrong), and 20 trials where the probe was not present in the cue, yet it was the product of the cue digits (Lure). In such task, even if participants are not required to perform any arithmetic calculation, automatic product retrieval may occur and interfere with the task at hand. That is in negative trials where the number has not been presented previously but is the product of the multiplication of the two number just seen, participants are biased towards a positive response, since in a sense the product was active when its operands were shown on the screen, whereas the trial requires a negative response). In fact, Rusconi et al. (2004) found that in a non-arithmetic (number-matching task) and even when the multiplication sign was absent multiplication facts are activated. Performance was also unaffected by asking participants to perform concurrent task such as articulatory suppression, random generation and backward subtraction tasks.

Therefore unlike for the verification task we predicted that both groups will perform this task similarly, since automatic (and often unconscious) retrieval is not supposed to evoke any control mechanisms or additional working memory resources.

4.4.9.3 Results

Since the purpose of the present experiment was to investigate whether monolinguals and bilinguals performed differently on number tasks involving or not working memory resources, only data concerning wrong and lure trials were analyzed.

For the verification task, an ANOVA having the Associative Confusion condition (lure trials; wrong trials) as within subjects factor and Language Groups as between subjects factor (monolinguals; bilinguals) was conducted. Results showed that the main effect of Language Groups were not significant [$F(1,42)=2,08, p>.15$] although bilinguals seemed faster (mean RTs: 1746; SE=110) than monolinguals (mean RTs = 1972; SE= 110). The main effect of associative confusion condition (lure; wrong trials) was not significant either [$F(1,42)=.08, p>.77$] showing that overall, the time needed to reject lure trials was not significantly higher than the time required reject wrong trials. Such results could mean that in general our participants still used immature strategies to solve those additions (e.g. counting strategies). However, the interaction between associative confusion and language group was statistically significant [$F(1,42)=5.8, p<.02$] and showed that bilinguals, compared with monolinguals, were slower with lure than wrong trials. The latter significant interaction, suggest that bilinguals showed an advanced ability to perform simple arithmetic by using retrieval strategies (which allow performing more efficiently) instead of counting strategies. Children at this stage stay in a transition period where they are practicing more efficient strategies to perform arithmetic: bilinguals show to reach such advanced step before their monolinguals peers.

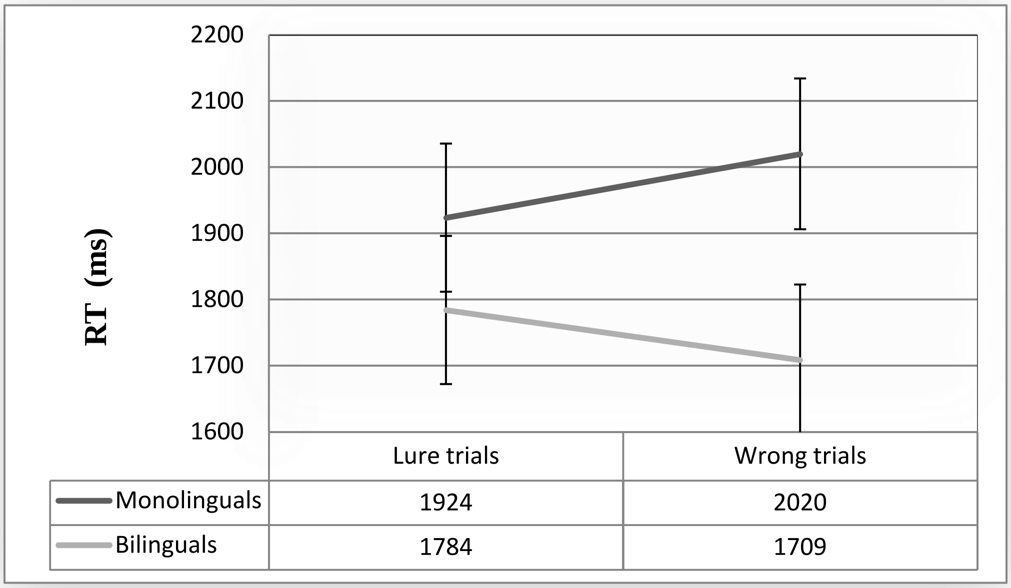


Figure 11. Verification Task: results of Experiment 8

Data from the number matching task were entered into an ANOVA having the arithmetic confusion effect as within factor (lure; wrong trials) and language groups as between factor (monolinguals; bilinguals). Differently from the previous task, neither main effects nor the interaction with the language groups were statistically significant [$F(1,42)=1,49$, $p>.22$] suggesting that, in absence of working memory demands, bilinguals exhibit the same performances than monolinguals. Moreover it is possible that simple multiplication retrieval is not automatised enough in these group of participants to give a significant associative interference effect.

4.4.9.4 Discussion

Experiments 7 and 8 were aimed at exploring possible differences between monolinguals and bilinguals in performing simple arithmetic. As far as I know, no studies have investigated this matter with bilingual children: Experiment 7 found that bilinguals are significantly faster than monolinguals in solving simple multiplications.

Such result contrasts to that of the first studies investigated arithmetical performances in bilinguals. These studies assumed that the disadvantage was due to the difficulty of bilinguals, as compared with monolinguals, to manage two linguistic representations. Both self-report and more recent studies suggest that results of additions and multiplications are stored as verbal codes in LTM, but only in the language which has been used to learn such operations. Dehaene (1992) proposed that simple arithmetic facts (additions and multiplications) are stored and also retrieved in this way because, specially for multiplications, they have been leant by rote at school.

In a developmental view there are at least two kinds of strategies that children can use to perform multiplications: Carpenter and Moser (1984) reported that children attending the first to the third grade of primary school show a gradual decrease of counting strategies in behalf of retrieval strategies to perform arithmetic faster and more efficiently (also in Cooney and Swanson1988). The results of Experiment 8 showed that in solving multiplications, while monolinguals still use less advantaged and slower strategies (e.g. Counting), bilinguals are faster and showed an incipient presence of retrieval strategies.

4.5 General Discussion

In this dissertation relations between the experience of using two languages in everyday life and the development of basic number skills were explored. Such relations have been stressed by assuming that findings found in previous studies on the effects of bilingualism on lexical access and attentional tasks would apply on number tasks requiring the involvement of these general cognitive functions.

Experiments 1, 2 and 3 showed that differences between 10-years old bilinguals and monolinguals peers are shown in enumerating dots. Bilinguals were slower than monolinguals in enumerating dots in the counting range but they exhibited the same performance than monolinguals in the subitizing range. Such result, although interesting for education, are not surprising, since many research have consistently showed that bilinguals are hampered in tasks requiring access to verbal representations.

As it happens for other concepts, balanced bilinguals possess two lexical representations for each cardinal concept (e.g., “due” and “zwei” for the numerosity of two): once they need to use or produce one (e. g., “due”) or the other lexical form of this concept (e.g., “zwei”), they might solve an additional and more demanding problem than monolinguals. After deciding which of two linguistic lexicons have to be used, resources should be addressed to select the intended lexical form of that concept, while at the same time, avoiding the alternative one. Ideally, the more a bilingual uses the two languages in everyday life, the more the two linguistic forms sharing the same concept will compete for activation and thus more resources will be needed to solve the task at hand.

Experiments 1, 2 and 3 found the same results: bilinguals are less efficient than monolinguals when verbal labels have to be used whereas their performance within the same task was not affected when other mechanisms were required. Subitizing, the ability to enumerate few number of items at a glance, is among the other skills the one which humans share with animals and infants and thus it is not affected by experience or education. Counting indeed can be affected by many different variables. For instance, Maloney, Risko, Ansari and Fugelsan (in press) found that individuals who are anxious in mathematics show a deficit in the counting but not in the subitizing range. More importantly for the purpose of the dissertation, counting can be also affected by the spatial arrangement of stimuli on the screen. Stimuli's spatial location can hint the use of some strategies different from counting such as visual-spatial strategies by considering stimuli as verteces of geometrical shapes (e.g., for the numerosity of four, the four stimuli could suggest the shape of a square). The bilingual disadvantage in the counting range has been found in Experiment 1 and confirmed in Experiment 2, where children who had participated in Experiment 1 were tested again one year later; the same results were found also when care was devoted to create stimuli preventing any strategies to use other strategies than counting. Further, as reported by Ivanova et al. (2008) in non-numerical tasks, bilingual disadvantage is evident when they are allowed to use their preferred language.

While in speech production bilingualism exert a disadvantage, the use of the same mechanism seems to give them for an enhanced ability to deal with interfering information both in language and non language tasks requiring control processes. Although many studies seem to confirm this claim, the bilingual advantage is subject of many critics within the field. Doubts involve different perspectives: such advantage is not always consistent among studies, the title of a recent paper wrote Costa et al. (2009) refers to this advantage with these words: "*On the bilingual advantage in conflict processing: Now you see it, now you don't".* Such flashing presence on this effect among studies is for many due to faults linked to the sample procedures, for others it relates with the paradigms used (Bialystok et al., 2004).

For its complexity, bilingualism should be investigated with stricter criteria than the one used so far. This is because, in some circumstances, it can be the consequence of such effect rather than the cause. I'm referring to complex issue of disentangling the development of control processes (as component of the executive functions) from SES. When immigrant children or children attending special bilingual programs are selected to participate to these studies, doubts can be raised about the fact that the experience of being bilingual or instead socio-economic contexts (such as children belonging to lower and higher classes) are responsible of positive effects. For this reason I took care of the bilingual sample in many ways. Historical and social contexts of the bilingualism being subject of study were firstly examined. Then, strict criteria were used to be sure that the knowledge of the second language was matched with its actual use by considering as bilinguals only children whose parents had different mother-tongues and reported to speak both languages with their children on a daily basis and very early in life.

Experiments 4-8, were devoting at investigating whether, when these variables were properly controlled, the bilingual advantage was still evident.

Experiments 3, 4, and 5 did not find any difference between monolinguals and bilinguals, neither when a different sample of bilinguals was enrolled. In a number Stroop task, where participants were asked to compare the magnitude of numbers while ignoring a task-irrelevant information (the physical size of stimuli), all groups did not differ statistically from each other. Using the same task, Experiment 3 compared the performance of Alto-Adige bilinguals and Italian-speakers while Experiment 4 employed a different group of bilinguals. Experiment 5 tested the three groups one year later with the same task. None of these experiments revealed any difference between groups. A different point of view, in addition to the ones previously mentioned, could explain the reasons for the inconsistency of the bilingual advantage. Tasks as the Simon task or the Stroop tasks could not be sensitive enough to enlighten such effect: in fact when more demanding version of the Simon task were employed using more attentional demanding stimuli and manipulating the number of switches between trials (Bialystok, 2006; Costa et al., 2008) such effect appeared again. This is the reason why a further series of experiments was conceived as to investigate more deeply this issue. In experiment 7, bilinguals and monolinguals were compared in solving multiplications. Bilinguals were not only significantly faster than monolinguals in solving these operations but their performance differed from that of monolinguals in verifying the correctness multiplications whose results was wrong but it was numerically close to the correct one. Many research showed that rejecting the wrong result of a multiplication require more working memory resources when this result is “numerically close” to the correct one than when it is “numerically far” from the correct one (Ashcraft et al. 1992).

Experiments 8 and 9 was aimed at investigating such effect more deeply by employing two more tasks involving numbers and different use of working memory resources: a verification task and a number matching task. In a verification task (Experiment 8), participants are asked to judge the correctness of additions by pressing one key for additions whose proposed result is correct and a different key for additions whose product is wrong. Among the wrong trials (additions with the wrong results), half of the trials proposed wrong products for additions (e.g., wrong trials) and the other half proposed wrong results which are the correct results for the correspondent multiplication, that is the multiplication having the same operands as the addition (e.g. Lure trials). This method allows to investigate whether results of multiplication tables are stored and retrieved from LTM. Trials whose proposed result is wrong but it is the correct result for the correspondent multiplication, a confusion between operation is promptly perceived and additional time is needed to ignore the multiplication misleading result in favor of the correct result of the addition.

The ability to retrieve and deal with arithmetical facts is not taught immediately at school. Children are first taught to solve additions and multiplications using counting strategies and then to solve such operations more accurately and efficiently, they are asked to learn by rote results of simple additions and multiplications. Such method allow storing in LTM these information and retrieving them when needed. Note that simple arithmetic is not only used when simple operations have been calculated but also when more complex arithmetical operations have been solved. That is, many adults reports to solve complex arithmetic operations by split them in more simple operations, retrieving the result of these operations separately and finally putting together the interim results. Therefore being able to store and retrieve the results of these arithmetic operations instead of using counting gives children for an advanced number skills, since it allows them to solve the task more accurately and efficiently and use such knowledge in situations where more complex arithmetical operations have been solved.

For many (e.g., Carpenter and Moser, 1984), 10- years old children still rely on counting strategies to solve simple arithmetic and are starting to use more advanced abilities such as retrieving number facts from LTM. Results from the verification task employed in Experiments 8 and 9 suggested that only bilinguals use retrieving strategies.

While many studies claim that working memory resources are needed to solve the verification task, others suggest that the number-matching task does not involve such resources (e.g. Rusconi et al. 2004). This task was employed as to verify whether in a task with numbers but where the involvement of working resources was low or absent, difference between groups were evident. Children were asked to pay attention to the two numbers (shown on the right and on the left of the screen) because after their presentation, they had to decide whether a third number had been already presented or not. Among trials containing a new number as third number, half of the trials contained a number that was not already shown and the other half, the number was the product of the first two numbers. Results from this task showed that performances of both groups did not differ.

Studies presented here confirm findings achieved in other domains (e.g. Ivanova et al. 2008) and at the same time, contribute to enlarge, by employing stricter criteria, the body of studies achieved so far. The bilingual disadvantage in counting can be a useful information for teachers who could set up their educational programs and supply bilinguals for alternative strategies of counting (such as by using visual-working strategies). Results achieved Experiments 4-6 contribute to inform this field about methodological issue that the field of bilingualism necessarily entails. Finally, the bilingual advantage found in Experiments 7-9 suggest that the reasons for its inconsistency presence across studies could not be univocally related to such methodological issues (SES and criteria for defining the phenomenon). Perhaps more sensitive measures to detect and define such effect might be set up, because, the phenomenon of bilingualism assumes crucial importance for the education of the modern and future citizens.

Chapter 5
Conclusion

5.1 Numbers, Education and Society

Although studies keep bringing further evidence for the fact that both humans and animals come to life with an innate kit of numerical competence, which can be later on expanded with the tools provided by culture and education, a paradox must be here highlighted: despite the innate capacity of humans to be tuned with numbers, mathematics still remains for children and adults as the most complex issue to learn.

In Italy, mathematics is the most difficult discipline: in 2008 the Italian government has notified that 47,5% of children who encounter difficulties at school show their lower marks especially in mathematics. This problem has been recently pointed out by the current Minister of Education, Mariastella Gelmini who maintained that mathematics is for Italian schools, a "didactic urgency". Its character of urgency is given by statistics clearly showing that that is a problem shared by all Italian students, regardless of their region of residence, gender, or typology of school attended. Therefore attention should be focused on finding new methodologies for education in mathematics (http://www.affaritaliani.it/cronache/ scuolamatematica 220708 .html).

This issue assumes unique importance if one consider that mathematic and technical (made possible by mathematics) achievements are probably seen as the greatest intellectual attainments of human beings, in a world where logical and rational thoughts are particularly valued. Sharpening minds towards this direction can contribute to develop fields like Science, Engineering and Technology but even to Medicine, Social Sciences and Economics.

Cognitive Science and Neuroscience can provide some help in addressing this paradox, by informing education on the development of basic number skills and also by indentifying the most successful methods of teaching. In this dissertation attention was focused on the development of basic number skills because they constitute the foundation of what is considered of great importance for future academic and occupational attainments. Counting provides the foundation for the development of simple arithmetical skills. In everyday life we need to make quick sums or products for buying things, cooking, telling time etc. The automaticity of access to numerical magnitude, in addition to other cognitive abilities, allows stepping up to more complex arithmetic. Establishing how these abilities develop; how they interact with more general cognitive abilities, and whether they can be influenced by experiences, educational methodologies, or different cultures might give useful insights to solve this huge and urgent problem.

Bilingualism can be one of those experiences influencing the development of mathematical achievements and is becoming, at the same time, fundamental in our lives. Being able to speak more languages is nowadays not only a cultural enrichment but a smashing opportunity to have good chances for working and improve the own career. Today a more and more increasing number of people, for chances or need, speak fluently a second language and certainly such number will vastly increase.

5.2 Conclusions

Bilingualism and mathematics have been extensively studied in separate fields of cognitive psychology. This is not surprising since both set of skills are extremely needed in modern lives. Much less research has been devoted to bring together both fields. Reasons explaining such lack of knowledge are not clear. Knowledge in the fields could not be sufficiently developed to be extended in other domains or perhaps language and mathematics have been viewed as too much remote domains to bring together.

The idea that cerebral areas are responsible for specific and independent mental functions was proposed by Fodor (1983) in the seminal book on the modular mind. More recently, such approach has been substituted by a more holistic view of the mind. Today the mind is not even considered as a set of independent functions but as a dependent and influencing body of abilities.

The present dissertation is a result, or perhaps an effort, of such new way of thinking on the functioning of the mind. Countless research on bilingualism and mathematics would enrich it: studying more advanced arithmetic operations, investigating the effect, if any, of different degrees and types of bilingualism; studying whether different languages or linguistic systems could exert some effect on number skills; investigating whether particular bilingual programs in mathematics can influence the performance. That is only a spoilt for choice.

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APPENDIX A : Language Background Questionnaire

UNIVERSITÀ DEGLI STUDI
DI TRENTO

Facoltà di Scienze Cognitive

QUESTIONARIO PER I GENITORI DEGLI ALUNNI

Le chiediamo di compilare il questionario

sull'utilizzo della lingua

italiana e tedesca di Suo/a figlio/a.

La preghiamo di aggiungere qualsiasi informazione Lei ritenga possa esserci utile, anche se non richiesta nelle domande

di seguito presentate.

La ringraziamo anticipatamente per il suo prezioso aiuto.

QUESTIONARIO SULL'UTILIZZO DELLE LINGUE

Nome e Cognome di Suo/a figlio/a ....

Data di nascita.................................... Età...................................

Lingua madre del padre...................... Lingua madre della madre................................

Professione del padre......................... Professione della madre ....

Anni di scolarità del padre................. Anni di scolarità della madre ....

Titolo scolastico del padre................. Titolo scolastico della madre ....

1- A che età Suo/a figlio/a ha cominciato ad ascoltare in maniera continuativa

l' Italiano............................

2- A che età Suo/a figlio/a ha cominciato a parlare l'Italiano...

3- Come ha appreso l'Italiano...

4- A che età ha cominciato ad ascoltare in maniera continuativa il tedesco............................

5- A che età ha cominciato a parlare il tedesco.....................

6- Come ha appreso il tedesco ....

....

7- Indicare la lingua (Italiano, tedesco, entrambe o nessuno) che Suo/a figlio/a utilizza con:

padre: madre: fratello/sorella: nonni:

8- In quale lingua preferisce parlare con Suo/a figlio/a?..

9- Quale lingua generalmente Suo/a figlio/a utilizza per rispondere? ....

10- In quale lingua generalmente si rivolge spontaneamente a lei suo marito\sua moglie? ……………………………………………………………………………………………….

11- In quale lingua esegue i calcoli numerici? ……………………………………………..

12- Quando Lei si rivolge a suo/a figlio/a in una lingua, il bambino/a continua la conversazione nella stessa lingua o cambia lingua? …..

13- Che lingua il bambino utilizza in contesti extrascolastici (sport, corsi di musica, etc)? ....

14- Quale lingua Suo figlio\a preferisce parlare?

Italiano Tedesco Entrambe

15- Se avesse un cane o un gatto, in quale lingua gli parlerebbe?

Italiano Tedesco Entrambe

16- Quale altra lingua utilizza (parla, legge o scrive)?

17- Segnalare l'opzione che meglio rappresenta rispettivamente il livello di comprensione, lettura, fluenza, pronuncia, e scrittura di Suo/a figlio/a:

Quale livello di comprensione ha in Tedesco:

perfetto buono sufficiente scarso

Quale livello di lettura ha in queste in Tedesco:

perfetto buono sufficiente scarso

Come parla (fluenza) in Tedesco:

perfetto buono sufficiente scarso

Come parla (pronuncia) in Tedesco:

perfetto buono sufficiente scarso

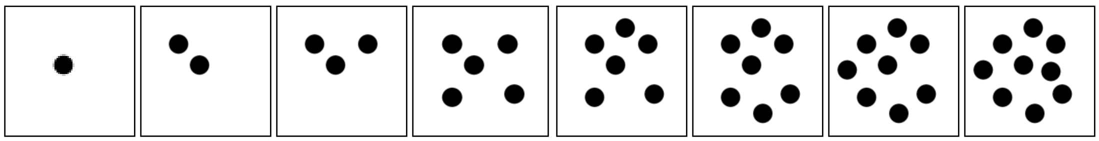
Come scrive in Tedesco:

perfetto buono sufficiente scarso

GRAZIE!!

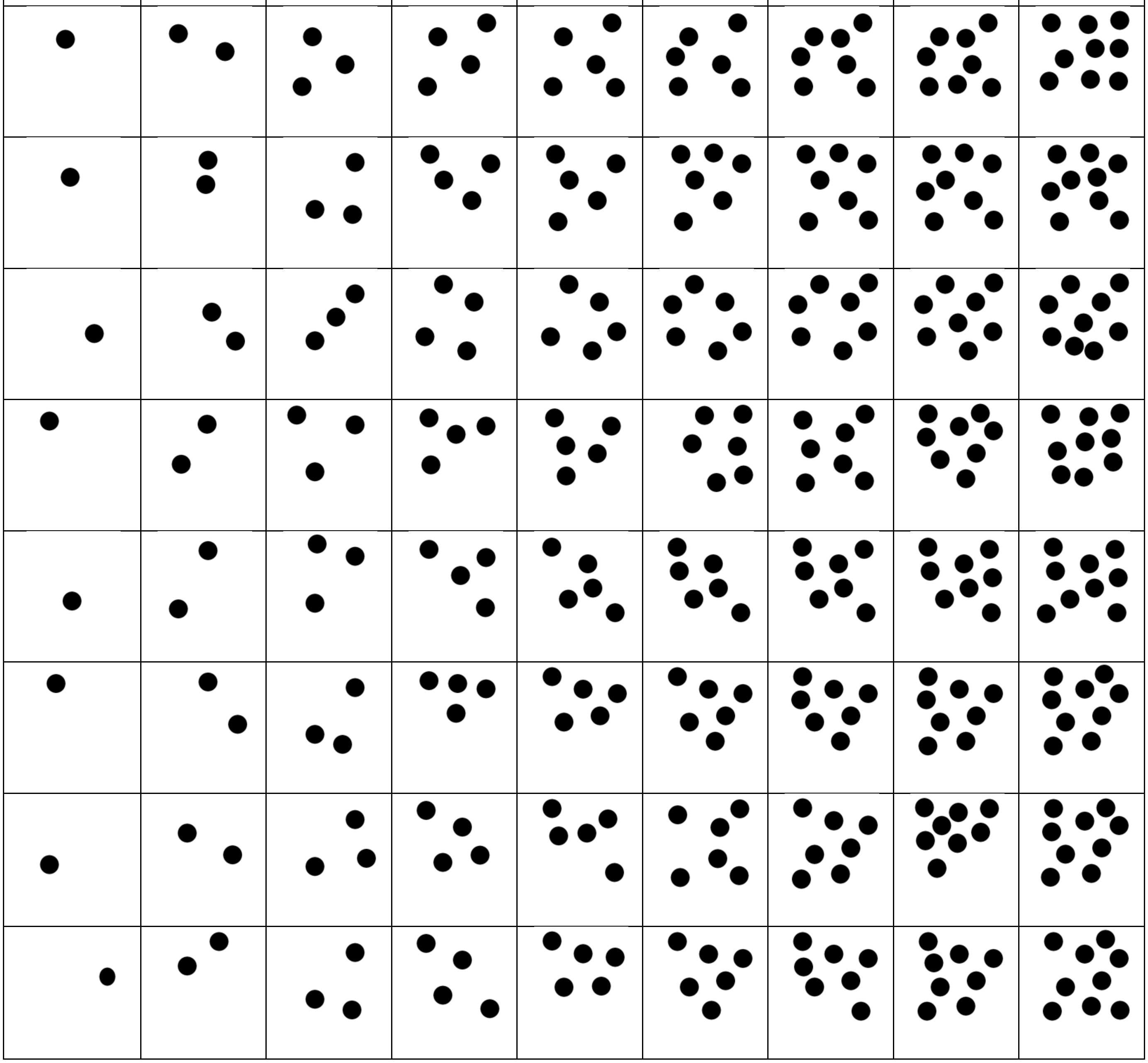
APPENDIX B: STIMULI

Enumeration Task: Experiments 1 and 2 (number of dots to be counted)



Enumeration Task: Experiment 3 (number of dots to be counted)

NUMBER OF DOTS								
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**



Multiplication Test: Experiment 7

Stimuli				Correct product	Number of repetitions	Close product	Number of repetitions	Far product	Number of repetitions
3	x	7	=	21	2	19	1	25	1
8	x	3	=	24	2	26	1	20	1
3	x	9	=	27	2	25	1	22	1
7	x	4	=	28	2	26	1	30	1
4	x	9	=	36	2	38	1	32	1
9	x	6	=	54	2	52	1	58	1
7	x	8	=	56	2	54	1	60	1
9	x	7	=	63	2	65	1	58	1
8	x	9	=	72	2	74	1	67	1
6	x	4	=	24	2	26	1	20	1
3	x	1	=	3	2	5	1	9	1
1	x	6	=	6	2	8	1	2	1
7	x	1	=	7	2	5	1	3	1
1	x	8	=	8	2	10	1	4	1
9	x	1	=	9	2	7	1	5	1
1	x	13	=	13	2	15	1	17	1
16	x	1	=	16	2	14	1	20	1
1	x	17	=	17	2	19	1	22	1
18	x	1	=	18	2	16	1	22	1
1	x	19	=	19	2	21	1	23	1

Verification Task: Experiment 8

Stimuli				Correct	Number of repetitions	Lure	Number of repetitions	Wrong	Number of repetitions
3	+	7	=	10	2	21	1	19	1
8	+	3	=	11	2	24	1	26	1
3	+	9	=	12	2	27	1	25	1
7	+	4	=	11	2	28	1	26	1
4	+	9	=	13	2	36	1	38	1
9	+	6	=	15	2	54	1	52	1
7	+	8	=	15	2	56	1	54	1
9	+	7	=	16	2	63	1	65	1
8	+	9	=	17	2	72	1	74	1
6	+	4	=	10	2	24	1	26	1
3	+	1	=	4	2	3	1	1	1
1	+	6	=	7	2	6	1	1	1
7	+	1	=	8	2	7	1	1	1
1	+	8	=	9	2	8	1	1	1
9	+	1	=	10	2	9	1	1	1
1	+	13	=	14	2	13	1	1	1
16	+	1	=	17	2	16	1	1	1
1	+	17	=	18	2	17	1	1	1
18	+	1	=	19	2	18	1	1	1
1	+	19	=	20	2	19	1	1	1

Number Matching Task: Experiment 8

Stimuli		Cue	Number of repetitions	Product related	Number of repetitions	Unrelated	Number of repetitions
3	7	3	2	21	1	19	1
8	3	8	2	24	1	26	1
3	9	9	2	27	1	25	1
7	4	4	2	28	1	26	1
4	9	4	2	36	1	38	1
9	6	9	2	54	1	52	1
7	8	8	2	56	1	54	1
9	7	7	2	63	1	65	1
8	9	8	2	72	1	74	1
6	4	6	2	24	1	26	1