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Language and Executive Functioning Skills in Greek-English Bilingual Children in the U.K.

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Language and Executive Functioning Skills in Greek-English Bilingual Children in the U.K.

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Supervised by Dr Eirini Sanoudaki

A Thesis submitted in partial fulfilment of the requirement for the degree of Doctor of Philosophy in Bilingualism at Bangor University

School of Languages, Literatures, Linguistics and Media

Bangor University

September 2020

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Yr wyf drwy hyn yn datgan mai canlyniad fy ymchwil fy hun yw'r thesis hwn, ac eithrio lle nodir yn wahanol. Caiff ffynonellau eraill eu cydnabod gan droednodiadau yn rhoi cyfeiriadau eglur. Nid yw sylwedd y gwaith hwn wedi cael ei dderbyn o'r blaen ar gyfer unrhyw radd, ac nid yw'n cael ei gyflwyno ar yr un pryd mewn ymgeisiaeth am unrhyw radd oni bai ei fod, fel y cytunwyd gan y Brifysgol, am gymwysterau deuol cymeradwy.

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General Abstract

Background and aims: Bilinguals have been argued to show superior executive functioning (EF) skills compared to monolinguals, due to long-term experience in dual-language management. Despite extensive investigation during the past twenty years and a persistent debate regarding the existence of a bilingual advantage in the EF skills of bilingual children, the results remain mixed; namely bilinguals might perform better, worse, or similarly in EF tasks compared to their monolingual counterparts. The current thesis investigates the EF skills as well as the language skills of Greek-English bilingual children attending a Greek supplementary school in England. The cognitive performance of the bilingual children is compared to that of Greek monolingual and English monolingual control groups. This thesis has three aims: i) to investigate the performance of Greek-English bilingual children in EF tasks compared to monolingual Greek and monolingual English children after closely matching them on a large number of relevant variables, ii) to propose a novel approach to evaluate the EF performance of bilingual and monolingual children holistically, and iii) to explore the variables that might affect scores in language tasks of expressive/receptive vocabulary and receptive grammar of the Greek-English bilingual children attending a Greek supplementary school in England and investigate if and how the exposure to a supplementary school setting affects these scores.

Methods: A total of 109 children took part in this study, namely 39 Greek-English bilingual children, 45 Greek monolingual children and 25 English monolingual children aged 63-153 months. Bilingual Greek-English children were recruited from a Greek supplementary school in the north-west of England. We use an array of executive functioning tasks which tap into inhibition, updating and shifting, as operationalised by Miyake et al. (2000). We use k-means nearest neighbour methods to match bilingual to monolingual children on a wide array of control

variables and frontier methodologies which allow us to jointly consider multiple tests and metrics in a new measure; the technical efficiency (TE).

Results: In the first study (Chapter 3) the results suggest that bilinguals' accuracy on executive function tasks is at par to their monolingual peers. However, bilinguals are faster in the inhibition and the working memory task compared to the English monolingual control group and were comparable to the Greek monolingual control group. In the second study (Chapter 4), bilinguals seem to have superior technical efficiency than their monolingual counterparts. We find bilinguals to be around 6.5% more efficient than their monolingual counterparts in executive function. Overall, we find that the TE analysis utilises the information in a more efficient way; and can thus yield similar results to the more complex MANCOVA analyses while using fewer resources. In the last study (Chapter 5), the results suggest that language use significantly predicts performance in Greek vocabulary and grammar tasks whereas age in months significantly predicts performance in English vocabulary and grammar tasks. Years in supplementary school do not significantly predict neither scores in the Greek tasks nor in the English tasks.

Conclusions: This thesis has both methodological and educational implications. Namely, we contribute to the literature in three distinct ways. Firstly, we take into consideration the majority of potential variables such as age, non-verbal intelligence, years of education in the supplementary school, years of education in a Greek medium school, language proficiency in both languages, language use, socioeconomic status (SES), music ability. To the best of our knowledge no studies have controlled for both languages of the bilingual group of children. In the first research study (Chapter 3) we control for both languages, Greek and English, using factor analysis to take as many variables as possible into consideration. Secondly and directly following the first study, we propose a novel approach to evaluate performance in the EFs of bilingual and monolingual children. In this way we deal with the extended array of executive function tasks and metrics used across the literature. Lastly, we investigate variables that affect the performance in vocabulary and grammar tasks in Greek and English and if the exposure to a supplementary school setting influences the performance in both the heritage (Greek) language and the medium of mainstream education (English). In this way, we investigate the role of the educational setting in bilingualism, namely a supplementary school, a topic that has attracted minimal attention by the relevant literature.

Table of Contents

Declaration and Consent 2

Acknowledgements 7

General Abstract 9

Chapter 1 - General Introduction 18

1.1 Overview of the thesis 18

Chapter 2 - General Literature Review 20

2.1 Defining Bilingualism 20

2.2. Development of Language Skills in Bilingualism 25

2.3 Does Bilingualism affect Cognition? 29

2.3.1 Early Studies in Bilingual Cognition 29

2.3.2 Cognitive Abilities in Bilingualism 30

2.3.3 Executive Functioning System 31

2.3.4 Bilingual Effect in Children 34

2.3.5 Bilingual executive advantage (BEA) hypothesis 38

2.3.6 Possible reasons underlying contradictory findings 41

2.4 General Statement of the Problem 47

Chapter 3 - A study on the executive functioning of Greek-English bilingual children. 50

Abstract 50

3.1 Introduction 52

3.2 Current Study 54

3.3 Method 55

3.3.1 Participants 55

3.3.2 Materials 59

Parental Questionnaire 59

Non-verbal Intelligence 60
Language Measures. 60
Executive Function Tasks. 63
3.3.3 Procedure 67
Greek Session. 67
English Session. 67
Monolingual Participants' Session. 68
3.4 Results 68
3.4.1 Preliminary analyses 68
Outlier analysis. 68
3.4.2 Language background measures 69
3.4.3 Matching method 72
3.4.4 Main Analyses 76
Comparison 1 77
Comparison 2 81
3.5 Discussion 83
3.6 Limitations and future directions 87
3.7 Conclusion 88
Chapter 4 - The Executive Function of Bilingual and Monolingual Children: A Technical Efficiency Approach 90
Abstract 90
4.1 Introduction 92
4.2 Bilingualism and Executive Control: Mechanisms and challenges 93
4.2.1 The current study 97
4.2.2 Efficiency studies across disciplines 99

4.3 Method 103
4.3.1 Participants 103
4.3.2 Technical efficiency 104
4.3.3 Data transformations 110
4.3.4 Second stage analysis 114
4.4 Results 115
4.4.1 Descriptive statistics 115
4.4.2 Efficiency estimates 122
4.4.3 Second stage analysis 124
4.5 Robustness tests 126
4.5.1 Comparison with conventional designs 126
4.5.2 Comparison to an alternative dataset - The Antoniou et al. (2016) dataset 131
4.5.3 The balanced bilinguals assumption 136
4.6 Discussion and conclusion 139
Chapter 5 - Language skills in Greek-English bilingual children attending Greek supplementary schools in England. 142
Abstract 142
5.1 Introduction 144
5.1.1 Supplementary schools 145
5.1.2 The Greek community and Greek educational provision in the U.K. 146
5.1.3 Previous studies 151
5.1.4 The Present Study 155
5.2 Method 155
5.2.1. Participants 155
5.3 Results 158

5.3.1 Test performance ... 158
5.3.2 Multiple Regression Analysis ... 160
5.4 Discussion ... 169
5.5 Implications, Future Directions and Limitations ... 170
5.6 Conclusion ... 172
Chapter 6 - General Discussion ... 174
6.1 Review of results in Chapter 3 and links to EF hypotheses ... 174
6.2. Review of results in Chapter 4 and comparison to Chapter 3 results ... 174
6.3. What is the role of supplementary education and use of the home language in English and Greek language skills? ... 179
References ... 183
Appendices List ... 230
List 1: Parent/Guardian Information Sheet and Consent forms (English and Greek) ... 231
List 2: School Information Sheet (English and Greek) ... 235
List 3: Head teacher consent form (English and Greek) ... 239
List 4: *Ethics Approval* ... 241
List 5: *Questionnaires for parents/guardians (English and Greek)* ... 242
List 6: Technical Appendix A ... 250

List of Tables and Figures

Table 1 *Participant information: parent questionnaires and scores on language and IQ tests (raw scores reported for tests)* 58

Table 2 *Results of factor analysis on the four language variables for Greek-English bilinguals and Greek monolinguals.* 70

Table 3 *Results of factor analysis on the four language variables for Greek-English bilinguals and English monolinguals.* 71

Table 4 *Correlations between the control background variables* 72

Table 5 *Descriptive Statistics - RTs in Executive Function Tasks* 78

Table 6 *Executive Function Tasks Descriptive statistics - accuracy* 79

Table 7 *Executive functioning tasks: comparison of bilingual group and Greek control group* . 80

Table 8 *Executive functioning tasks: comparison of bilingual group and English control group* 82

Table 9 *Examples of technical efficiency studies* 101

Table 10 *Performance ratios and technical efficiency* 105

Table 11 *Test mapping per group* 113

Table 12 *Descriptive statistics* 116

Table 13 *Technical efficiency estimates by group* 123

Table 14 *Second-stage analysis* 125

Table 15 *Comparison with conventional designs – ANCOVA analysis* 128

Table 16 *Comparison with conventional designs – MANCOVA analysis* 130

Table 17 *Comparison to alternative datasets – the Antoniou et al. (2016) dataset* 134

Table 18 *Technical efficiency estimates by group – Balanced Bilinguals Assumption* 138

Table 19 *Participant information: parent questionnaires and scores on language and IQ tests (raw scores reported for tests)* 157

Table 20 *Descriptive Statistics – Performance in tests (out of 100 scale)* 159

Table 21 *Collinearity Statistics* 162

Table 22 *Regression for DVIQ* 163

Table 23 *Regression for adapted PPVT* 164

Table 24 *Regression for PWFT* 165

Table 25 *Regression for TROG* 166

Table 26 *Regression for BPVS* 167

Table 27 *Regression for CELF* 168

APPENDIX Table A28 *Correlation matrix* 250

Figure 1 *Efficient frontiers* 107

Figure 2 *Box-Plots of executive function metrics* 120

Figure 3 *Grammar, Language and Vocabulary skill standardised scores* 121

Figure 4 *Performance in English and Greek tasks (out of 100 scale)* 158

Chapter 1 - General Introduction

1.1 Overview of the thesis

This thesis aims to i) to investigate the performance of Greek-English bilingual children in executive functioning (henceforth EF) tasks compared to monolingual Greek and monolingual English children after closely matching them on a large number of relevant variables, ii) to propose a novel approach to evaluate the EF performance of bilingual and monolingual children, and iii) to explore the variables that might affect scores in language tasks of expressive/receptive vocabulary and receptive grammar of the Greek-English bilingual children attending a Greek supplementary school in England and investigate if and how the exposure to a supplementary school setting affects these scores.

This thesis is divided in 6 main chapters: the General Introduction, a General Literature Review, three research articles, the General Discussion and Conclusion. Chapter 1 (current Chapter) presents the structure of the current thesis. Chapter 2 will present an overview of bilingualism, more specifically definitions of bilingualism and types of bilingual individuals, language skills of bilinguals, a brief review of EFs and theories around these in relation to bilingualism, as well as research findings on EFs and bilingualism. Chapter 3 will explore the performance in executive functioning tasks of Greek-English bilingual children in the north of England compared to two control groups of monolingual Greek children in Greece and monolingual English children in the north of England after closely matching these groups on a large number of variables. Chapter 3 describes in detail the ethics procedure, the materials and the procedure which were used in all three studies. The two subsequent studies in Chapter 4 and 5 refer back to the Method section in Chapter 3 regarding ethics, materials and procedure. Chapter 4 will present a novel approach to evaluate performance in the EFs of bilingual and monolingual children, namely technical efficiency. Chapter 5 will explore predictors of the performance in Greek and English vocabulary and grammar tasks and if the years in a supplementary school setting influences the performance in both languages. Chapter 6 will include a brief additional discussion of the key findings related to hypotheses about the bilingual advantage in EFs and to their implications and future directions within research and education. Finally, it will present general conclusions.

Chapter 3, 4 and 5 are version of three research articles that are accepted for publication (Chapter 4) and submitted to research journals (Chapter 3 and 5). The contribution of Eirini Sanoudaki and Marco Tamburelli includes revisions and supervision of the candidate. Vasileios Pappas contributed the econometric methodology. Otherwise, the one published and two submitted papers, Chapter 3, 4, 5, are my own original work.

Chapter 2 - General Literature Review

Over 50% of the population all around the world uses two or more languages in their communication (European Commission, 2012; Grosjean, 2010). In England and Wales, 4.2 million people reported another main language in addition to English or Welsh, with London having the highest proportion of another main language (Office for National Statistics, 2019). The current chapter will present an overview of the definitions of bilingualism, the development of language skills among bilingual individuals, types of EFs and tests tapping these, as well as approaches to the link between EFs and bilingualism. The presentation of the above information concerning bilinguals is necessary in order to investigate the cognitive and language abilities in bilingual children. Main aim of this thesis is to explore how bilingualism affects executive functions. Therefore, it is necessary to explain some key factors in bilingualism in order to give a better understanding of our aims.

2.1 Defining Bilingualism

The definition of bilingualism has been a much-debated topic. The word *bilingual* may refer to a person that has acquired two languages (Wei, 2000). It can also refer to people having various degrees of proficiency in more than two languages (Wei, 2000).

On one end stands the classic definition of bilingualism which is 'the native-like control of bilingualism' (Bloomfield, 1933) that may appear extreme, maximalist and ambiguous in terms of the words *control* and *native group* (Baker, 1993). On the other end the minimalist definition of bilingualism, such as the concept of *incipient bilingualism* provided by Diebold (1964), states that a person who can use a single expression in a foreign language, such as tourists or business people, can be regarded bilingual. However, this definition may be inclusive, ambiguous, and imprecise

(Baker, 1993). One misconception about bilingual people is that they are equally proficient in all aspects of each language (Bee Chin & Wigglesworth, 2007). Yet, bilinguals rarely develop balanced competence in their first and second language (Shin, 2004).

Grosjean (2010) proposes the following definition of bilinguals: ‘Bilinguals are those who use two or more languages (or dialects) in their everyday lives’ (p. 4). Grosjean (2010) places emphasis on the regular use of the languages by the bilinguals and not on fluency, while including dialects along with languages. Hence an Italian who uses one of Italy’s dialects, such as Pugliese, along with Italian is considered bilingual. Grosjean’s definition of bilingualism is very similar to the one by Weinreich (1968) and Mackey (1962), who defined bilingualism as the alternate use of two (or more) languages. Based on Grosjean (2010), when the definition of bilingualism focuses on language use, the range of who can be considered bilingual is wider. For example, an interpreter or a translator who is fully fluent in speaking and writing both languages, or a researcher that might be fluent in writing articles in a second language but rarely speaks the language, while communicating in a first or even third language with a spouse or friends. These people use two or more languages in their everyday lives. Consequently, Baker and Prys Jones (1998, p.2) suggest the following questions when defining someone as a bilingual person:

- Should bilingualism be measured by the fluency of a person in two languages?
- Are bilinguals the people who are equally competent in both languages?
- Is language proficiency the only factor that should be considered or is language use important as well?
- What about a person who can understand a second language but cannot speak it? What about a person who can speak a language but is not literate in it? What about

if someone can read and write a language but cannot speak it. Are these people considered as bilinguals?

- Does self-perception and self-categorisation reflect who is bilingual?
- Are there different degrees of bilingualism that can alter over time or over a change of circumstances? For example, a person in their infancy and childhood may be exposed to a minority language or to a language spoken by immigrant parents at home. Later on, during school years a second language might become more dominant and might result to a loss in fluency in the first language acquired?

These questions may introduce more uncertainty; therefore, classifications of bilinguals may be introduced to capture differences in i) age of acquisition and ii) proficiency in the second language.

The age that a person acquires a language has a great impact on the learning trajectory in the study of bilingualism. Many researchers categorise bilinguals depending on the age that they acquired a second language (e.g., Bialystok & Hakuta, 1999; Birdsong, 1992; Genesee & Nicoladis, 1995; Flege, 1999). A bilingual speaker might be *simultaneous* (e.g. two languages are spoken in a household; Pavlenko, 2014) namely speakers that acquired two languages at the same time. Another name for this category, for example used in developmental research, is *crib bilinguals* for infants who are exposed to two languages (e.g., Kovács & Mehler, 2009). In these categories these individuals might have been exposed to two languages since birth or early in childhood as a result of family bilingualism where the language is spoken by the parents, the grandparents, or the environment surrounding the infant. This might happen, for example, in countries such as Canada, Switzerland, or Wales where two or more languages are spoken in the community.

A bilingual speaker might also be *sequential* (e.g. people that attained the language due to immigration. These bilinguals have acquired a second language after their first language usually before 12 years of age. Individuals in this category might have acquired the second language as a result of education or immigration. Another category that might be used is that of *early* bilinguals (e.g. Kreiner & Degani, 2015; Montrul, 2005; Yoshida 2008), which is contrasted to *late* bilinguals, who acquired their second language in adulthood after the acquisition of their first language had been completed.

In terms of proficiency, bilingual speakers might be *balanced* (also equilingual or ambilingual), namely speakers that have equal competence in both languages; however balanced bilingualism is very rare (Grosjean, 1997; 2010). Their competences in both languages may be well developed (Baker, 2001) or speakers may be more or less fluent across various language abilities.

Bilingual individuals might show diverse proficiency in speaking, listening, reading, and writing their languages. Furthermore, the amount of input and use of the two languages might be different due to factors such as the status of each language (majority, minority, heritage), medium of education, and whether children develop literacy skills in the languages. Their ability in the two languages depends on the use of each language (Silva-Corvalán & Treffers-Daller, 2015) and on whether the language is used at the same rate or not (Montrul, 2016). Differences in language use can lead to language dominance, which is most often defined as the relative strength of a bilingual individual’s proficiency in each of their languages, with the dominant language being the more proficient or more developed language (Snape & Kupisch 2016).

As mentioned above, bilinguals might be defined in different ways depending on certain factors, such as age of acquisition, bilingual proficiency, language background etc. Grosjean (2010) mentions the factors that should be taken into account when describing bilinguals: First, the biographical data of a person (age, sex, socioeconomic status (SES) etc.), in addition to which languages are known and which are used, as well as the relationship between those languages (e.g. if they are similar to each other like English and Dutch). Additionally, information such as if languages are still being acquired or if a language is being modified by a more dominant language, for example due to business purposes. Very important factors are the language history of a bilingual and more specifically which languages and at what age they were acquired, as well as if they were acquired at home, at a formal environment like school, or both. Also, the proficiency in all four skills (speaking, listening, reading, writing) of a person in each language is necessary to be identified and the functions of their languages, more specifically in what context, to what purpose and extent do they use each language. Finally, the language mode, meaning the state of activation of the languages of a bilingual person, needs to be taken into account, as well as biculturalism, meaning whether the bilinguals communicate with two or more cultures. For example, a Greek-English bilingual who emigrated from Cyprus to the USA can be bicultural.

Based on the above definitions, in the following three studies (Chapters 3, 4 and 5), the Greek-English bilingual children chosen to take part were early bilinguals, either simultaneous or sequential, with at least one of their parents speaking Greek to them. They attended English mainstream school together with a Greek supplementary school programme once a week and mostly use Greek in the home and English at school. Similar to Peets et al (2019) and consistent with the review by Surrain and Luk (2017), our criteria, therefore, in identifying bilingualism are based on use, whereby both languages are used repeatedly by the bilingual child and at the same time taking many of the above factors into consideration.

2.2. Development of Language Skills in Bilingualism

This section focuses on factors that might play a role in the development of vocabulary and grammar skills in bilingual children.

Recent studies often report that bilingual individuals have a smaller vocabulary in each language than their monolingual counterparts of that language (e.g., Oller, Pearson & Cobo-Lewis, 2007). Children from immigrant families reach school age with weak skills in the majority language (Hammer, et al., 2014; McCabe et al., 2013) and at the same time do not possess strong skills in the heritage language (Scheele et al., 2010). This is crucial since there is strong evidence that vocabulary size is a significant predictor of academic achievement and literacy acquisition (Adams, 1990; Kastner, May & Hildman, 2001; Ouellette, 2006; Ricketts, Nation & Bishop, 2007; Rohde & Thompson, 2007; Swanson et al., 2008). Often young bilinguals might show delayed abilities in both of the languages when compared to monolingual counterparts, however they seem to catch up as they become more experienced with the two languages (e.g., Bharick et al., 1994; Hammer, Miccio, & Rodriguez, 2004; Kovelman, Baker, & Petitto, 2008; Oller & Eilers, 2002; Oller, Pearson, & Cobo-Lewis, 2007; Umbel et al., 1992). These findings have been demonstrated extensively in vocabulary knowledge (e.g., Bialystok, 2006; Umbel & Oller, 1994) and have been linked to the *distributed characteristic* of the bilingual speaker (Oller, 2005) or to the *Complementarity Principle* (Grosjean, 2008). Based on this Principle, the vocabulary of a bilingual individual is distributed across the two languages, based on the fact that bilingual individuals often are exposed to and use a language with different people, for different purposes, in different contexts. As a result, bilinguals develop language and context specific lexicons. Hence, vocabulary development (Gathercole, 2007) is affected by language exposure, based on the different contexts bilinguals are exposed to (Oller, 2005).

In language contexts with a majority and a minority language, findings demonstrate that home language use significantly affects children's language skills. For example, Dijkstra et al. (2016) tested 91 preschoolers in receptive and expressive vocabulary in the minority language, Frisian, spoken in the north of the Netherlands, and Dutch, the majority language. The Dutch input was higher for the participants with Frisian as their home language compared to the participants with Dutch as home language receiving Frisian input from the outside community. They found that home language use significantly influenced Frisian receptive and expressive vocabulary, and Dutch expressive vocabulary, but not Dutch receptive vocabulary. Outside home exposure significantly affected the receptive vocabulary scores only.

Strong evidence exists regarding the contribution of the quantity of language input to language growth (Hoff, 2018) as evidenced in the study described in the previous paragraph. Spanish-English simultaneous bilingual children who hear only 20% of their input in one of their languages have substantial vocabularies in that language at 22 months (Hoff et al., 2012), and children who hear 80% of their input in a language have smaller vocabulary than children who hear 100% of their input in a language (Deanda et al., 2016). Receptive skills are usually more advanced than expressive skills in at least one of the bilingual's languages (Gibson et al., 2014; Oller et al., 2007; Ribot & Hoff, 2014), which might be linked to reduced language use and exposure to one or both of the bilingual's languages, compared to monolinguals. Hearing and using each of the languages may affect more the development of expressive than receptive skills (Pham, & Kohnert; 2014; Thordardottir, 2011). This could result in lexical access difficulties, even when the lexical knowledge is there. The argument is that more experience hearing and/or using a language is needed for word production (Yan & Nicoladis, 2009).

In a stable bilingual community, Wales, Rhys and Thomas (2013) assessed the receptive vocabulary in Welsh and English of 207 first language (L1) Welsh, simultaneous Welsh-English and L1 English bilinguals, aged between 7 and 11 years. They also assessed the English receptive vocabulary skills of English monolinguals who formed the control group. By the end of primary school education, L1 English bilinguals and English monolinguals performed closer to age norms than L1 Welsh and Welsh-English simultaneous bilinguals in terms of English vocabulary. No differences were found between the groups of L1 English bilinguals and English monolinguals. However, the L1 Welsh bilinguals and simultaneous Welsh–English bilinguals scored lower than their L1 English bilingual counterparts on English receptive vocabulary and reading tasks. The authors suggest that children's vocabulary and reading skills in their second language (L2), Welsh or English in this case, were not as developed as those of their monolingual peers by 11 years of age and link these findings to classroom practices.

Regarding grammatical skills, Gathercole and Thomas (2009) tested three groups of Welsh-English bilingual children (divided based on the Welsh and/or English language use at home) receptive knowledge of grammatical gender and word order (in addition to Welsh vocabulary). Up to 11 years of age, children speaking only Welsh at home outperformed the other groups on these tasks, with the Welsh-English home children sometimes performing in between the only Welsh home and only English home groups. Similarly, Spanish speaking children in Grades 2 and 5 in Lima, Peru, performed better that Spanish-English bilingual children in Miami Spanish–English in morphosyntactic constructions (e.g., Gathercole 2002a,b,c) revealing a link between performance and amount of exposure to a language.

In the south of England, Papastefanou et al. (2019) tested 40 Greek-English bilingual children in Year 1 and Year 3 on vocabulary, morphological awareness, morphosyntax amongst other skills. The bilingual children were Greek dominant before the age of 4 but English dominant at Year 3. Language use and test scores were strongly correlated in the heritage language, Greek, underlining the importance of heritage language use in the home. The use of the minority language (Greek) had no negative effect on children's English skills.

Other variables might act as significant predictors of bilingual children’s vocabulary and grammar in both of their languages. These could be age, SES, amount of exposure to each language, nonverbal IQ. Lauro et al. (2020) found that age, relative amount of exposure to each language, and phonological memory skill were significant predictors of Spanish-English bilingual 2.5 to 5-year-old children’s expressive vocabulary scores in both of their languages, similarly to previous findings (Hoff, 2018; Parra et al., 2011; Unsworth, 2016). Higher SES children were better than lower SES children (Gathercole 2002a,b,c) and nonverbal intelligence was a significant predictor only for English (majority language). This is in line with Blom (2019) and Hakuta (1987) suggesting a relationship between social contexts, cognitive demands and language learning as well as the actual demands of vocabulary knowledge in this non-linguistic task.

Hoff (2018) states that findings related to the bilingual development in children of immigrant families suggest that bilingual development is supported when exposure to both languages is maintained. Also, this exposure to each language should originate from highly proficient speakers, children should be provided with opportunities to use these languages and the heritage languages should be valued by the society.

2.3 Does Bilingualism affect Cognition?

One of the questions that bilingualism research has sought to address has been how bilingualism affects cognitive and linguistic processes (Kroll & de Groot, 2005). For instance, research suggests that increased metalinguistic awareness (Bialystok, 2001) or delayed onset of dementia might be such outcomes (e.g., Alladi et al., 2013; Bialystok, Abutalebi, Bak, Burke, & Kroll, 2016; Bialystok, Craik, & Freedman, 2007).

2.3.1 Early Studies in Bilingual Cognition

The effects of bilingualism on cognitive development have been researched for almost a century. Psychological research on bilingualism and cognitive abilities began in the early 1920s out of the concern that bilingual children may be linguistically deficient compared to monolinguals, as measured by psychometric tests of intelligence (e.g., Saer, 1923).

However, early studies on the effects of bilingualism did not properly match bilingual and monolingual participants along several dimensions, including SES, second language proficiency (pseudobilingualism), language of assessment, gender, age, and urban–rural contexts (e.g., Peal & Lambert, 1962).

A new era in the research field of bilingualism and a positive approach towards the bilingual experience began with Peal and Lambert (1962). They revealed that bilingual French-English children in Montreal had better scores than monolingual English children on a variety of measures, including intelligence tests and non-verbal intelligence tests, while demonstrating the methodological weaknesses of previous studies. Bilingual children showed an advantage on tests of mental flexibility, which led Peal and Lambert to the suggestion that bilinguals show an advantage in cognitive ability perhaps due to their regular switch between two languages. Peal and

Lambert (1962) made a great methodological contribution to the field of bilingualism concerning the selection and matching of bilingual and monolingual participants (Hakuta & Diaz, 1985).

Since the work of Peal and Lambert (1962), it has been found that bilinguals perform better than monolinguals in a variety of experimental tasks. However, these advantages are not always apparent. The link between bilingualism and cognitive processes, more specifically executive functioning, will be discussed below.

2.3.2 Cognitive Abilities in Bilingualism

Language acquisition involves many cognitive processes (Bialystok, 2001). The acquisition of two language systems in bilingualism requires attentional and executive control in order for the speaker to switch to the target system (Costa, Hernández, & Sebastián-Gallés, 2008). Subsequently, the cognitive outcomes associated with bilingualism have been documented in a number of recent studies (Bialystok, 2017). In general, findings indicate that bilingualism affects cognitive abilities such as attention, metalinguistic awareness, problem solving, working memory, and abstract and symbolic representation skills (Adesope, Lavin, Thompson, & Ungerleider, 2010). The experience of speaking two or more languages on a daily basis has been shown to produce positive changes in cognitive performance (see review in Bialystok, 2009). These advantages in the cognitive abilities of bilinguals are thought to be linked to the fact that this population manages multiple languages and continuously monitors the appropriate language for each communicative situation (Bialystok, 2009). More specifically, bilinguals need to select the right language for each circumstance, attend to cues in order to select the right language, select the suitable lexicon while at the same time suppressing the interference of the other language/s, thus generating executive function advantages (Bialystok, 2017). This constant and regular switching between two languages of a population may be behind the reported bilingual advantage in suppressing and inhibiting.

These two mechanisms of executive functioning will be described in detail in the following section.

2.3.3 Executive Functioning System

The executive functions are a set of control functions that underlie goal-directed behaviour (Bernier, Carlson, & Whipple, 2010). Research in executive functions has roots in neuropsychological studies of people with frontal lobe damage. These patients demonstrated problems with control and regulation of behaviour and had severe issues in their everyday lives. However, these patients had typical performance in cognitive tasks and IQ tests (e.g., Damasio, 1994, cited in Miyake et al., 2000). Though genetics play a significant role in the EF skills of individuals (Friedman et al., 2008), EFs can be improved by training (Karbach & Kray, 2009; Moreno et al., 2011).

The first executive function is *shifting* between tasks or mental sets, which involves shifting back and forth between multiple tasks, operations, or mental sets (Monsell, 1996, as cited in Miyake et al., 2000). This term is also known as attention or task switching. Behavioural tasks that have been used to tap this executive function are the plus–minus task (Jersild, 1927), the number–letter task (Rogers & Monsell, 1995), and the local–global task (Miyake et al., 2000).

The second executive function is *updating,* which involves monitoring and coding of the relevant incoming information to each task/context and then appropriately updating the old, no longer relevant information held in working memory, with newer, more relevant information (Morris & Jones, 1990). Updating does not only maintain task-relevant information but dynamically manipulates working memory contents. Some of the experimental tasks used to tap the updating function are the keep track task (Yntema, 1963), the letter memory task (Morris & Jones, 1990), and the tone monitoring task.

The third executive function is *inhibition*, which is the ability to inhibit automatic or dominant responses when they are inappropriate for the task/context (Miyake et al., 2000; St Clair-Thompson & Gathercole, 2006; Toplak et al., 2013) and to suppress interfering information (Barkley, 1999; Bexkens et al., 2015). Tasks tapping inhibition are the Stroop task (Stroop, 1935), the antisaccade task (Hallett, 1978), and the stop-signal task (Logan, 1994). These tasks measure someone’s sensitivity to interference, which is computed as the difference in reaction times to performance in congruent trials and incongruent trials. These differences are called conflict or congruence effects (Stroop effect in the case of the Stroop task, for more details see Chapter 3). In the case of bilinguals, they are hypothesised to outperform monolingual counterparts in accuracy and response times in incongruent trials, while at the same time exhibiting a smaller conflict effect. A smaller conflict effect would be an indicator of better inhibition.

According to Bialystok and Craik (2010) the development of the executive functioning system is the most crucial cognitive achievement in early childhood. EFs are important for learning and memory (McCauley et al., 2010) and have been linked to academic achievement in reading and math for a variety of age groups (Becker et al., 2014; Foy & Mann, 2013; Fuhs et al., 2014; McClelland et al., 2007; St Clair-Thompson & Gathercole, 2006). The ability to control attention, inhibit distraction, monitor sets of stimuli, expand working memory, and shift between tasks develops gradually in childhood. At the same time these cognitive processes are the first to decline in aging.

Researchers have investigated executive functioning in bilingual children (Bialystok & Martin, 2004), young adults (Costa, Hernández, & Sebastián-Gallés, 2008), and older adults (Gold, Kim, Johnson, Kryscio, & Smith, 2013). Some of these studies (e.g., Bialystok, Craik, & Luk, 2012; Bialystok & Martin, 2004; Costa et al., 2008, Kroll & Bialystok, 2013) have found that bilingual populations outperform monolinguals on tests of executive functioning. This is considered as a bilingual advantage in executive functions (Bialystok, 2001; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Ryan, 2006; Emmorey, Luk, Pyers, & Bialystok, 2008) and is noted as a superior performance by bilinguals in tasks that require executive processing (Bialystok, 2006; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Luk, 2008; Costa et al., 2008) such as the ones described here. However, many studies have reported mixed or null findings when comparing bilingual groups to monolingual ones (Lowe et al., 2021)

For example, a smaller conflict effect was found in bilingual young adults (Bialystok, 2006), children (Bialystok, Martin, & Viswanathan, 2005; Martin-Rhee & Bialystok, 2008) and the elderly (Bialystok, Craik, Klein, & Viswanathan, 2004) compared to their monolingual counterparts. In addition, Costa et al. (2009) investigated how bilinguals perform in response conflict and if there is a bilingual advantage. They stated that bilinguals had better overall reaction times compared to the monolingual control group, but only when the task demanded high monitoring; however, they did not find better conflict resolution when comparing the two groups. Kousaie and Phillips (2012) examined young adults and older adults in the Stroop, Simon, and flanker task and found no differences. Additionally, Kirk, Fiala, Scott-Brown, and Kempe (2014) found no differences in the Simon task between older Gaelic-English bilinguals and older English monolinguals. It has also been observed that better executive function is larger in older adults than younger ones (Bialystok et al., 2007; 2014).

Similarly, in children the results have been mixed (e.g., Antón et al., 2014; Gathercole et al., 2014). For example, Gathercole et al. (2014) investigated Welsh-English fully fluent, simultaneous and early sequential bilinguals, from childhood through adulthood as well as English monolinguals. They tested 650 children in seven age groups (from 3 years to over 60 years of age) on executive function tasks, such as cart-sorting, Simon, and metalinguistic tasks. Additionally, participants were administered English and Welsh grammar and vocabulary tests, general and cognitive abilities tests. Parents and participants filled in questionnaires including language use at home and at school, parental language, and socioeconomic information of the parents. The authors did not observe a bilingual advantage in their study. More specifically, the results from the metalinguistic tasks were not in favour of the bilingual advantage contrary to predictions. In the above tasks, differences were found only in the participants who were tested in their dominant language performing better than the participants who were less dominant in that language. The card sorting tasks failed to reveal an overall bilingual advantage while the Simon task had neutral results or monolinguals outperformed bilinguals in accuracy or reaction times. The researchers argue that in many previous studies participants were L2 bilinguals and not simultaneous bilinguals. Finally, they summarize that mechanisms in previous studies, where bilinguals performed better compared to their monolingual counterparts, might be less relevant to this sample of simultaneous or early sequential bilinguals.

2.3.4 Bilingual Effect in Children

This section focuses specifically on studies investigating bilingual children since this thesis explores the skills of Greek-English bilingual children.

Many studies have repeatedly reported a bilingual effect in executive functions. For example, Bialystok (1999) reports that bilingual children showed better attentional control involving shifting between different task criteria. This study investigated 30 English - Chinese bilingual and English monolingual children 3-5 years old and 30 English - Chinese bilingual and English monolingual children aged 5-6 years old using the Dimensional Change Card Sort (DCCS) task (Zelazo, Frye, & Rapus, 1996). Results revealed that bilingual children gave more target responses compared to their monolingual counterparts, indicating higher levels of executive control, and suggesting that bilingualism aids the development of attentional control in task rule shifting. Similar findings were presented by Bialystok and Martin (2004). In another study, 24 bilingual and 24 monolingual 6-year-olds were comparable in identifying a simple shape hidden within drawings of complex objects in the Children's Embedded Figures Task, but the bilingual children were more able to change their interpretation of the two figures (e.g., the duck-rabbit) to acknowledge the other image in an ambiguous figures task (Bialystok & Shapero, 2005). Both tasks required perceptual analysis, but only the ambiguous figures task required inhibiting the original meaning of the stimulus.

In line with the above, Carlson and Meltzoff (2008) aimed to investigate if there was an advantage in executive functioning, previously observed in other languages, in 6-year-old Spanish-English bilingual children attending second-language immersion and traditional kindergartens. The bilingual children showed an advantage in executive-function tasks that require inhibition of attention to conflicting response options but not in tasks requiring inhibition of a habitual response to a familiar stimulus. Extending this pattern to infants, Kovács and Mehler (2009) investigated 40 preverbal 7-month olds; 20 infants raised in bilingual homes (14 infants exposed to Italian-Slovenian, 2 to Italian-Spanish, 2 to Italian-English, 1 to Italian-Arabic,1 to Italian-Danish) and 20 in monolingual Italian homes. The infants brought up in bilingual homes were better able to switch responses after a change in the requirements of the task compared to their monolingual counterparts.

Additionally, Yang, Yang, and Lust (2011), in order to separate language effects and cultural effects, compared 15 Korean-American bilinguals, 13 Korean American (English-speaking) monolinguals, Korean monolinguals, and non-Korean-American (English-speaking) monolinguals, five years of age. Overall, the bilingual group was faster and more accurate compared to the monolinguals on all conditions of the Attentional Network Task (ANT), suggesting a bilingual advantage.

Finally, Poarch and van Hell (2012) found benefits of trilingualism on the Simon task and a bi- and trilingual advantage for the ANT. They investigated four groups of children 5-8 years of age using the Simon task: i) German-speaking monolingual children, ii) German speakers who were learning English as a second language (L2) in school (second language learners), iii) German-English bilingual children, and trilinguals for whom either German or English was a native language along with a different language, and who were learning German or English or both at school. Findings for the Simon task provided evidence of a trilingual advantage compared to monolinguals and a strong trend towards a benefit for bilinguals compared to monolinguals. Bilinguals and trilinguals did not differ, nor did any other pairs. The L2 learners, the bilingual children and the trilingual children only took part in the ANT, six to eight months after the Simon task (Poarch & van Hell, 2012). Results showed no significant difference between bilingual and trilingual children; however, they both outperformed the L2 learners with regards to incongruent trials. There was no significant difference in response times across all children, irrespectively of language status.

Large scale studies have tended to show weaker or no effects compared to smaller sample studies (Valian, 2015). For example, two recent large-scale studies, presented below, did not report any effects of bilingualism. More specifically, Antón et al. (2014) compared 360 bilingual Spanish and Basque children to Spanish monolingual children on the ANT. The researchers divided the children into three groups; i) children in 2nd and 3rd grade, ii) children in 4th and 5th grade, and iii) children in 6th and 7th grade. The first language of the bilingual children was Spanish and based on parental report the children were more fluent in Spanish compared to Basque. In addition, the bilingual children attended bilingual schools where Spanish and Basque were equally used as the languages of instruction. Their monolingual peers attended monolingual Spanish schools and they did not differ in age, reading and arithmetic skills, non-verbal IQ, and socioeconomic status (SES) compared to the bilinguals. No differences were found between the monolingual and bilingual groups. In their discussion, the authors noted that the absence of a bilingual advantage might be a result of uncontrolled factors and conditions associated with design and procedure.

In line with the above findings, Duñabeitia et al. (2014) using a non-verbal and a verbal Stroop task in the Spanish language compared 504 monolingual Spanish and bilingual Spanish-Basque children. The children were enrolled in the 3rd to 8th grade. The findings suggested that the participants did show a cost of incongruence; however, the two groups of participants were comparable. Additionally, the distribution of reaction times, overall reaction times and error rates were parallel for both bilinguals and their control group. Finally, in the regression analyses there was no effect of language status, teachers' judgments of children's reading, arithmetic, or attention skills, or IQ scores. In their discussion, the authors stated that they covered factors such as age, scores from teachers regarding reading, mathematics, and attention, general IQ test, and SES. Therefore, their groups differed only in linguistic profile; more specifically one group of children was immersed in bilingual (academic) context and the second consisted of purely monolingual children. No evidence of a bilingual advantage was observed (see also Paap & Greenberg, 2013).

Similar to the above findings, Goldman, Negen, and Sarnecka (2014) recruited 32 English monolingual children and compared them to 40 bilingual children who were exposed to two languages other than English at home and to 20 bilingual children who were exposed to one extra language in addition to English. The children took part in a numerical discrimination task, tapping inhibitory control. The findings revealed no differences between the groups. In line with the above results, Kapa and Colombo (2013) found no group differences using the Flanker task with early and late Spanish-English bilingual children as well as their English monolingual control group aged 6-15 years.

Additionally, mixed results were presented by Poulin-Dubois et al. (2011). In this study, a partial bilingual advantage was observed in the shape Stroop task, a conflict task, one of the five tasks (two delay and three conflict tasks) used to measure executive functions in 33 bilingual and 30 monolingual two-year-olds. This suggested that a bilingual advantage in executive functions is first expressed in conflict inhibition. A bilingual effect was not found in the other two conflict tasks, possibly due to increased demands of those tasks or to them requiring both inhibitory control and working memory. An advantage in inhibitory control was found in simultaneous 7-month old bilinguals when readily supressing the previously learned response and updating their predictions according to the changing requirements of the task, compared to monolinguals (Kovács & Mehler, 2009). Advantages in other executive functions were observed in slighter older children, 3-4 ½ years of age (Bialystok et al., 2010) suggesting that it might be possible that more language experience is necessary to observe a bilingual advantage in switch-tasks due to the fact that the experience of infants has been primarily in receptive language rather than expressive language.

2.3.5 Bilingual executive advantage (BEA) hypothesis

This so-called bilingual advantage has attracted much research attention (see Bialystok, 2017) and has been the centre of wide debate (Duñabeitia & Carreiras, 2015; Paap, Johnson & Sawi, 2015). In general though, there is a lack of detailed and falsifiable theory on the underlying mechanisms of a bilingual advantage in executive functions (Laine & Lehtonen, 2018).

Green (1998) proposed the Inhibitory Control Model which highlights the role of inhibition of the non-target language in resolving interference between two languages. Language-switching studies in bilinguals provide evidence for the above role of inhibition. For example, Meuter and Allport (1999) found that switching into the dominant first language was slower than switching into the non-dominant second language. This can be explained in terms of inhibition since more cognitive control is needed for the dominant, highly activated language, which takes more time. This language dominance is explained as relative proficiency in each language of the bilingual individual (Costa & Santesteban, 2004; Philipp, Gade, & Koch, 2007; Schwieter & Sunderman, 2008; Verhoef, Roelofs, & Chwilla, 2009). On the one hand, studies (Philipp et al., 2007; Schwieter & Sunderman, 2008) show that a larger switch cost is observed in unbalanced bilinguals for the dominant than for the non-dominant language, whereas on the other hand similar switch costs for both languages are found in balanced bilinguals (Costa, Santesteban, & Ivanova, 2006). Timmer, Christoffels, and Costa (2019) argue that this switch cost might be influenced by the frequency of the dominant and non-dominant language use during the switching task or shortly after the task (Declerck & Grainger, 2017).

In their review, Hilchey and Klein (2011) analysed empirical data on nonlinguistic interference tasks (e.g., ANT, Simon task) to evaluate the inhibitory processing in bilinguals and whether there is an advantage favoring the bilinguals in inhibition. They name this bilingual advantage in inhibitory control processes, the *bilingual inhibitory control advantage*. More specifically, they reviewed 31 experiments and observed a more widespread advantage in EFs, with a faster performance by bilinguals, which they name a *bilingual executive processing advantage.* They explain that this widespread advantage in reaction times is consistent from childhood to old age and it would originate from the need to monitor and select competing linguistic representations.

Paap (2018a) proposed the Controlled Dose hypothesis, according to which the bilingual advantage might only be present during a specific period of L2 acquisition, when the L1 is clearly stronger than the L2 and bilinguals are still in the process of learning how to manage their two languages. In this case constant monitoring and inhibition of the non-target language is needed. When bilinguals have had sufficient training in controlling language selection, then cognitive control might not be required since this selection has become automatic. Hence, any potential increase to executive functions would be evident in these early stages of L2 acquisition. This is a new hypothesis that still needs further investigation (Laine & Lehtonen, 2018).

Another model on executive processing in the bilingual mind is the Adaptive Control hypothesis (Green & Abutalebi, 2013). It states that the type of language-use context, namely single-language (where each language used in its own context, e.g. at home and at work), dual-language (each language used with different conversation partners), or dense code-switching context (the two languages are often interleaved within single utterances), determines the recruitment of the relevant executive control networks. More specifically, a dual-language context where each language is used with different communication partners would boost executive functions, in contrast to dense code-switching and single-language contexts. Hartanto and Yang (2016) tested this hypothesis and observed executive advantages for bilinguals who used both languages within the same communicative contexts. Furthermore, they found that intersentential switches (language switches at phrasal, sentence, or discourse boundaries) were more demanding for executive functions than intrasentential ones (switching language in the middle of a sentence).

Valian (2015) states two possibilities for the contradictory results in the study of executive functions in bilinguals. Firstly, she states that it may be the case that there is a bilingual advantage in executive function tasks in specific populations (depending on the composition and demographics of each group, e.g., age of acquisition, levels of language proficiency, etc). However, there is another possibility, namely that there is no cognitive benefit of bilingualism at all. Instead, findings showing a supposed advantage might occur due to confounding factors such as SES or due to correlations of bilingualism with other properties that might be difficult to separate. According to the latter analysis, studies that control for such factors do not report results showing a bilingual advantage. For example, Morton and Harper (2007) tested 17 French-English bilingual children 6 to 7 years of age and compared them with 17 monolingual cohorts. The children were similar in age, gender, general intelligence, language vocabularies, language use, SES and ethnicity. Both bilingual and monolingual groups showed similar performance in the Simon task, where they were slower and more prone to mistakes on incongruent trials compared to the congruent ones. However, Bialystok (2009) rejected this claim, explaining that, at least in her research, SES was controlled by sampling the bilingual and monolingual children from the same schools in economically homogeneous middle-class neighbourhoods (Bialystok, 2010).

2.3.6 Possible reasons underlying contradictory findings

As shown in the previous sections, while there is a large body of research showing bilingual advantages (see Valian, 2015 for an overview), the field has not reached a consensus due to inconsistent findings. Several factors have been found to be relevant to this bilingual effect in executive functions. Some studies show bilingual advantages in particular tasks, conditions of those, or in measures such as accuracy or reaction times, but not both (Valian, 2015). Results seem dependent on types of stimuli (e.g., verbal–nonverbal; Moreno-Stokoe & Damian, 2020). Also, the participants might get different amounts of physical exercise or might have had some other beneficial experience (e.g. musical training; Valian, 2015), or differ in terms of SES. Another, very important factor is the actual definition of bilingualism and how this is determined in each study. Bilinguals might differ in many aspects related to age of acquisition, language use, proficiency in each language, medium of education, bilingual experiences, culture (e.g., Adesope et al., 2010; Antoniou et al., 2016; Carlson & Meltzoff, 2008; Paap, Johnson & Sawi, 2016). Finally, De Bruin, Treccani, and Della Sala (2015) found a publication bias to report a bilingual effect.

Musical ability

Both bilingualism and musical activities involve coordination of multiple abilities and domains of performance. This consistent exposure to a context where higher-level cognitive function is constantly required may contribute to advanced cognitive performance. Higher-level cognition is theorized to be required for both skills, such as working memory to maintain and manipulate semantic information (e.g. notes, mechanics, rhythms in music; words, syntax, and timing in language) and inhibitory control to block or ignore competing information internally or from the environment (e.g. external noise, irrelevant notes or words). It is plausible that expert musicians or language speakers, both of whom typically have spent at least ten years practising their skills, demonstrate enhanced cognition compared to untrained individuals. The possible enhancement of cognitive functions in these two populations has been captured in the executive function model in musicians (Hannon & Trainor, 2007) and the inhibitory control model in bilinguals (Bialystok, 2009), which was followed by a more general global cognitive model (Bialystok, 2011).

SES

Bilinguals might differ from monolinguals or other bilingual participants in socioeconomic factors, such as education, immigrant status and profession (Paap, Johnson & Sawi, 2015). The observed correlation between SES and executive functions may be due to the link of SES with the provision of emotional and academic resources in childhood (Linver, Brooks-Gunn & Kohen, 2002). Morton and Harper (2007), argued that previous studies did not appropriately match participants on SES, with the consequence that higher-SES children were being compared with monolingual children from low socioeconomic backgrounds. Some studies matching language groups on SES report a bilingual effect. For example, Engel de Abreu et al. (2012) compared 40 Portuguese-Luxembourgish bilinguals and 40 Portuguese monolinguals from low-income immigrant families using flanker interference tasks. In line with Bialystok (1991; 2001; 2009), Engel de Abreu, et al. (2012) found that regardless of the low-income background, this continuous use of executive functioning skills to resolve language conflict strengthened these processes in bilinguals. The results suggest that the higher the control demand of the task, the more likely it is that a bilingual effect will emerge.

Similarly, Calvo and Bialystok (2014) divided children from eight public schools into four groups which were: i) working-class monolinguals (n=20), ii) bilinguals (n=44), iii) middle-class monolinguals (n=46), iv) middle-class bilinguals (n=65) based on questionnaire data on SES and on language status. The children spoke English at school and another language at home. The tasks included an intelligence test, language tests, a working memory task and a flanker task (Calvo & Bialystok, 2014). Middle-class children outperformed working-class children on all measures, and monolingual children outperformed bilingual children on language tests. Bilingual children scored higher than monolingual children on the executive functioning tasks.

Other studies closely matching bilingual and monolingual participants on SES found no bilingual advantage (Farah & Noble, 2005; Noble, Norman, & Farah, 2005; Morton & Harper, 2007; Paap, Johnson & Sawi, 2015).

Linguistic factors of bilingualism

Namazi and Thordardottir (2008) suggested that the way in which bilingualism is defined might vary across studies making them difficult to compare. Other factors that might yield different findings might be the language background of the participants, including language exposure and language use, language of schooling, and proficiency in both languages (e.g., Bialystok & Barac, 2012; Crespo, Gross, & Kaushanskaya, 2019; Iluz-Cohen & Armon-Lotem, 2013; Kubota, Chevalier, & Sorace, 2020; Kuzyk et al., 2020).

Language exposure and language use can be linked to the frequency of input and output a child might receive and produce (number of hours in a day, percentage of use of language and in which context). It has been shown that reduction in exposure to the L2 contributed to smaller improvement in monitoring and updating abilities, however it did not affect the inhibition domain (Kubota et al., 2020).

In terms of language of schooling, Purić, Vuksanović, and Chondrogianni, (2017) compared Serbian children in Year 2 attending a high exposure L2 immersion program (about 5 hours of daily exposure for one year), a low exposure immersion program (about 1.5 hours of daily exposure for one year), and a monolingual control group. The high exposure group outperformed the other two groups in working memory tasks, but there were no group differences for the inhibition and shifting domain. Similarly, initial findings of a recent pilot study based in Wales suggest that children receiving minimal exposure to Welsh for a year are faster than their English monolingual counterparts in a backwards digit recall task tapping on working memory (Papastergiou, Sanoudaki, & Collins, 2019). Based on Purić et al. (2017), working memory (updating) may be specifically linked to these early stages of intensive L2 learning.

The monolingual participants in many studies speak and are exposed to only one language, are truly monolinguals, especially when very young and have not started to learn a second language as part of the educational curriculum of their country. Such cases are English monolingual participants and Welsh monolingual participants in studies such as Vihman et al. (2007) and English monolingual participants in Rhys and Thomas (2013). However, when English monolingual children were recruited in Canada, they have had some access to a second language, but this was not further explained (e.g., Barac & Bialystok, 2012). More frequently, when non-English monolinguals are recruited as control groups in countries where English is not an official language, it is stated that monolinguals do not have fluent knowledge of another language (e.g., Antón et al., 2014; Duñabeitia et al., 2014), but no further information is provided about exposure to an L2 English program in school which is the norm in the first grades of primary school around the world (e.g., European Commission, 2019). This again highlights the difficulty defining bilingualism and the importance of taking all these variables into consideration.

Language proficiency has also been linked to executive functions. Iluz-Cohen and Armon-Lotem (2013) found that balanced high-proficiency, L2-dominant, and L1-dominant bilingual children performed better than their balanced low-proficiency counterparts on inhibition. The balanced high-proficiency and L2-dominant bilingual children outperformed the other two groups on shifting. However, Kubota et al. (2020) found that proficiency did not affect the development of executive functioning skills in childhood.

Fluent bilingual settings and minority and majority languages

Gathercole et al. (2014) propose that it might not be a coincidence that fluent bilinguals within bilingual communities such as Welsh-English bilinguals (Gathercole et al., 2014) and Basque-Spanish bilinguals (Antón et al., 2014; Duñabeitia et al., 2014) showed either no or mixed bilingual effects. These bilinguals are brought up with both languages as part of everyday life in their respective bilingual communities in Wales and the Basque country. It has been suggested by Lam and Dijkstra (2010) that these populations have strong between-language links and a great automaticity of the linguistic knowledge in both languages. As a result, the daily switch between both languages might not require the same cognitive effort and control, consequently not leading to bilingual effects in executive functions. However, other studies including participants speaking minority languages within bilingual communities (e.g., Sardinian and Italian; Garraffa, Beveridge, & Sorace, 2015) do show advantages, but in most cases only one test was used to tap one executive function not leading to general theoretical implications.

Publication bias

Finally, a study by De Bruin, Treccani, and Della Sala (2015) examined abstracts from conferences between 1999 and 2012. The authors observed that studies which reported a full bilingual advantage in executive control were most likely to be published, followed by those either supporting or challenging this bilingual advantage. In contrast, those that argued against the bilingual advantage were the ones to be less published. This did not have any relation to differences in sample size, tests used, or statistical power, thus suggesting the existence of a publication bias. This is in line with Paap et al. (2014), who raised the concern that the literature based on executive control in bilinguals may be influenced by this bias to report a bilingual advantage. As a result, many studies that have not found evidence suggesting a bilingual advantage might have not reached publication and their hypotheses and methodologies have not enhanced our knowledge on executive functioning.

2.4 General Statement of the Problem

A large amount of recent studies show bilingual advantages in both children and adults in executive functions (e.g., Calvo & Bialystok, 2014; Engel de Abreu et al., 2012) due to long-term experience in dual-language management. However, despite extensive investigation during the past twenty years and a persistent debate regarding the existence of a bilingual advantage in the EF skills of bilingual children, these findings favouring the bilingual advantage are not consistent; namely bilinguals might perform better, worse or similarly in EF tasks compared to their monolingual counterparts (Paap, Johnson, & Sawi, 2014).

At the same time, though vocabulary and grammar skills have been assessed in several bilingual populations speaking a majority and minority language (e.g., Hoff, 2018; Parsons & Lyddy, 2009; Rhys & Thomas, 2013; Scheele, Leseman, & Mayo, 2010; Sheng et al., 2011) in relation to a number of related variables such as age, language exposure and SES, to the best of our knowledge no other study has explored the role of supplementary educational setting on the Greek and English language skills of Greek-English bilingual children. The school we visited offered a Greek-speaking supplementary program for 2.5 to 3.5 hours a week to enhance the reading, listening, speaking and writing skills in the Greek language and to offer knowledge around the Greek culture. The above review gave rise to the following research questions:

1. Do Greek-English bilingual children outperform two monolingual control groups in EF tasks when matching them on many relevant variables? This will be explored in more detail in Chapter 3.

2. Can a different method cover more holistically the investigation of EF skills in these bilingual children? This will be explored in more detail in Chapter 4.
3. What variables affect vocabulary and grammar skills in both languages of these bilingual children and does the exposure to a supplementary school setting affect these scores? This will be explored in more detail in Chapter 5.

The current thesis investigates the EF skills as well as the language skills of Greek-English bilingual children attending a Greek supplementary school in England. Performance in EF tasks of the bilingual children is compared to that of Greek monolingual and English monolingual control groups. This thesis has three aims: i) to investigate the performance of Greek-English bilingual children in EF tasks compared to monolingual Greek and monolingual English children after closely matching them on a large number of relevant variables (Chapter 3), ii) to propose a novel approach to evaluate the EF performance of bilingual and monolingual children (Chapter 4), and iii) to explore the variables that might affect scores in language tasks of expressive/receptive vocabulary and receptive grammar of the Greek-English bilingual children attending a Greek supplementary school in England and investigate if and how the exposure to a supplementary school setting affects these scores (Chapter 5).

We use an array of executive functioning tasks which tap into inhibition, updating and shifting, as operationalised by Miyake et al. (2000). These are the *Attentional Network Task* (ANT; Fan et al., 2002), the *Counting recall task*, which was an adaptation of the Automated Working Memory Assessment (Alloway, 2007), the *Backward digit span task*, adapted from Huizinga, Dolan, & Van der Molen (2006), the *Nonverbal Stroop task*, adapted from Lukács, Ladányi, Fazekas, & Kemény (2016) and the *Colour-Shape task*.

We use k-means nearest neighbour methods to match bilingual to monolingual children on a wide array of control variables. In particular, we control for language proficiency in both languages using receptive and expressive vocabulary and grammar tasks, such as the *British Picture Vocabulary Scale*, Third Edition (BPVS3; Dunn & Dunn, 2009) and the *Picture Word Finding Test* (PWFT; Vogindroukas, Protopapas, & Sideridis, 2009). Further language and social background information of the children is obtained through the Language and Social Background Questionnaire for Children (LSBQ; Luk & Bialystok, 2013).

We also use frontier methodologies which allow us to jointly consider multiple tests and metrics in a new measure; the technical efficiency (TE) (Chapter 4). We use a Data Envelopment Analysis technique to estimate technical efficiency of the bilingual and monolingual children's performance. In a second-stage we compare the TE of bilingual and monolingual children using an ANCOVA, a bootstrap regression and a k-means nearest neighbour technique, while controlling for differences on age, intellectual ability, grammar/language/vocabulary skill, SES and language use. We compare the TE approach to an alternative dataset in a related topic (Antoniou et al., 2016).

Chapter 3 - A study on the executive functioning of Greek-English bilingual children.

Abstract

Findings of bilingual participants outperforming their monolingual counterparts in executive functioning tasks, namely showing a bilingual advantage, have been repeatedly reported in the relevant literature (Bialystok, 2017). However, uncontrolled factors or imperfectly matched samples might affect the reliability of these findings (Antón, Carreiras, & Duñabeitia, 2019). The current study aims to take into account recently identified relevant variables in combination with innovative analyses to investigate the performance in executive functioning tasks of one unstudied language group, Greek-English bilingual children in the north of England, compared to two control groups of monolingual Greek children in Greece and monolingual English children in the north of England. Our battery of executive function tasks taps into inhibition, updating and shifting, as operationalised by Miyake et al. (2000). We use k-means nearest-neighbour methods to match bilingual to monolingual children on a wide array of variables, including age, socioeconomic status, Greek and English proficiency. We control for language proficiency in both languages using receptive and expressive vocabulary and grammar tasks, as well as parental ratings of the children's proficiency in both languages. We use a factor analysis on four indicators of language proficiency to reveal one factor which we interpret as proficiency in English and Greek, closely matching on language background information that we obtained from both objective and contextual factors. Our results suggest that bilinguals' accuracy on executive function tasks is on a par with their monolingual peers. However, bilinguals are faster in the inhibition and the working memory task when compared to their English monolingual counterparts. Our study provides strong evidence for the presence of a bilingual advantage in these domains, while making important methodological contributions to the field.

Keywords: executive function, supplementary school, Greek, English, bilingualism, language skills, language use, k-means

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3.1 Introduction

As presented in Chapter 2, many recent studies have focused on childhood bilingualism and executive control, showing that bilingual children outperform their monolingual peers on executive functioning tasks (see Adesope et al., 2010; Bialystok, 2017). This is considered as a bilingual advantage in executive functions (Bialystok, 2001; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Ryan, 2006; Emmorey, Luk, Pyers, & Bialystok, 2008) and has been observed in cognitive control tasks such as selective attention (Bialystok, 2001), cognitive flexibility (Poulin-Dubois et al., 2011) and working memory (WM) (Morales, Calvo, & Bialystok, 2013). However, other studies have tended to show weaker or no effects of bilingualism (e.g., Valian, 2015).

The executive functioning system is a set of control functions, vital for the flexibility and regulation of cognition and goal-directed behaviour (Best & Miller, 2010). It is referred to as the most crucial cognitive achievement in early childhood (Bialystok & Craik, 2010). Children gradually master the ability to control attention, inhibit distraction, monitor sets of stimuli, and shift between tasks, while their working memory develops. More specifically, *shifting* involves shifting back and forth between multiple tasks, operations, or mental sets (Monsell, 1996, as cited in Miyake et al., 2000). *Updating* includes monitoring and coding task-relevant information and replacing any no longer relevant information held in working memory with the new, more relevant information (Morris & Jones, 1990). Lastly, *inhibition* is the ability to knowingly inhibit dominant, automatic, or prepotent information (Miyake et al., 2000).

The advantages in executive functions associated with bilinguals is noted as a superior performance by bilinguals in tasks that are thought to require executive processing, which is the ability to monitor goal-setting cues, to switch attention to goal-relevant sources of information, and to inhibit those that are irrelevant or competing (Bialystok, 2006; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Luk, 2008; Costa et al., 2008). These advantages are thought to be linked to the management of multiple languages and to the continuous monitoring of the appropriate language for each communicative situation (Bialystok, 2009). More specifically, bilinguals need to select the right language for each circumstance, attend to cues in order to select the right language, select the suitable lexical set and at the same time suppress the interference of the other language/s. This process is thought to generate executive functioning advantages (Bialystok, 2017).

There have been several meta-analytic reviews regarding the cognitive outcomes of bilingualism (e.g., Adesope et al., 2010; Hilchey & Klein, 2011; Hilchey, Saint-Aubin, & Klein, 2015; Lehtonen et al., 2018) reporting mixed results in adults. More specifically, Adesope et al. (2010) analysed data from 63 studies and found positive effects of bilingualism, including increased attention, working memory, metalinguistic awareness, and abstract and symbolic representation skills, however there was high variability in terms of effect sizes, especially for attentional control. For inhibition, Hilchey and Klein (2011) found a global bilingual performance advantage, however insufficient evidence was provided for a bilingual effect in inhibition. Hilchey, Saint-Aubin, and Klein (2015) in their re-analysis of the Hilchey and Klein (2011) study included more recent studies, this time not observing a global bilingual performance advantage.

Similar mixed findings are reported in studies examining the executive functioning skills of children. Overviews by Bialystok and colleagues (Bialystok, 2015; Bialystok et al., 2012) suggest that the bilingual advantage can be mostly observed in children and elderly, possibly due to the fact that these two populations are not at the peak of their executive functioning skills as young adults are. Bialystok and colleagues agree with the idea that this advantage could be more general rather than linked to a specific executive domain such as inhibition (Bialystok, 2015; Bialystok et al., 2012). However large-scale studies are not in line with this suggestion in other official bilingual settings such as the Basque country and Wales, where limited or no evidence of a bilingual advantage has been found (Antón et al., 2014; Duñabeitia et al., 2014; Gathercole et al., 2014).

As discussed in Chapter 2, several factors have been found to be relevant to this bilingual effect in executive functions, such as: i) musical ability (Hannon & Trainor, 2007), ii) SES (Paap, Johnson & Sawi, 2015), iii) the language background of the participants, including language exposure and language use, language of schooling, and proficiency in both languages (Kubota et al., 2020), iv) fluent bilingual settings and minority and majority languages (Gathercole et al., 2014), v) publication bias (De Bruin, Treccani & Della Sala, 2015).

3.2 Current Study

It is evident from the previous section that matching bilinguals with a monolingual control group/s has proven challenging, especially due to the variability within bilingual groups. Despite numerous studies investigating the cognitive effects of bilingualism, it is still not clearly understood which factors influence executive functioning and in what way. In the current study, we aim to control for relevant variables using innovative analyses in order to investigate the performance in executive functioning tasks of one unstudied language group of Greek-English bilingual children in the north of England. Our battery of executive function tasks taps into inhibition, updating and shifting, as operationalised by Miyake et al. (2000).

Bearing in mind previous studies on bilingualism and executive functions, we compare our Greek-English bilingual group to two monolingual control groups from both language backgrounds; namely a control group of monolingual Greek-speaking children and a control group of monolingual English-speaking children. To the best of our knowledge no studies have controlled for both languages of the bilingual group of children. In our study we control for both languages, Greek and English, using factor analysis to take as many variables as possible into consideration, such as language proficiency, language use and standardised vocabulary and grammar tasks. The group of bilingual children taking part in the current study attend a Greek complementary language school, a group not studied before in the U.K. for their executive functioning skills linked to language (for information about this type of schools see Chapter 5). The majority of these children are predominately exposed to Greek in the household and English at school.

In combination to this, we use innovative analyses to control for as many variables as possible, a challenging issue in the study of bilinguals, and more specifically bilingual children. As a result, we aim to inform the debate and models of executive functions in relationship to bilingualism. More specifically, we aim to answer the following research question: Do Greek-English bilingual children outperform two control groups of monolingual Greek children and monolingual English children in executive functioning tasks tapping into inhibition, updating and shifting, when closely matched on recently identified relevant variables?

3.3 Method

3.3.1 Participants

19 Greek-English bilingual children, 15 Greek monolingual children and 25 English monolingual children, aged 63-108 months took part in this study. Details of the groups are presented in Table 1. The bilingual children were competent in both Greek and English languages to varying degrees. The Greek-English bilingual children lived in England and were recruited if at least one of their

parents used Greek with them. The mean age of acquisition was 5 months (*SD* = 1 year and 2 months) for Greek and 2 years and 6 months (*SD* = 2 years and 2 months) for English. Four children had one English speaking and one Greek speaking parent and 15 children had only Greek speaking parents. We have excluded any trilingual participants. A further three children took part but were subsequently excluded because they did not meet the language criteria (they were exposed to a third language). Also, children's scores were included in the analysis if their nonverbal intelligence score was within normal range (over 80; Kaufman & Kaufman, 2004). In this case, all children had standardised scores over 80 (*M* = 100.77, *SD* = 14.44). Children included had limited or no musical training. The SES was average and above average. Based on parental and teacher reports the children did not have any hearing, behavioural, emotional, or mental impairment.

Bilingual Greek-English children were recruited from a Greek supplementary school in the north-west of England. The school offers a Greek-speaking supplementary program for 2.5 to 3.5 hours a week to enhance the reading, listening, speaking and writing skills in the Greek language and to offer knowledge around Greek culture. All children attended a Greek supplementary school and mainstream English school. This programme is supplementary to the mainstream English education that these children attended. Eight of the bilingual children were born in Greece and had lived in England for at least two years at the time of the study, while remaining bilingual children were born in England. The English monolingual control group was recruited from an infant school in the north-west of England and all the children were born in England. The Greek monolingual control group consisted of children born and based in Greece.

Ethical approval was granted by the College of Arts and Humanities Research Ethics Committee at Bangor University. Information sheets were sent to the head teachers and to parents and informed consent was obtained before the collection of data. Teachers, parents, and children were provided enough time to ask any questions about the nature of the study. Parents and children were informed that they could withdraw at any time and were subsequently debriefed after the study.

Table 1 *Participant information: parent questionnaires and scores on language and IQ tests (raw scores reported for tests)*

		Language Group		
Variable		**Bilinguals**	**Greek Control**	**English Control**
Age in months	*N*	19	15	25
	M (SD)	84.89 *(15.39)*	88.47 *(13.69)*	78.16 *(5.83)*
	Range	63 - 108	68 - 108	67 - 88
Sex		11f 8m	7f 8m	12f 13m
PWFT	*M (SD)*	36.95 *(24.28)*	77.6 *(8.36)*	
	Range	0 - 82	58 - 88	
Adapted PPVT	*M (SD)*	34.23 *(17.85)*	59.23 *(12.88)*	
	Range	10.98 - 68.21	23.70 – 73.41	
CELF-4	*M (SD)*	51.50 *(22.93)*		62.07 *(12.69)*
	Range	9.26 – 81.48		33.33 - 83.33
BPVS3	*M (SD)*	53.35 *(11.08)*		55.93 *(6.71)*
	Range	34.52 - 73.21		40.48 - 70.83
DVIQ	*M (SD)*	79.12 *(12.87)*	87.10 *(6.57)*	
	Range	58.06 - 96.77	77.42 - 96.77	
Trog-2	*M (SD)*	60 *(15.26)*		61.40 *(12.79)*
	Range	20 - 80		40 - 90
K-BIT-2	*M (SD)*	104.26 *(10.83)*	97.73 *(11.26)*	99.96 *(18.06)*
	Range	85 - 124	80 - 119	80 - 139
Language Use	*M (SD)*	52.46 *(22.33)*	95.96 *(4.05)*	0.28 *(0.91)*
	Range	4.84 - 76.79	87.10 - 100	0 - 3.33
SES	*M (SD)*	77.96 *(16.32)*	64.17 *(12.60)*	77.25 *(13.84)*
	Range	37.5 - 100	43.75 - 87.5	25 - 87.5

Note. Age = participants' age in months, PWFT = Greek expressive vocabulary score, Adapted PPVT = Greek receptive vocabulary score, CELF-4 = English expressive vocabulary score, BPVS3 = English receptive vocabulary score, K-BIT-2 = non-verbal intelligence standardised score, DVIQ = Greek receptive grammar score, Trog-2 = English receptive grammar score, Language Use = Percentage of language use with 0% being only English and 100% being only Greek (For English monolingual group 100% being language other than English), SES = the average percentage of mother and father education.

3.3.2 Materials

Parental Questionnaire

The children's language experience was investigated through the Language and Social Background Questionnaire for Children (LSBQ; Luk & Bialystok, 2013). The LSBQ was forward and backward translated in Greek and it was completed by at least one of the parents/guardians in their preferred language (Greek or English). It consisted of information about the child's age, grade, date of birth, country of birth, age of onset of all the languages, knowledge of playing a musical instrument, and length of exposure to different educational mediums. The questionnaire also included information about the parents' language backgrounds. Children's SES was measured as the mean of the highest attained educational level of both parents rated on an 8-point scale, which was then converted into percentages. Parental education is the most commonly used index of SES, is highly predictive of other SES indicators (e.g., income, occupation), and is a better predictor of cognitive performance than other SES indicators (see Calvo & Bialystok, 2014).

The child's speaking and understanding in Greek, English, or another language was rated by the parent on a 5-point scale ranging from Poor to Excellent. A Greek proficiency parental score was derived from both scores for speaking and understanding in Greek and was included in the analysis. Similarly, both scores for speaking and understanding in English was used as the English proficiency parental score included in the analysis. General language use throughout the child's lifetime with parents, siblings, grandparents, neighbours, friends, and caregivers in various situations was measured on a 7-point scale ranging from 1 (only English) to 7 (only Greek/or other language).

Non-verbal Intelligence

Non-verbal intelligence was assessed using the Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman & Kaufman, 2004). The test consists of 46 items including a series of abstract images, such as designs and symbols, and visual stimuli, such as pictures of people and objects. Participants are required to understand the relationships among the presented stimuli and complete visual analogies by indicating the relationship between the images by either pointing to the answer or saying which letter it corresponds to. All items include an option of at least five answers thus reducing chance guessing. The Matrices non-verbal subtest is individually administered, and standardised scores were calculated for the purposes of the screening, while raw scores were used in the analyses.

Language Measures.

To assess the proficiency of the bilingual children in their languages, receptive and expressive vocabulary measures in each language were administered along with receptive grammar assessments. Raw scores converted to percentages were used in the analysis.

English Language Measures.

The British Picture Vocabulary Scale, Third Edition (BPVS3; Dunn & Dunn, 2009) was used to assess the receptive vocabulary of the bilingual and monolingual children in the English language. It is an individually administered, standardised test of Standard English receptive vocabulary for children ranging from 3 years to 16 years and 11 months. In this task, children are asked to select, out of four coloured items in a 2 by 2 matrix, the picture that best corresponds to an English word read out by the researcher. The assessment consists of 14 sets of 12 words of increasing difficulty (e.g., ball, island, fictional). The administration is discontinued when a minimum of eight errors is produced in a single set.

The Clinical Evaluation of Language Fundamentals, Fourth UK Edition - CELF-4UK (Semel et al., 2006) is an individually administered standardised language measure which is used for the comprehensive assessment of a student's language skills by combining core subtests with supplementary subtests. The expressive vocabulary subtest was used here to assess the participants' expressive vocabulary in the English Language. This measure is designed for children and adolescents ranging from 5 to 16 years of age. Expressive vocabulary was screened through the Expressive Vocabulary subtest for children. Children were asked to look at a picture and name what they see or what is happening in each picture (e.g., a picture of a girl drawing, the child should give the targeted response 'colouring' or 'drawing' to score 2 points or the response 'doing homework' to score 1 point). The administration is discontinued after seven consecutive zero scores.

The Test for Reception of Grammar – Version 2 (TROG-2; Bishop, 2003) was used to assess receptive grammar. It is an individually administered standardised test for children and adults and it comprises 80 items of increasing difficulty with four picture choices. Children are asked to select the item that corresponds to the target sentence read out by the researcher. For each grammatical element there is a block of four target sentences. A block is considered to be failed unless all four items of each block are established by the child. The sentences include simple vocabulary of nouns, verbs, and adjectives. If a child fails five consecutive blocks the administration is terminated.

Greek Language Measures.

A standard Modern Greek version of the Peabody Picture Vocabulary Task (PPVT; Dunn & Dunn, 1981) was adapted and used based on the Greek adaptation by Simos, Sideridis, Protopapas and Mouzaki (2011). The children clicked on the image, out of four possible choices, that best corresponded to the target word they heard, such as nouns, verbs, or adjectives. There were 173 items of increasing difficulty. If eight incorrect responses were provided to ten consecutive items, then the task was stopped. The answers were scored as correct (1) or incorrect (0).

The Picture Word Finding Test (PWFT; Vogindroukas, Protopapas, & Sideridis, 2009) is an individually administered standardised measure used to assess standard Modern Greek expressive vocabulary. It is a tool norm-referenced for Greek adapted from the English Word Finding Vocabulary Test - 4th Edition (Renfrew, 1995). The children are presented with 50 black and white images consisting of nouns in developmental order. The words included originate from objects, categories of objects, television programs and fairy-tales very familiar to children. A score sheet is used to record the responses provided during testing which are later scored as correct (1) or incorrect (0). The children are asked to name the objects they saw and when they are ready, they move to the following one. The assessment is discontinued after five consecutive wrong replies.

The Developmental Verbal Intelligence Quotient (DVIQ; Stavrakaki & Tsimpli, 2000) was used to assess Greek receptive grammar. It consisted of five subtests used to measure children's language abilities in expressive vocabulary, understanding metalinguistic concepts, comprehension and production of morphosyntax, and sentence repetition. This was an assessment that measured language development in standard Modern Greek and it was administered individually. For this study, only the subtest measuring comprehension of morphosyntax was used for both Greek monolingual and Greek-English bilingual children. Each child was given a booklet with 31 pages, each including 3 images. The researcher read out a sentence and each child was asked to point to the picture that best represented the situation in the sentence. For example, the sentence might have been *"μην καπνίζετε"* (do not smoke) and the correct answer depicted a "No

Smoking" sign. An answer sheet was used to record the child's answers (as A, B, or C) during testing which were later scored as correct (1) or incorrect (0).

For each of the background language measures we define percentage scores as the number of correct responses/number of correct and incorrect responses. Bilinguals were assessed on each of these background measures using one test in each language. Percentages were used in order to create a comparable scale for all tests which allows us to produce a composite measure.

Executive Function Tasks.

In this section we present the administration details for the five executive function tasks that span attention, working memory, inhibition and shifting. All cognitive tasks were administered on a 15.6-inch laptop screen using the experimental software E-Prime 2.0 (Schneider et al., 2002). E-Prime 2.0 is a behavioural experiment software which provides an environment for computerised experiment design and data collection with millisecond precision timing ensuring accuracy of data. We discuss each of these tasks in turn below.

Attention task.

The Attentional Network Task (ANT) (Fan et al., 2005) was designed to evaluate three different attentional networks: i) alerting; ii) orienting, and iii) executive control (Posner & Petersen, 1990). According to this model, the attention system can be divided into: the alerting network which allows producing and maintaining attention; the orienting network prioritises sensory input by selecting a modality or location; and the executive control network is responsible for monitoring and resolving conflict (Zhang et al., 2015).

In the ANT, participants are asked to indicate the direction (left or right) that the target stimulus (center arrow) points to. Similar to the flanker task, the target arrow is flanked by other arrows pointing to the same direction or the opposite one. In the congruent trials, the arrows are pointing to the same direction as the center arrow. On the contrary, in the incongruent trials, the other arrows point to the opposite direction compared to the center arrow. Most importantly for the purpose of this thesis, the *conflict index* reflects inhibitory skills and is the comparison between reaction times in incongruent and congruent trials.

Before the flanker trial and after a random time period, cues are provided about the position of the arrows, presented as an asterisk. These can be an asterisk in the same position as upcoming arrows, a double cue (e.g., one asterisk on the top and one asterisk on the bottom of the screen) , a neutral cue (e.g., asterisk in the middle of the screen) and no cue. The alerting network index is the difference in reaction times between the double cue conditions and the no cue conditions. Likewise, the orienting index is the comparison between the central cue and the spatial cue conditions.

In this study, participants were asked to indicate the direction (left or right) that the target stimulus (centre fish here) pointed to. The child's distance between his/her head and the centre of the screen was approximately 50cm. The child's task was to press either the right or left key button on the mouse (with the right or left index finger) corresponding to the direction in which the middle fish was swimming. The child was presented with a training block of 16 trials and 128 trials distributed in four experimental blocks. There were breaks in between the four experimental blocks. During both the training and experimental blocks auditory feedback was provided to the child.

Working memory tasks.

The first working memory task was a *Counting recall task*, which was an adaptation of the Automated Working Memory Assessment (Alloway, 2007). The children were presented with a varying number, between four and seven, of red circles and blue triangles on the laptop screen. The children were asked to count and memorise the number of red circles in each block of trials. During the recall phase the children typed the number of red circles in each trial of that block. The number of trials increased in each block, reaching seven numbers. If the child failed to correctly recall three trials in a block the task stopped.

The second working memory task was a *Backward digit span task* (BDST) and it was adapted from Huizinga, Dolan, & Van der Molen (2006). The children began with two training trials in order to understand the task and were instructed to type the reverse order of the numbers presented. For example, if a child heard the number 7 and 4 they should type 4 and 7. The sequence begins with four trials of two numbers gradually reaching eight numbers. Similar to the above task, if the child failed to correctly recall three trials in a block the task stopped.

Both tasks were administered in the preferred language of the child. In all cases the preferred language was English for the bilingual children.

Inhibition task.

The *Nonverbal Stroop task* was adapted from Lukács, Ladányi, Fazekas, & Kemény (2016) and the stimuli consisted of arrows pointing upwards, downwards, left and right. Three experimental blocks of 60 trials each were presented to the children. The aim was to select the direction that the arrows indicated regardless of their position on the screen. The children used the arrow buttons on the laptop's keyboard. The task began with the control block, where arrows were presented in the middle of the screen. In the second block, which was the congruent block, the direction of the arrows matched their position on the screen (e.g., an arrow indicating upwards was presented at the top of the screen). Finally, the third experimental block was the incongruent block. Here the direction of the arrows was the opposite compared to their position on the screen (e.g., an arrow indicating upwards was presented at the bottom of the screen).

For accuracy measures, the number of correct answers for the incongruent items was subtracted from the number of correct answers for the congruent items. The difference in RT for congruent and incongruent trials represents the inhibition cost.

Shifting task.

All children were also administered one shifting task, the *colour-shape task,* developed for Purić et al. (2017). This task included three blocks each, where children were presented with two shapes (triangle, circle) coloured either red or blue. The same buttons, one for the left hand and one for the right, corresponded to one of the choices (circle-triangle, red-blue). In the first two experimental blocks, the children's task was to either recognise the shape of the stimulus and ignore their colour or the reverse. The shape stimuli were presented in the top half and the colour stimuli in the bottom half of the screen. In the third block children were required to alternate between identifying colour and shape depending on the object's location on the screen. Cues directing the participant to the relevant dimension are presented simultaneously with the stimuli on all trials, in all blocks. The first two blocks contained 32 trials each, while the third block contained 64. The number of shifting and non-shifting sequences within the third block was balanced. The difference in RT for the first two (non-shifting) and the third (shifting) block represents the shifting cost.

3.3.3 Procedure

A pilot study with 4 children was conducted before the actual data collection. As a result of the pilot study, the choice of the above fixed order of tasks was such so the children did not feel tired or uninterested. After the end of each session the researcher thanked the child for their participation. All children participated enthusiastically.

The children were tested individually in a quiet school classroom setting, during one session in Greek for the Greek monolingual children and one session in English for the English monolingual children that lasted 40 minutes on average. The bilingual children were tested in two separate sessions; the English language session was conducted within one month of the Greek language session. The second session was conducted no more than one month's time after the first one. The researcher informed the children that they would play some games. Parents were administered the questionnaire (LSBQ) and returned it to the classroom teacher, the school head teacher, or directly to the researcher.

Greek Session.

The bilingual participants began with the Greek language session. Each child completed the tasks in the following fixed order: i) Greek adapted PPVT, ii) ANT, iii) Picture Word Finding Test, iv) Colour shape task, v) Nonverbal Stroop task, and vi) DVIQ.

English Session.

The second session for the bilingual participants was the English session. Each child completed the tasks in the following fixed order: i) KBIT-2, ii) BDST, iii) BPVS, iv) counting recall task, v) CELF-4, and vi) TROG-2.

Monolingual Participants' Session.

The Greek monolingual children completed the tasks in one session in the following fixed order: i) Greek adapted PPVT, ii) ANT, iii) PWFT, iv) Colour shape task, v) Nonverbal Stroop task, vi) DVIQ, vi) KBIT-2, vii) BDST, viii) Counting recall task.

The English monolingual children completed the tasks in one session in the following fixed order: i) BPVS, ii) ANT, iii) CELF-4, iv) Colour shape task, v) Nonverbal Stroop task, vi) TROG-2, vi) KBIT-2, vii) BDST, viii) Counting recall task.

3.4 Results

3.4.1 Preliminary analyses

Outlier analysis.

Response accuracy and RTs were recorded for all the EF tests. All RTs shorter than 200 ms and all RTs for incorrect trials were excluded from the analysis; thus, only analyzing RTs from correct responses (e.g., Purić et al., 2017). Furthermore, in order to prevent extreme RTs from influencing participants' mean scores, we established ±3 standard deviation values both between and within participants. Every value that surpassed ±3 standard deviations away from the mean RT was substituted by the established lower and upper bound RTs (see also, Miyake et al., 2000). The inhibition cost for the nonverbal Stroop task was calculated as the difference between congruent and incongruent mean RTs. Local shifting costs (LSC) were calculated in the third block as the difference between the average RT for the shift trials and the average RT for the non-shift trials. General shifting costs (GSC) were calculated as the difference between the average RT for the third block and average RT for the first and second block together.

3.4.2 Language background measures

In order to reduce the number of control variables included in the analysis, Greek and English language measures together with the proficiency scores from the parental questionnaires were submitted to a factor analysis. The analysis was conducted between the two groups of Greek-English bilinguals and Greek monolinguals and between the two groups of Greek-English bilinguals and English monolinguals. For the Greek-English bilinguals and Greek monolinguals the following four independent measures were entered into the analysis: PWFT, DVIQ, adapted PPVT, Greek proficiency parental score. For the Greek-English bilinguals and English monolinguals the following four independent measures were entered into the analysis: BPVS3, TROG-2, CELF-4, English proficiency parental score.

A Maximum Likelihood factor method was applied to the four variables for each of the two cases. Based on the analysis it was observed that participants' scores in the PWFT, DVIQ, adapted PPVT, Greek proficiency score (based on the parental report) and the BPVS3, TROG-2, CELF-4, English proficiency score (based on the parental report) clustered on one component, which represented the proficiency in each language. The analysis showed that the Greek proficiency factor explained 71.27% of the variance and the English proficiency factor 55.31% of the variance. Tables 2 and 3 summarise the Maximum Likelihood results. Table 4 indicates the correlations between the control background variables.

Table 2 *Results of factor analysis on the four language variables for Greek-English bilinguals and Greek monolinguals.*

Measure	Factor Loadings
	Factor 1
DVIQ	**.708**
Greek proficiency parental score	**.750**
Adapted PPVT	**.955**
PWFT	**.935**
% of variance	71.27%

Note. Factor loadings over .40 are presented in bold.

Table 3 *Results of factor analysis on the four language variables for Greek-English bilinguals and English monolinguals.*

Measure	Factor Loadings
	Factor 1
CELF-4	**.655**
BPVS3	**.977**
TROG-2	**.818**
English proficiency parental score	**.401**
% of variance	55.31%

Note. Factor loadings over .40 are presented in bold.

Table 4 *Correlations between the control background variables*

	Greek prof	PWFT	adapted PPVT	DVIQ
Greek prof	1	.70	.69	.56
PWFT	.70	1	.89	.66
adapted PPVT	.69	.89	1	.71
DVIQ	.56	.69	.71	1

3.4.3 Matching method

For the analysis of the data we applied k:1 nearest neighbour matching (Rubin, 1973). The idea behind matching methods is to compare the outcomes (Y) of subjects that are as similar as possible to a number of covariates (X), with the sole exception of the treatment status. In our case, we would like to compare the executive function accuracy and response time of a monolingual with those of a bilingual child as long as they have similar values in other background scores namely the Age in months, Sex, K-BIT-2, SES, English proficiency factor, Greek proficiency factor. Only then can we be sure that any difference in the outcome variable is a consequence of the action rather than of the correlation between a test and the outcome.

For a single covariate, like the PWFT, identifying a pair of comparable children is simple. Adding a second covariate that is binary (e.g., Sex) or categorical (e.g., SES) would require more effort on our behalf and a larger dataset. However, if we want to consider more covariates, particularly if they are continuous (e.g., K-BIT-2), then finding matches becomes a daunting task. To circumvent this problem, a similarity measure or similarity index may be constructed, which quantifies how close two observations (i.e., scores from two children) are. Two well-established methods are the k-means nearest neighbour matching and the propensity score matching.

The k-means nearest neighbour matching calculates the "distance" between pairs of observations with regard to a set of covariates (X's) and then "matching" each subject to comparable observations that are closest to it. For example, suppose that a bilingual participant has a PWFT score of 65.7 and we also have information on two monolingual children – monolingual A and B – where A has a PWFT score of 55.3 and B of 64.1. Naturally, monolingual B represents a closer match to the bilingual, and B would therefore be selected by the k-means nearest neighbour matching. In this case, the distance is simply $d = |65.7 - 64.1| = 1.6$, which is also known as the Eucleidian distance. If more than one variable is used to match, then the distance statistic that is used is the Mahalanobis, which takes into account the correlation between the covariates and the fact that they may be measured on different scales.

The k-means nearest neighbour matching does not use a formal model for either the outcome or the treatment status and this makes it very flexible. However, when matching on more than one continuous covariate, the k-means nearest neighbour estimator must be augmented with a bias-correction term (Abadie & Imbens, 2006; 2011).

The k-means nearest neighbour matching relies on some distance function. For example, initially assume a single covariate – the PWFT score. In the general form we can denote this variable as x. Then the distance between two individuals i, j where the i individual is bilingual and the j individual is not can be given as

$$\left|x_i - x_j\right| = \frac{(x_i - x_j)(x_i - x_j)}{Cov(x, x)}$$

We can generalise this formula for when we have p number of covariates using matrix algebra. Assume that $x = \{x_1, x_2, \dots, x_p\}$ and that each individual, i, has the following set of covariates $\mathbf{x}_i = \{x_{1,i}, x_{2,i}, \dots, x_{p,i}\}$. The distance between individuals i, j is now given as:

$$\left\|\mathbf{x}_i - \mathbf{x}_j\right\| = \left((\mathbf{x}_i - \mathbf{x}_j)'\mathbf{S}^{-1}(\mathbf{x}_i - \mathbf{x}_j)\right)^{1/2}$$

where **S** is the variance-covariance matrix of the covariates.

Coming back to observation i, we can define the following set of nearest-neighbor index

$$\Omega(i)^x = \left\{j|t_j = 1 - t_i, \left\|\mathbf{x}_i - \mathbf{x}_j\right\| < \|\mathbf{x}_i - \mathbf{x}_l\|_{\mathbf{S}}, t_l = 1 - t_i \forall l \neq j\right\}$$

where i is the observation (i.e., the participant) who is bilingual and for whom we want to find a matching monolingual. j denotes the matching monolingual (only one in this case) and l denotes another monolingual candidate. t denotes the treatment effect and takes the value of 1 for bilinguals, zero otherwise. $\left\|\mathbf{x}_i - \mathbf{x}_j\right\|$ and $\|\mathbf{x}_i - \mathbf{x}_l\|$ denote the distance between i, j and i, l respectively and in the formula above we require that the distance between i, j is smaller than i, l (since we select the matching j participant as our match). The notation $t_j = 1 - t_i$ and $t_l = 1 - t_i$ implies that our i participant who is bilingual (hence $t_i = 1$) needs to be matched with some monolingual participant for whom $t_j = 1 - 1 = 0$ or $t_l = 1 - 1 = 0$

The above can be generalised for m matching participants

$$\Omega(i)_m^x = \left\{j_1, j_2, \ldots, j_m | t_{j_k} = 1 - t_i, \left\|\mathbf{x}_i - \mathbf{x}_{j_k}\right\|_{\mathbf{S}} < \left\|\mathbf{x}_i - \mathbf{x}_{j_k}\right\|_{\mathbf{S}}, t_l = 1 - t_i \forall l \neq j_k\right\}$$

The structure of **S** depends on our initial assumption and can be one of Euclidean, Mahalanobis or inverse variance. Formally

$$
\mathbf{S} = \begin{cases} \mathbf{I}_{\boldsymbol{p}} & \text{for the Euclidean case} \\ \dfrac{(\mathbf{X} - \bar{\mathbf{x}}'\mathbf{1}_{\boldsymbol{n}})'\boldsymbol{W}(\mathbf{X} - \bar{\mathbf{x}}'\mathbf{1}_{\boldsymbol{n}})}{\sum_i^n w_i - 1} & \text{for the Mahalanobis case} \\ \operatorname{diag}\left\{\dfrac{(\mathbf{X} - \bar{\mathbf{x}}'\mathbf{1}_{\boldsymbol{n}})'\boldsymbol{W}(\mathbf{X} - \bar{\mathbf{x}}'\mathbf{1}_{\boldsymbol{n}})}{\sum_i^n w_i - 1}\right\} & \text{for the inverse variance case} \end{cases}
$$

where $\mathbf{1}_{\boldsymbol{n}}$ is an $n \times 1$ vector of ones, $\mathbf{I}_{\boldsymbol{p}}$ is the identity matrix of order p, same as the number of covariates used. w_i is the frequency weight for the i observation, $\bar{\mathrm{x}} = \sum_i^n w_i \mathrm{x}_i / \sum_i^n w_i$ which denotes a weighted mean and $\mathbf{W}$ is an $n \times n$ diagonal matrix containing the frequency weights.

For the prediction of the potential outcomes we use the following: $y_{1,i}$ is the potential outcome of the i individual that has received the treatment or in our case is bilingual ($t = 1$). Conversely, $y_{0,i}$ is the potential outcome of the i individual that has not received the treatment or in our case is monolingual ($t = 0$). As we have discussed, the problem posed by the potential-outcome model is that only $y_{1,i}$ or $y_{0,i}$ is observed, never both. The k-means nearest neighbours can predict the potential outcome for the i observation as follows:

$$
\hat{y}_{t,i} = \begin{cases} y_i \ \text{ if } t_i = t \quad \text{for } t \in \{0,1\} \\ \dfrac{\sum_{j \in \Omega(i)} w_j y_j}{\sum_{j \in \Omega(i)} w_j} \end{cases}
$$

The first is the case where the outcome of the individual (y_i) is observed whether he is bilingual (t=1) or monolingual (t=0). The second case is the counterfactual outcome which does not exist and is estimated as the outcome of the closest match (or matches).

Once the above are estimated we can define the following quantities of interest, namely the Average Treatment Effect (ATE) and the Average Treatment Effect on the Treated (ATET). These are defined as

$$ATE = \tau_1 = E(y_1 - y_0)$$

$$ATET = \delta_1 = E(y_1 - y_0 | t = 1)$$

and obviously as $y_{1,i}$ and $y_{0,i}$ are realisations of the y_1 and y_0 random variables respectively, y_1 is the average of all $y_{1,i}$ and the equivalent holds for y_0

3.4.4 Main Analyses

Tables 5 and 6 report descriptive statistics for the accuracy and RT measures from each executive function task for each group in. In the case of accuracy in the two working memory tasks (BDST and Counting Recall tasks) a higher score indicates better performance, whereas for the RT a lower score indicates better performance. Similarly, for the accuracy in attention, switching and inhibition tasks (ANT, Arrow Stroop, & Colour-Shape tasks) a higher score indicates better performance, whereas a lower RT score indicates better performance. We performed comparisons between the three groups of children. Table 7 and Table 8 show the results of the monolingual and bilingual groups on the attention and working memory tasks.

Comparison 1.

The first comparison was between the bilingual group and the Greek monolingual group. Participants were matched via nearest neighbour matching as described above. The matching variables were Age in months, Sex, K-BIT-2, SES, English proficiency factor, Greek proficiency factor. There were no differences between the bilingual group and the Greek monolingual group based on RTs on the Arrow Stroop. No group difference was found for the inhibition accuracy scores. Similarly, no significant group differences were found for the remaining tasks, where the groups performed comparably (see Table 7 for p-values).

Table 5 *Descriptive Statistics - RTs in Executive Function Tasks*

	Bilinguals				Greek Monolinguals				English Monolinguals			
Tasks	M	SD	Min	Max	M	SD	Min	Max	M	SD	Min	Max
GSC	-291.42	240.80	-757.72	79.56	-268.753	204.2933	-573.7827	68.11292	-331.217	229.9095	-823.735	109.9965
LSC	-125.91	151.42	-452.32	98.30	-128.332	196.4123	-526.9701	93.01868	-156.176	142.9145	-475.535	142.9883
Inhibition Cost	-233.9352	186.9592	-546.9808	188.338	-272.37	227.1293	-568.037	204.0914	-381.233	191.0973	-765.184	95.6483
Back Count	865.1175	313.8921	273	1612.429	1089.913	816.3311	401.1667	3818.859	1920.779	717.0673	911.875	3518.739
Count Recall	2915.154	1278.187	1033.887	4986.751	2374.906	1252.296	1039.916	4766.141	2844.503	1456.564	952.1733	6717.39
ANTcong	1000.159	208.7245	686.1579	1394.72	987.3016	187.3585	717.0995	1394.581	1107.997	152.3785	775.7869	1399.675
ANTincong	1124.714	243.9346	809.6393	1668.079	1099.647	224.9456	745.6984	1516.116	1216.706	167.2387	895.7541	1525.547
Stroop cong	994.5229	357.4001	501.1017	1681.476	946.3075	272.5045	445.0204	1498.74	1116.352	221.8276	493.5714	1475.074
Stroop incong	1239.598	329.6895	575.4286	1991.7	1238.133	320.4497	708.1667	1700.744	1497.585	316.3162	397.9231	1956.878
Colour-Shape cong	901.0499	130.4189	658.6734	1126.833	961.6368	125.1502	747.3365	1176.129	951.1903	166.3187	622.6957	1263.273
Colour-Shape incong	1187.341	276.124	686.3704	1694.677	1229.012	167.6315	948.1464	1547.466	1280.2	279.1717	687.2692	1739.979

Note. GSC = Global shifting cost; LSC = Local shifting cost; Inhibition cost = The difference RT for congruent and incongruent trials; Back Count = BDST; Count Recall = Counting recall task; cong = congruent trial; incong = incongruent trials.

Table 6 *Executive Function Tasks Descriptive statistics - accuracy*

	Bilinguals				Greek Monolinguals				English Monolinguals			
Tasks	M	SD	Min	Max	M	SD	Min	Max	M	SD	Min	Max
Back Count	0.59	0.10	0.29	0.73	0.56	0.12	0.25	0.73	0.57	0.07	0.45	0.73
Count Recall	0.42	0.15	0.21	0.75	0.32	0.14	0.14	0.61	0.35	0.09	0.14	0.50
ANTcong	0.92	0.08	0.77	1.00	0.84	0.18	0.43	1.00	0.91	0.08	0.64	1.00
ANTincong	0.82	0.21	0.22	1.00	0.62	0.29	0.03	0.97	0.87	0.10	0.59	0.98
Stroop cong	0.93	0.07	0.78	1.00	0.84	0.18	0.43	1.00	0.86	0.16	0.22	1.00
Stroop incong	0.74	0.31	0.10	1.00	0.62	0.29	0.03	0.97	0.64	0.20	0.27	0.97
Colour-Shape cong	0.89	0.08	0.69	0.98	0.83	0.09	0.69	0.97	0.88	0.06	0.75	0.97
Colour-Shape incong	0.67	0.13	0.42	0.89	0.68	0.11	0.48	0.88	0.63	0.11	0.38	0.77

Table 7 *Executive functioning tasks: comparison of bilingual group and Greek control group*

Executive Function Task	**Nearest - Neighbour Matching**	
Working Memory	***Coef***	***p***
Back Count Overall ACC Score	.010	.799
Counting Recall Overall ACC Score	.098	.115
Back Overall Count RT Score	-207.52	.354
Counting Overall Recall RT Score	327.49	.641
Attention		
ANT Overall ACC Score	-.010	.821
ANT Overall RT Score	42.014	.566
ANT Congruent RT Score	29.418	.695
ANT Incongruent RT Score	54.100	.497
ANT Congruent ACC Score	-.020	.399
ANT Incongruent ACC Score	-.001	.992
Inhibition		
Arrow Stroop Overall RT Score	-1.5231	.986
Arrow Stroop Congruent RT Score	105.12	.293
Arrow Stroop Incongruent RT Score	39.61	.744
Inhibition Switch Cost	55.040	.473
Arrow Stroop Overall ACC Score	.015	.792
Arrow Congruent ACC Score	.030	.531
Arrow Incongruent ACC Score	.037	.774
Shifting		
Colour -Shape Congruent ACC Score	.050	.168
Colour - Shape Incongruent ACC Score	-.024	.511
Colour - Shape Congruent RT Score	-7.674	.902
Colour - Shape Incongruent RT Score	52.96	.559
Colour – Shape GSC	-64.33	.598
Colour – Shape LSC	-29.08	.777

Note. Matching variables: Non-Verbal Ability (K-BIT-2), Age, SES, Sex, Greek Proficiency Factor.

Comparison 2.

The second comparison was between the bilingual group and the English monolingual group. Nearest neighbour matching was again applied to match participants for the same matching variables, namely Age in months, Sex, K-BIT-2, SES, English proficiency factor, Greek proficiency factor.

The differences between the groups based on RTs emerged on the inhibition task, namely Arrow Stroop, where the bilingual group was faster compared to the monolingual group. In addition, there was a significant Stroop effect ($\widehat{b}$ = 139.728, p = .033). However, no group difference was found for the inhibition accuracy scores. A significant group difference was also found for the Backcount task where the bilinguals were faster compared to their monolingual counterparts ($\widehat{b}$ = -1021.77, p < .001). In the remaining tasks, the groups performed comparably.

Table 8 *Executive functioning tasks: comparison of bilingual group and English control group*

Executive Function Task	**Nearest - Neighbour Matching**	
Working Memory	***Coef***	***P***
Back Count Overall ACC Score	-.001	.974
Counting Recall Overall ACC Score	.0354	.487
Back Overall Count RT Score	-1021.77	**.000**
Counting Overall Recall RT Score	-1802.183	.511
Attention		
ANT Overall ACC Score	-.041	.365
ANT Overall RT Score	-90.959	.184
ANT Congruent RT Score	-89.746	.177
ANT Incongruent RT Score	72.879	.267
ANT Congruent ACC Score	-.019	.573
ANT Incongruent ACC Score	-.061	.361
Inhibition		
Arrow Stroop Overall ACC Score	.029	.604
Arrow Stroop Congruent RT Score	-155.147	.148
Arrow Stroop Incongruent RT Score	-294.875	**.031**
Inhibition Switch Cost	139.728	**.033**
Arrow Congruent ACC Score	.044	.435
Arrow Incongruent ACC Score	.061	.489
Shifting		
Colour -Shape Congruent ACC Score	.041	.087
Colour - Shape Incongruent ACC Score	.057	.170
Colour - Shape Congruent RT Score	57.263	.900
Colour - Shape Incongruent RT Score	-71.264	.504
LSC	41.671	.551
GSC	76.280	.430

Note. Matching variables: Non-Verbal Ability (K-BIT-2), Age, SES, Sex, English Proficiency Factor.

3.5 Discussion

The present study investigated differences in the executive functioning skills of Greek-English bilingual children compared to two groups of Greek and English monolingual children. We investigated the executive functioning scores using a battery of tests assessing inhibition, shifting, and updating, and matching closely for language proficiency, SES, language use, vocabulary and grammar scores, and non-verbal intelligence. Our aim was to see if the Greek-English bilingual children would outperform their monolingual counterparts in line with multiple previous findings (see Bialystok, 2017), once a large number of potentially confounding variables was controlled for using innovative analyses, and therefore to contribute methodologically to the debate on whether a bilingual advantage exists and/or how reliable it is.

To achieve this, the bilingual children were compared to two closely matched monolingual control groups, one consisting of Greek monolinguals and the other of English monolinguals. We used a factor analysis on four indicators of language proficiency to reveal one factor which we interpreted as proficiency in English and Greek and closely matched the participants using the k-means nearest neighbour matching. This close matching gives us greater confidence in the results taking into consideration a large number of relevant variables. The results showed that Greek-English bilinguals were faster than the English monolinguals in two EF measures in terms of RT. Namely: i) in the inhibition task (Stroop), the bilingual children were faster in the incongruent inhibition trials and demonstrated a lower inhibition switch cost, ii) in the backward WM digit span (BDST), the bilinguals were faster than the English monolinguals. In all the other EF measures the bilingual children were comparable to the English monolingual children. The bilingual children showed no difference in their performance compared to the Greek monolingual control group.

These findings support the hypothesis that bilingualism influences the development of executive functions and extend previous research (Costa et al., 2009; Blom et al., 2017; Bosma et al., 2017; Garraffa et al., 2015; Lauchlan et al., 2013). After controlling and closely matching this group of bilinguals to two monolingual control groups on a large number of relevant variables, a bilingual effect was observed in inhibition and working memory. The comparison between the bilingual group and the English monolingual group elicited a bilingual effect only in one working memory task and in the inhibition task. Our study is in line with previous research that has showed mixed findings in EF tasks (Paap & Greenberg, 2013; Ross & Melinger, 2016).

In contrast to the previous comparison where a bilingual effect was found, the bilingual group was comparable in all the measures to the Greek monolingual group. The fact that there was no significant difference in any task between the bilingual and the Greek monolingual group may be linked to the fact that due to the Greek educational system, we could not avoid recruiting children in Greece that were exposed to English at least one hour a week starting in Year 1 and reaching three hours a week in Year 3 (Greek Ministry of Education and Religious Affairs, 2016). This is in combination with after school language classes, where children attend English classes at least two hours a week. It is possible that these few hours of English a week have mitigated any differences in executive functioning scores. Other studies investigating dual language development and executive functions of bilingual children attending L2 education programs have found advantages in working memory after as little as one year of immersion education, for example in a group of Serbian-speaking second-grade children (Purić et al., 2017). Nicolay and Poncelet (2013) found positive effects after 3 years of immersion education in alerting, auditory selective attention, divided attention, and mental flexibility, in line with Carlson and Meltzoff (2008) who reported a bilingual advantage on a battery of EF tasks after 6 months of immersion. In our case, it might be that the amount of exposure and the length of exposure of the Greek monolingual group to English was sufficient to yield comparable results to the bilingual group.

In contrast, the monolingual English group did not have any exposure to an L2 and the bilinguals did outperform them in the reaction times of the inhibition and working memory task. Based on Purić et al. (2017), working memory may be specifically linked to these early stages of intensive L2 learning. This finding is in line with previous research showing a bilingual advantage in working memory (Antoniou et al., 2016; Bialystok, 2010; Blom et al., 2014; Purić et al., 2017). This advantage in working memory ability may be related to the continuous monitoring of the lexicon and the grammatical structures used in both languages together with their continuous storing and updating.

The bilingual effect in the inhibition domain is in line with previous research on bilingualism (Bialystok, 2017). It has been argued that continuous interference of the two languages is resolved through inhibiting the activation of the non-target language (Green, 1998). These children mostly interact in a dual language context, where they may interact with siblings or friends in English and use exclusively Greek with a parent. Based on the adaptive control hypothesis (Green & Abutalebi, 2013) it is assumed that this context imposes the highest demands on cognitive control processes because the speaker is required to handle a variety of multimodal sociolinguistic cues within the interaction and the environment (e.g., Hernández et al., 2013).

However, the other tasks, one tapping into working memory (Counting recall task) and one tapping into inhibition (ANT; only the *conflict index* was analysed here) revealed no significant differences on either accuracy or response times. This might be an issue linked to reliability and validity of commonly used EF tasks. The view that EF tasks are far from optimal is supported by many researchers in the field (e.g., Laine & Lehtonen, 2018; Paap & Greenberg, 2013; Paap & Sawi, 2014; Soveri, Lehtonen, Karlsson, Lukasik, Antfolk & Laine, 2016). This dissociation between tasks might also be linked to the lack of theory on the bilingual advantage in EF and the lack of clarity in the architecture of EF despite the division by Miyake et al. (2000) into three interrelated components (shifting, inhibition, and WM). Even though the above tasks supposedly tap the same domain, that does not mean that they are correlated with each other (Jylkkä, Lehtonen, Lindholm, Kuusakoski, & Laine, 2017; Laine & Lehtonen, 2018). Though some researchers have reported that forwards and backwards recall tasks load onto the same factor during factor analysis (e.g., Colom, Abad, Rebello, & Shih, 2005; Engle et al., 1999), others state that a reversal of order requires the involvement of executive-attentional resources (e.g., Elliot, Smith, & McCulloch, 1997). On the other hand, Costa et al. (2008) and Pelham and Abrams (2014) found a significant bilingual conflict effect using the ANT when testing young adults. This might be linked to the engagement of the monitoring processes during an EF task which may depend on several properties of the design, such as different type of stimuli. If for example, a task involves one type of trials, monitoring processes may not be recruited as much (Costa et al., 2009). As Costa et al. (2009) hypothesise in their study, a bilingual advantage could be linked to a more efficient monitoring processing system, that checks which strategy should be applied in a specific trial. They found that in low-monitoring conditions no bilingual advantage was detected in contrast to high monitoring condition where a bilingual conflict effect was observed. Perhaps, the child-friendly version of the ANT used in the current study was not challenging enough. Similarly, in Antón et al. (2014) and Carlson and Meltzoff (2008) no difference was found in the children's version of the ANT task between the bilingual and monolingual children. The fact that we only found the significant difference in RT in the Stroop and the BDST tasks might be linked to the fact that a bilingual advantage in monitoring and updating may speed up performance, leading to not only overall faster RTs but also to a smaller conflict effect (Costa et al., 2009).

On the shifting task, we did not find any bilingual effect. As Huizinga et al. (2006) stated, various EF components may develop asynchronously. This is in line with previous research not finding effects of bilingualism in any EF tasks (Paap & Greenberg, 2013).

3.6 Limitations and future directions

Due to practical matters, we used one shifting task, non-standardised tasks to assess Greek receptive vocabulary and grammar skills in Greek monolingual and bilingual children as well as English tests which are not standardised for bilingual children. Future development of tests is needed in Greek and English which should also include bi-mutilingual children (Babatsouli, 2019; Marinis, Armon-Lotem, & Pontikas, 2017). Also, standardised Greek tests assessing language skills are lacking or are outdated, and a large study would allow test standardisation and the establishment of quantitative norms.

Future studies can shed light on the possibility that limited exposure to a second language could enhance executive functions. Pursuing this might clarify the reasons why no differences were identified between the Greek-speaking cohort and the Greek-English bilingual cohort as well as mixed findings in other studies. This finding has important educational implications especially for Greece, where there has been a pilot project of teaching English for two hours a week, as a compulsory topic, in state nurseries since September 2020 (Greek Ministry of Education and Religious Affairs, 2020). Additionally, the European Commission is working together with national governments aiming for all citizens to begin learning foreign languages at an early age (European Commission, 2019). Finally, in Wales similar findings were obtained in a pilot study where children receiving minimal exposure to Welsh for a year were faster in a working memory task than their English monolingual counterparts (Papastergiou, Sanoudaki, & Collins, 2019). Future longitudinal studies can further investigate these groups with minimal exposure to a second language and how this interacts with executive functions.

The relatively small sample size of this study is one of its limitations. Nevertheless, our findings extend previous research and demonstrate that after controlling and closely matching this group of bilinguals to two monolingual control groups on related factors, a bilingual effect is observed in inhibition and working memory.

Finally, this dissociation between inhibition and working memory tasks on one hand and shifting and attention tasks on the other can lead us to look at EF holistically. Based on these results and as a further step, we propose to approach this bilingual advantage debate on EF in a comprehensive approach, using frontier methodologies which allow us to jointly consider information from multiple domains of EF in a new measure; *technical efficiency (TE)*. This will be further explored and discussed in the following chapter, Chapter 4.

3.7 Conclusion

The aim of this study was to examine the differences in the executive functioning skills of Greek-English bilingual children compared to two control groups of Greek and English monolingual children. The contribution of this study to the field is empirical and methodological, namely we considered recently identified relevant variables in combination with innovative analyses and one unstudied language group of Greek-English bilingual children from the north of England. More specifically, we used k-means nearest neighbour methods to match bilingual to monolingual children on a wide array of variables, including age, SES, Greek and English proficiency. We used a factor analysis on four indicators of language proficiency to reveal one factor which we interpret as proficiency in English and Greek, closely matching on language background information that we obtained from both objective and contextual factors. This close matching gives us greater confidence in the results that revealed a bilingual advantage in two domains, inhibition and working memory, compared to the English monolingual group, while the Greek monolingual group was comparable to the Greek-English bilingual group. The latter finding might be explained by Greek children's exposure to small amounts of English in Greece due to the nature of the Greek educational system or it could be clarified in the way EF is divided and analysed. In the next chapter, we will propose a novel method analysing EF holistically.

Chapter 4 - The Executive Function of Bilingual and Monolingual Children: A Technical Efficiency Approach

Abstract

This study introduces a novel approach to evaluate performance in the executive functioning skills of bilingual and monolingual children. This approach targets method- and analysis-specific issues in the field, which has reached an impasse (Antoniou et al., 2021). This study moves beyond the traditional approach towards bilingualism, by using an array of executive functioning tasks and frontier[1] methodologies which allow us to jointly consider multiple tasks and metrics in a new measure; *technical efficiency (TE)*. We use a Data Envelopment Analysis technique to estimate TE for a sample of 32 Greek-English bilingual and 38 Greek monolingual children. In a second stage we compare the TE of the groups using an ANCOVA, a bootstrap regression and a k-means nearest-neighbour technique, while controlling for a range of background variables. Results show that bilinguals have superior TE compared to their monolingual counterparts, being around 6.5% more efficient. Robustness tests reveal that TE yields similar results to the more complex conventional MANCOVA analyses, while utilising information in a more efficient way. By using the TE approach on a relevant existing dataset, we further highlight TE's advantage compared to conventional analyses; not only does TE use a single measure, instead of two principal components, but it also allows more group observations as it accounts for differences between the groups by construction.

Keywords: Bilinguals, Technical efficiency, DEA, Executive function, k-means, bootstrap

[1] In frontier methodologies the performance of a decision-making unit (DMU) is evaluated against the best-performers or efficient units that constitute the efficient frontier and envelops all inefficient units. Data Envelopment Analysis (DEA) and Stochastic Frontier Approach (SFA) are two commonly referred frontier methodologies.

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4.1 Introduction

A large strand of the empirical research on bilingualism focuses on the comparative performance of bilingual and monolingual populations with regards to executive function, as also discussed in Chapter 2.[2] On the one hand, a number of studies suggest that bilinguals outperform monolinguals on executive function tasks, in a so-called "bilingual advantage" (Bialystok, 2001; Bialystok et al., 2004, 2006; Bialystok & Martin, 2004; Calvo & Bialystok, 2014; Emmorey et al., 2008). On the other hand, there is increasing evidence that the "bilingual advantage" may not be as universal as originally suggested, also observed in the findings of Chapter 3. In particular, the bilingual advantage may be confined within particular age ranges, such as preschool children or older adults (Bialystok, 2017; Hilchey & Klein, 2011), or specific subcategories of executive function; thus prohibiting generalisations (Bialystok et al., 2009).

This lack of consensus in the literature may be attributed to several factors, broadly grouped into two categories; method-specific and analysis-specific. Method-specific differences comprise the particulars of executive function tasks, such as the administered task, and whether the investigated quantity is the accuracy and/or the reaction time. Some of the executive function tasks that have been used include the ANT (Antón et al., 2014; Poarch & van Hell, 2012; Yang et al., 2011) and the Stroop task (Antón et al., 2014; Poulin-Dubois et al., 2011) which have been discussed in Chapter 3. The majority of studies report a single test, while Poulin-Dubois et al. (2011) is one of the few that report five, which, not surprisingly, lead to different conclusions. Analysis-specific differences comprise variations in the data cleaning, and subsequent analyses; most notably controlling for participant-specific

[2] The comparison of bilinguals and monolinguals is not exhausted within the executive function literature, see for example Hartsuiker, Pickering, and Veltkamp (2004) for a comparison in terms of lexical and syntactic information and Bialystok, Kroll, Green, MacWhinney and Craik (2015) for an investigation of how bilingualism affects particular aspects of the languages used.

characteristics. As most studies in this field feature small samples, certain limitations are, perhaps, unavoidable. For example, controlling for (or matching on) children's grade (or age) and SES might exclude performance differences attributed to vocabulary and grammar skill differences in both languages, to name but a few. The need to control for an extensive array of indicators has been highlighted in Paap and Greenberg (2013) within this context, and within Stuart (2010) in a broader sense.[3]

In this paper, we aim to address both method-specific and analysis-specific issues, by presenting a novel approach that relies on the frontier methodology that measures the relative efficiency of a decision-making unit (DMU) compared to the best practice, in what is termed as technical efficiency. This is a flexible methodology; due to it being a non-parametric, linear programming technique, it does not rely on distributional assumptions and is not computationally intensive. We apply this methodology in the context of executive function performance evaluation of Greek-English bilingual and Greek monolingual children, while using an extended array of executive function tasks and metrics that are in line with the related literature in this field.

4.2 Bilingualism and Executive Control: Mechanisms and challenges

Many studies have focused on childhood bilingualism and executive control, showing that bilingual children outperform their monolingual cohorts on executive functioning tasks (Adesope, Lavin, Thompson, & Ungerleider, 2010; Bialystok, 2017), including selective attention (Bialystok, 2001), cognitive flexibility (Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011) and working memory (Morales, Calvo, & Bialystok, 2013). However, several other studies have not detected a bilingual effect on the executive function domain (Antón et al.,

[3] In other contexts, and within the standard econometrics literature, this would amount to omitted variables bias (Greene, 2003).

2014; Gathercole et al., 2014; Valian, 2015). High-level cognition is theorized to be required, such as working memory to maintain and manipulate information and inhibitory control to block or ignore competing information internally or from the environment (e.g., irrelevant words). This high-level cognition has been purported to contribute to across-the-board cognitive performance gains, dubbed as "bilingual advantage".

Paap (2018) and Paap, Johnson, and Sawi (2014) highlight a number of reasons that may be driving the results towards a "bilingual advantage". Small samples might be one of the caveats, as studies with larger sample sizes tend to report no significant differences between bilinguals/monolinguals (Paap et al., 2015). Several studies featuring large datasets (Antón et al., 2014; Duñabeitia et al., 2014; Gathercole et al., 2014; Paap et al., 2014, 2017; Paap & Greenberg, 2013) reject the existence of a bilingual advantage.[4] In addition, a series of meta-analyses suggest that the bilingual advantage is either of very small magnitude (De Bruin et al., 2015; Grundy & Timmer, 2017) or non-existent (Donnelly, 2016; Lehtonen et al., 2018). Population-specific differences including variations in the bilingualism definition (Namazi & Thordardottir, 2010), differences/similarities in the languages the bilinguals manage (Bialystok, 2017; Yang et al., 2011), the switching intensity and/or frequency between the two languages (Baddeley, 2003) and cultural differences (Paap, 2018) may also affect the results.

Often the statistical analysis employs AN(C)OVA designs (Calvo & Bialystok, 2014; Poulin-Dubois et al., 2011), while regression techniques (Cox et al., 2016; Crivello et al., 2016), and propensity score matching (Tare & Linck, 2011) approaches tend to be limited. Over-reliance on ANCOVA and similar techniques is not a panacea, and underlying assumptions need to be checked thoroughly. In particular, Paap (2018) critiques how the

[4] No clear definition on the number of participants of a large sample size exists; however all cited studies feature at least 230 participants, while Paap et al. (2014) suggest that participants in each group should be at least 180.

correlation between the treatment variable and the control variables can be responsible for the appearance of a spurious bilingual advantage. For example, participation in team sports and musical dexterities have been linked to superior executive function (Paap et al., 2018; Paap & Greenberg, 2013; Valian, 2015).[5] Team sports performance is positively correlated with executive function; the relationship being more pronounced for professional sports at high levels of competition (Paap et al., 2018; Vestberg et al., 2012). Valian (2015) observed that in studies with bilingual and monolingual children, the participants might get different amounts of exercise or might have experienced some other beneficial experience (e.g., musical abilities) influencing their executive functioning skills.

Inappropriate controlling strategies may also play a role in whether a bilingual advantage is detected. While it is common practice to match on age and SES, less-clear guidance exists for non-verbal intellectual ability and/or language skills. As non-verbal intellectual ability is correlated with particular aspects of executive function (e.g., working memory) (Friedman et al., 2006), matching groups on non-verbal intellectual ability may mitigate the bilingual advantage (Lehtonen et al., 2018). Bilingual language skills may be inferior to monolinguals (Calvo & Bialystok, 2014; Lehtonen et al., 2018); hence both appropriately assessing language skills to ensure a level playing field and matching are imperative (Bialystok et al., 2008).

Differences in the particulars of the executive function tasks, such as the administered task and subsequent modifications, whether quantity of interest is the accuracy and/or the response time, may also be affecting the results. Miyake et al. (2000) classify the executive

[5] Paap and Greenberg (2013) identify a causality issue in this case, where it may be argued that players excel in sports *because* they exhibit higher executive function. Arguably this may have been attributed to their growing up in a bilingual environment, and therefore some bilingual advantage been bestowed upon them. However, empirically testing this appears challenging.

function into updating, switching, and inhibition subcategories using latent factor analysis. Subsequent research attempts to proxy these subcategories using certain measures (e.g., antisaccade tasks for inhibition). As highlighted in Paap and Greenberg (2013), studies often use a single task for each executive function component, while De Bruin et al. (2015) find that studies in support of a bilingual advantage tend to report fewer tasks. Proxying for any of the subcategories of executive function relies on the implicit assumption that all proxies for, say, inhibitory control would: i) lead to the same conclusion; ii) be correlated with each other. Failure to observe both conditions suggests that no compelling evidence with regards to the bilinguals' performance may be reached, as argued in Paap and Greenberg (2013). As such, puzzling results may be reached with a subset of measures suggesting a bilingual advantage, while others not concurring with these (Poulin-Dubois et al., 2011; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011). This has been identified as the "task impurity problem" where accurate measurement of particular domains of the executive function suffers from the fact that the multitude of measures do not tap into the same cognitive processes, besides reported reliability and validity concerns (Lehtonen et al., 2018; Paap & Sawi, 2016). For inhibition alone, a variety of tasks have been used including the antisaccade task (Paap & Greenberg, 2013; Paap et al., 2014), flanker task (Calvo & Bialystok, 2014; de Abreu, Cruz-Santos, Tourinho, Martin, & Bialystok, 2012; Kapa & Colombo, 2013; Paap et al., 2014; Von Bastian, Souza, & Gade, 2016; Yang et al., 2011), Simon task (Antoniou et al., 2016; Gathercole et al., 2014; Paap & Greenberg, 2013; Paap et al., 2014; Poarch & van Hell, 2012; Von Bastian et al., 2016), Stroop (Calvo & Bialystok, 2014; Duñabeitia et al., 2014; Poulin-Dubois et al., 2011; Von Bastian et al., 2016), ANT (Antón et al., 2014; Paap & Greenberg, 2013; Poarch & van Hell, 2012; Yang et al., 2011). Therefore, and also based on our results from Chapter 3, we propose to approach the bilingual advantage debate on executive function in a holistic approach that would be utilising information from multiple subcategories of executive function as per the Miyake et al. (2000) classification. The present study aims to address these issues by using a comprehensive approach utilising information from multiple subcategories of executive function as per the Miyake et al. (2000) classification.

4.2.1 The current study

In this paper we present a novel methodology that accounts for the extended array of executive function tasks and metrics. Our method relies on the frontier methodology that measures the relative efficiency of a decision-making unit (DMU) compared to the best practice, in what is termed as *technical efficiency*. The technique is well-established in the areas of banking, economics, finance, transportation and management (Berger & Humphrey, 1997; Berger & Mester, 1997; Chen et al., 2015). Chen, Delmas and Lieberman (2015) verify that efficiency analysis is scarce in the management literature, even though its applicability is justified on a number of occasions. Within the fields of linguistics and psychology, efficiency applications are non-existent. We could not find any study using the frontier methodology in any of the highest-ranked journals (*Cognition, Psychological Research, Psychonomic Bulletin & Review, Journal of Memory and Language, Psychological Methods, Psychometrika, Psychological Science, The British Journal of Mathematical and Statistical Psychology, Current Directions in Psychological Science*) despite the fact that issues faced by researchers in these areas are not markedly different from the areas where the efficiency methodology has been successfully used.[6]

Technical efficiency allows the researcher to jointly examine multiple executive function tasks, while taking into consideration both the accuracy and the response time of the participant in each task. As such technical efficiency may be viewed as a special case of

[6] This is not a unique problem in this research strand. In finance, a survey of 374 studies finds that a total of 56 different measures have been used to proxy firm performance (Chen et al., 2015).

principal component analysis (PCA) technique, however, the two techniques are markedly different. Like PCA, technical efficiency can handle a large number of executive function tasks (identified as "outputs"). Conversely to PCA, technical efficiency accommodates, by construction, factors that may affect the performance in executive function tasks, such as age and non-verbal intellectual ability to name but a few (identified as "inputs"). As technical efficiency is a single variable it dispenses with the need of PCA to interpret the retained factors. Due to its non-parametric nature, it does not impose any distributional assumptions on the data, while as it does not rely on correlations between variables, it can accommodate cases where executive function tasks show low correlation (see Paap and Greenberg, 2013, and references therein). For these advantages, we opt for a frontier approach in this paper.

We contribute to the literature in four distinct ways. First, we introduce technical efficiency methodology and highlight the similarities and advantages of the technique to alternative ones that are popular in this field. We provide an application of this technique to an unstudied dataset on the executive functions of Greek-English bilingual and Greek monolingual young children. In addition, we employ an alternative dataset which we analyse with our technical efficiency approach. Second, we contribute to the monolingual/bilingual literature by comparing the executive function scores of Greek-English bilingual and Greek monolingual young children. Our executive function tests span attention, working memory and inhibition; hence allowing us to consider multiple aspects of the executive function from 70 participants. Third, we augment the technical efficiency analysis with a second-stage analysis that controls for differences in terms of age, non-verbal intellectual ability, grammar skill, expressive vocabulary skill, receptive vocabulary skill, SES, and language use. A bootstrap regression is used to mitigate any small sample bias, while an ANCOVA and a k-means nearest-neighbour approach are used as robustness. Fourth, we analyse our bilingual/monolingual dataset using conventional ANCOVA/MANCOVA techniques using the same control variables comparing the results to the technical efficiency analysis.

4.2.2 Efficiency studies across disciplines

Assessing the performance of organisations such as firms, financial institutions, educational institutions, and hospitals is of interest to investors, regulators, policy makers and consumers. Perhaps the simplest performance ratio is in the form of $Ouput/Input$. The manager of an electricity power-plant may get a rough estimate of the performance by assessing output level produced (e.g., electricity in MWh), given a level of input (e.g., barrels of Oil) (Kumbhakar & Tsionas, 2011). This performance ratio combines two important concepts; first that higher values of output are more desirable; second, there is a cost element that needs to be minimised. The owner of a dairy farm may also be interested in benchmarking the performance of his/her firm in a similar manner. The output in this case may be viewed as the milk (in litres) produced by the cows, while the inputs may relate to the number of cows used, the size of the land, the labour quantity and the quality of the feeds (Alvarez & Arias, 2004). With such information the manager could benchmark the operations against the competition and/or against time and find areas for improvement. For example, Johnes, Izzeldin, and Pappas (2014) argue that Islamic banks have lower technical efficiency than commercial banks due to the formers' business model restrictions that prohibit the issuance of loans to certain types of businesses.

In the above examples, we shall refer to the business entity as a decision-making unit (DMU). The DMU is a flexible definition allowing the generalisation of the technique across a wide range of applications (see Table 9). In general, the DMU may be viewed as a "black-box" entity that transforms inputs into outputs. The term "decision" implies a mental process; in fact, it could be argued that the manager in the above examples would have some control over the production process and/or the output-input mix. However, this does not need to be the case as the DMU could be a jet engine (Bulla, Cooper, Wilson, & Park, 2000).

Table 9 *Examples of technical efficiency studies*

Inputs	DMU	Outputs	References
		Example 1	
Number of cows Size of land (in hectares) Labour (in man-equivalent hours) Feeds (in tons)	Dairy farms	Milk (in litres)	Alvarez & Arias (2004)
		Example 2	
Fuel Labour (in man-equivalent hours) Fuel (in tons) Capital (in millions USD)	Power plants	Electricity (in MWh)	Kumbhakar & Tsionas (2011)
		Example 3	
Labour (in millions USD) Physical capital (in millions USD) Financial capital (in millions USD)	Banks	Loans (in millions USD) Securities (in millions USD)	Johnes et al. (2014)
		Example 4	
Number of inpatients Number of doctors Number of nurses	Hospitals	Outpatients	Cooper, Seiford, & Tone (2007)
		Example 5	
Total cost	Universities	Full-Time Equivalent UG students Full-Time Equivalent PG students Research income Intellectual property income	Thanassoulis, Kortelainen, Johnes, & Johnes (2011)
		Example 6	
Non-verbal intellectual ability Grammar skill Expressive vocabulary skill Receptive vocabulary skill Age	Child	Executive function (Accuracy) Executive function (RT)	This study (Chapter 4)

Up to this point, we have referred to “performance” without giving an appropriate definition. In fact, this is a known issue in certain disciplines as the “true” firm performance is latent, with individual measures (i.e., proxies) not being comprehensive indicators. In the management literature, the creation of competitive advantage of a firm against its competitors is important, as it could enhance a firm’s performance (Douglas & Judge Jr, 2001). On this occasion, *performance* per se would relate to profitability; yet other aspects, such as the firm value may also have been relevant. In the banking literature, capitalisation, profitability, stability, and liquidity could fall under the umbrella term of *performance*; yet multiple indicators exist to separately quantify each of these concepts. Drivers of each of these indicators are not necessarily the same. Ultimately, one may be interested in a holistic *performance* of a bank. Therefore, the challenge lies in combining all the information from a set of indicators to arrive at a meaningful conclusion, which should be generalizable and replicable. Hence, the need for an approach that could capture multiple aspects of the complex organisational structure and present a single, straightforward indicator to the interested parties is apparent.

We assume that each participant is the DMU, with outputs comprising i) paying attention; ii) organisation; iii) maintaining focus; iv) self-monitoring (Diamond, 2013). These skills may be mapped against the three distinct and interrelated processes, namely working memory, inhibition, and switching identified in Miyake et al. (2000). Children enhance their skills through education in anticipation of increased future progress (Walker & Zhu, 2011). Inputs to the DMU are non-verbal intellectual ability, grammar skill, expressive vocabulary skill, and receptive vocabulary skill.

4.3 Method

4.3.1 Participants

Our sample comprises 32 bilingual (mean age = 9 years and 1 month, *SD* = 2 years and 2 months, 18 females and 14 males) and 38 monolingual (mean age = 9 years and 9 months, *SD* = 1 year and 8 months, 22 females and 16 males) children; a total of 70.[7] The bilingual children are competent in both Greek and English languages to varying degrees. The bilingual children were recruited if at least one of their parents spoke the Greek language with them. The mean age of acquisition is 7 months (*SD* = 1 year and 2 months) for Greek and 2 years and 6 months (*SD* = 2 years and 9 months) for English. We have excluded any trilingual participants.[8] Children were included in the study if their non-verbal intelligence score was not under 80. In this case, all children had scores over 80. Based on parental and teacher reports the children did not have any hearing, behavioural, emotional or mental impairment. More information is included in Table 12 and section 4.5.1 below.

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[7] This sample consists of the same children included in the Method section of Chapter 1 with the addition of older Greek-English bilingual children and older Greek monolingual children compared to the sample in Chapter 3. The English monolingual group has not been included in this study since we did not recruit older English monolingual children.

Our sample size, a total of 70 children, is impacted by the fact that five executive function tests are administered to all participants. As such, the sample size is larger than the study of Poulin-Dubois et al. (2011) who also administer multiple executive function tests, but is smaller than the study of Duñabeitia et al. (2014) who administer a single executive function test on about 500 children. We use regression with bootstraped standard errors to correct for any small sample bias.

[8] A few participants from either group have limited knowledge of other languages. This information is revealed to us via the parental questionnaire. The level of knowledge in these other languages is significantly inferior to the main languages under examination (i.e., English and Greek), with participants only knowing a handful of words. The level of knowledge between the Bilinguals and the Greek Monolinguals shows no significant difference between them, which suggests no potential heterogeneity induced by these participants in the analysis. As a robustness check we exclude these participants from the analysis, and the results remain qualitatively similar.

Please see 3.4 Method section in Chapter 3 for further information about the educational background of these bilingual children, the ethics procedure, the materials and procedure.

4.3.2 Technical efficiency

In this section we introduce the concept of technical efficiency, which may be viewed as a special case of a performance ratio. We use a random sample from our dataset and assume that each participant is a Decision-Making Unit (DMU) that produces two outputs from two inputs. The outputs are the accuracy scores on two executive function tasks; the Backward digit span (BDST) and the Counting recall. The inputs are a measure of the non-verbal intellectual ability (KBIT-2) and a measure of the grammar skill (DVIQ). Ultimately, we are interested in comparing the performance of the DMUs. We illustrate three cases; case A considers one Output and one Input; case B uses two Outputs and one Input; case C uses two Outputs and two Inputs.

Table 10, Panel A, presents the output and input values for each of the ten participants of the random sample. Panel B calculates an array of performance measures associated with each of the three cases outlined above.

Table 10 *Performance ratios and technical efficiency*

Participant	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Panel A: Random Sample details										
KBIT-2	89.13	89.13	82.61	54.35	69.57	52.17	60.87	67.39	71.74	82.61
DVIQ	96.77	96.77	87.10	93.55	90.32	90.32	58.06	38.71	96.77	58.06
BDST	75.00	75.00	75.00	66.67	60.00	66.67	66.67	66.67	75.00	68.42
Count recall	81.63	81.63	60.71	57.14	75.00	50.00	35.71	46.43	57.14	71.43
Panel B: Performance ratios										
Case A: 1 Output / 1 Input										
BDST / KBIT-2	0.841	0.841	0.908	1.227	0.863	1.278	1.095	0.989	1.045	0.828
Case B: 2 Outputs / 1 Input										
BDST / KBIT-2	0.841	0.841	0.908	1.227	0.863	1.278	1.095	0.989	1.045	0.828
Count recall /KBIT-2	0.916	0.916	0.735	1.051	1.078	0.958	0.587	0.689	0.797	0.865
Case C: 2 Outputs / 2 Inputs										
BDST / KBIT-2	0.841	0.841	0.908	1.227	0.863	1.278	1.095	0.989	1.045	0.828
Count recall / KBIT-2	0.916	0.916	0.735	1.051	1.078	0.958	0.587	0.689	0.797	0.865
BDST / DVIQ	0.775	0.775	0.861	0.713	0.664	0.738	1.148	1.722	0.775	1.178
Count recall / DVIQ	0.844	0.844	0.697	0.611	0.830	0.554	0.615	1.199	0.590	1.230
Technical efficiency	0.793	0.793	0.752	0.789	0.796	0.772	0.809	1.000	0.738	0.934

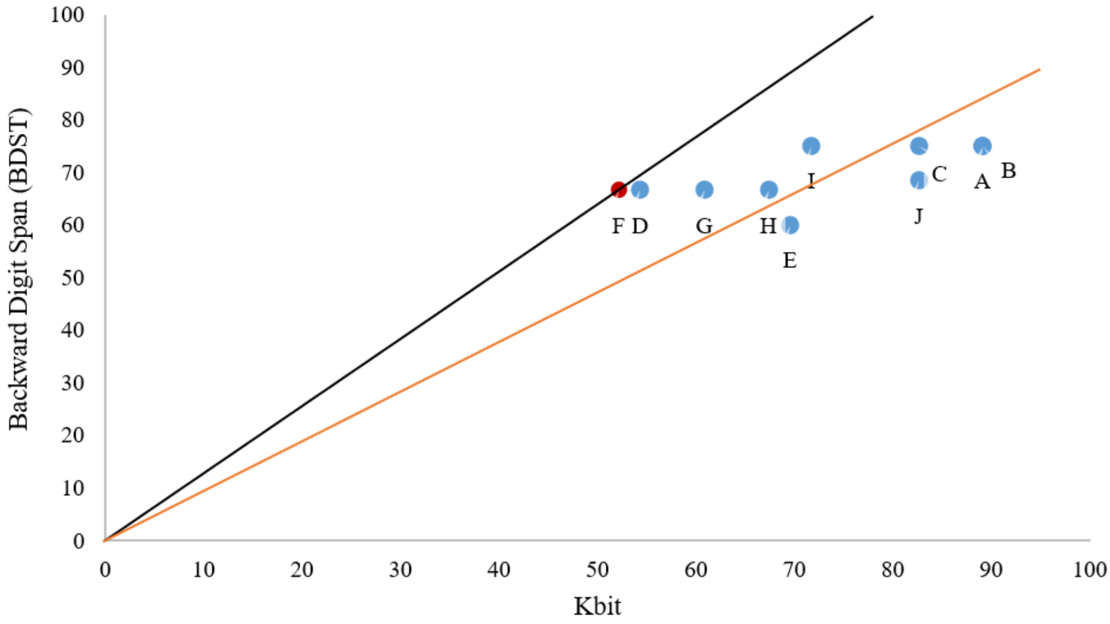
Notes. The table reports inputs and outputs used in the efficiency analysis for a random sample of 10 participants from our datasets. The outputs are the accuracy scores (on a percentage scale) on BDST and Count recall executive function tests. The outputs are the accuracy scores of two executive function tasks of working memory; BDST and Counting recall. The inputs are measures of non-verbal intellectual ability (KBIT-2) and grammar skill (DVIQ). Performance ratios are presented in Panel B for the cases of 1 output / 1 input (Case A), 2 outputs / 1 input (Case B) and 2 outputs / 2 inputs (Case C). The technical efficiency row presents the equivalent measure, which is estimated using Data Envelopment Analysis (DEA) as described in section 4.1.

In case A, the ratio BDST / KBIT-2 may be viewed as a performance measure where higher values denote a participant with a superior performance; i.e., a higher accuracy score in the BDST measure, using a lower KBIT-2 score. Participant F has the highest value (1.278), hence may be viewed as the one with the best performance, or the most efficient. That is, s/he is producing the highest BDST accuracy score by using the lowest KBIT-2 score. A graphical representation of the ten participants is given in Figure 1, Panel A. The line that connects the axis origin (black line) to point D (the left-most in the graph) is the efficient frontier and envelops all the other points. By contrast, a regression line (orange line) goes through the middle of these points; a direct consequence of the estimation technique used. As such, while the regression line considers the “average” as the benchmark unit, by allowing some to over-perform and others to under-perform, the frontier analysts consider the efficient (i.e., best-practice) unit as the benchmark; thus letting all others to under-perform.

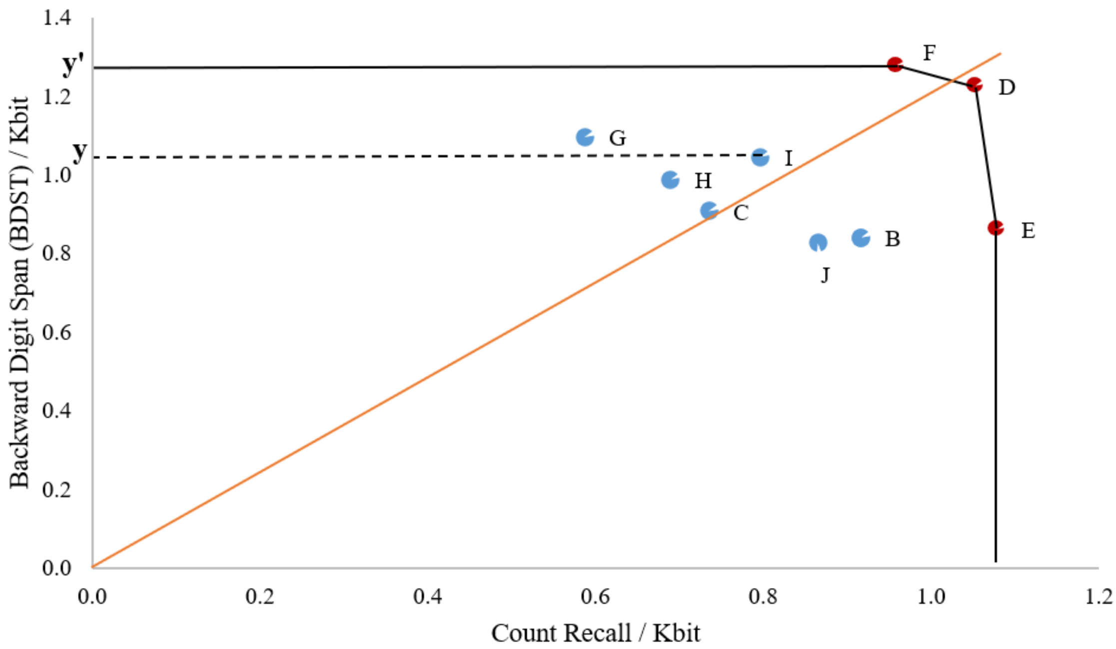
In case B, the ratios BDST / KBIT-2 and Counting recall / KBIT-2 are defined. Points F, D and E are of special attention as they are the furthest away from the axis origin, hence they represent the best-performers (i.e., efficient ones). The participants represented by these three points represent efficient combinations in the sense that they produce the maximum output for a given level of input. Contrary to case A, the efficient frontier here is a piecewise linear frontier that is made up of the efficient DMUs and envelops all the inefficient combinations. For example, point *I* lies inside the frontier and has an efficiency score of Oy/Oy’, which means that there is a margin of improvement in the performance of participant *I* by Oy’-Oy (i.e., the distance between point *I* and the efficient frontier).

Figure 1 *Efficient frontiers*

Case A: 1 Output / 1 Input



Case B: 2 Outputs / 1 Input



Notes. The figure shows the efficient frontier (solid black line) in the case of 1 ouput / 1 input (Case A), and 2 outputs / 1 input (Case B). The orange line represents the best-fit line from a regression model. The outputs are the accuracy scores in two executive function scores, BDST (Case A and B) and Count Recall (Case B). The input is the non-verbal intellectual ability as proxied by the KBIT-2 score (Case A and B). The 10 participants labelled A-J are a random sample from our dataset.

Case C would require the ratios BDST / KBIT-2, Counting recall / KBIT-2, BDST / KBIT-2 and Counting recall / DVIQ to be computed. However, in this case visual representation would have to be multidimensional. A particular challenge that was made apparent in case B is that the points (F, D, E) are all efficient but have a different output/input mix. For example, point F is superior in terms of BDST, while point E in terms of Counting recall. The fact that the output/input mix would vary among DMUs becomes more apparent as outputs and inputs considered increase. Consequently, it is difficult to identify the participant with the overall best performance, unless we assign some "desirability" on the outputs (and similarly the inputs). For example, this could take the form of a higher accuracy in the BDST having a higher value than in the Counting recall.

To address the issue, Charnes, Cooper, and Rhodes (1978) introduced the concept of technical efficiency in the form of a linear optimisation model – the CCR model. The novelty lies in the use of weighted outputs and weighted inputs to form a performance measure, known as *technical efficiency*. Technical efficiency may be viewed as a ratio where, on the nominator (denominator) each output (input) is assigned a weight. The weight, which lies between 0 and 1, is universal for all the DMUs, and could be viewed as a measure of the relative desirability of the outputs and inputs.

A linear optimisation technique that maximises the overall technical efficiency of the system is used to estimate the weights (Charnes et al., 1978). Hence, the weights, and consequently any ranking of outputs and inputs that is implied, is determined from the data themselves without any a priori information or assumptions.

Mathematically, and starting from the case of two outputs and two inputs (i.e., Case C), the technical efficiency ratio for a single DMU is given as:

$$TE = \frac{u_1 y_1 + u_2 y_2}{v_1 x_1 + v_2 x_2} \quad (1)$$

where y_1 and y_2 being the BDST and Counting recall accuracy scores (Outputs); x_1 and x_2 being the KBIT-2 and DVIQ scores (inputs); u_1, u_2, v_1 and v_2 are output and input weights respectively.

We can generalise this to the case of R outputs and M inputs as follows:

$$TE_j = \frac{\tilde{u}_1 y_{1,j} + \tilde{u}_2 y_{2,j} + \cdots + \tilde{u}_R y_{R,j}}{\tilde{v}_1 x_{1,j} + \tilde{v}_2 x_{2,j} + \cdots + \tilde{v}_M x_{M,j}} \quad (2)$$

Here we also add the subscript j which denotes the DMU with $j = 1,2, \dots, N$ as well as the tilde on top of the weights to denote that these are estimated through linear optimisation. Note that as the weights are common across all DMUs, they do not carry the j subscript.

The linear optimisation works by maximising the sum of TE_j across all DMUs subject to the TE_j being bounded between 0 and 1 (where 1 is assigned to the efficient DMUs) for each DMU, and to the weights being non- negative.[9] Mathematically:

$$\max_{u,v} \sum_{j=1}^{N} TE_j \quad (3)$$

subject to:

$$\text{subject to:} \begin{cases} 0 \leq TE_j \leq 1 \\ \tilde{u}_1, \tilde{u}_2, \dots, \tilde{u}_R \geq 0 \\ \tilde{v}_1, v_2, \dots, \tilde{v}_R \geq 0 \end{cases} \quad (4)$$

[9] We implement the DEA optimisation in LIMDEP. Other packages that have been used are Stata, R, Matlab as well as several dedicated software for DEA estimation (e.g, DEAP Frontier).

4.3.3 Data transformations

In our case, each child wishes to maximise certain outputs while receiving certain inputs. We consider the output to be the executive function score, which may be viewed as a proxy for brain performance and linked to future academic performance/achievements. Children would want to maximise this score as this is related to other aspects of performance in one's life, e.g., earnings, career etc. For example, a strong positive connection between academic performance and future earnings has been documented (Walker & Zhu, 2011).

As per the Miyake et al. (2000) classification, three distinct and interrelated components of executive function are defined. These relate to an individual's ability to switch between various tasks (switching/shifting), the ability to maintain and process information in mind (working memory), and the ability to suppress irrelevant information at any given moment (inhibition). Performance in each of these categories is assessed via the following tests: i) BDST, ii) Counting recall, iii) Colour shape, iv) Non-verbal Stroop (Stroop), v) ANT. All of these tests and their administration procedure have been explained in Chapter 3.

In each test we record: i) the accuracy (ACC); ii) the response time (RT) of the child, which form our two outputs. The accuracy for each test and each child is calculated as the average accuracy over the respective number of trials that each test consists of, and ranges theoretically between 0 and 1. For tests that have congruent and incongruent trials, we use the average accuracy. Empirically, extreme points are not observed, thereby the tests are appropriate for the children's age. The higher the accuracy the better the performance of the child.

The response time is measured in milliseconds and is only considered for the correct answers to test questions. The lower the response time, the faster the response is given. Consistent with the literature, we exclude any response time that is below 200ms (Antoniou et al., 2016). We also carry out an outlier treatment in line of Purić, Vuksanović, and Chondrogianni (2017) where we trim response times that lie outside of a 3 standard deviations bound.[10] As the two output variables are inversely coded, we consider the inverse of response time and dub this as *Response Speed* (1/RT).[11] Hence, the two outputs in our case are: i) Accuracy (y_1); ii) Response Speed (y_2). The inputs are as follows: i) non-verbal intellectual ability (x_1); ii) grammar skill (x_2); iii) expressive vocabulary skill (x_3); iv) receptive vocabulary skill (x_4); v) age (x_5).

The grammar, expressive vocabulary, and receptive vocabulary skills of monolingual children are assessed in Greek using the DVIQ, the PWFT, and the Greek receptive vocabulary test, respectively. The grammar, expressive vocabulary, and receptive vocabulary skills of bilingual participants are assessed in Greek using the same measures as with the monolinguals and in English using the equivalent English tests, namely TROG-2, CELF-4 and BPVS, respectively. With regards to the non-verbal intellectual ability, we used the Matrices subtest, which is the non-verbal component of the KBIT-2. Table 11 presents information about the mapping of the tasks for each group of participants.

To arrive at comparable estimates of grammar, expressive vocabulary, and receptive vocabulary skills, we standardise the scores of the monolinguals and bilinguals. As the bilinguals have two measures for each skill, one in Greek and another in English, we follow

[10] We also apply an alternative outlier treatment whereby we winsorise at the 1st and 99th percentiles of the response times within each executive function test. Using these response times does not challenge our results. For more detailed insights on data outlier treatments in the context of bilingualism we direct you to Zhou and Krott (2016).

[11] The transformation is inspired by Bayesian analysis where the inverse of standard deviation (dubbed as precision) is typically used. Other ways are also available. One would be to take the inverse of accuracy for output 1 instead. A more challenging approach would entail classifying response time as a "bad output" in line with the studies of Fukuyama and Matousek (2011). The approach of multiplying the response times by -1 (see Antoniou et al., 2016) does not work with efficiency analysis as the inputs and outputs need to be positive.

three strategies to arrive at a composite measure of the respective skill. In the most naïve and easiest-to-implement strategy, we assume that all bilinguals are balanced between English and Greek, hence their composite score would be a simple weighted average of the respective tasks, and this represents Composite Score 1 (CS1). As the balanced bilingual assumption may be strong, we introduce a second, more realistic composite score (CS2) that assumes that bilinguals may be more competent in a particular language. Hence, under CS2 the composite measure is a weighted average of the individual tasks, with the weights calculated from the relative performance of the participants in the Greek and English versions of the test. Composite Score 3 (CS3) is similar to CS2 with the only difference being that the relative weights are derived from the parental questionnaire; hence the relative competency level is self-declared. In the following analysis we present the results based on CS2, and we compare with the results of CS1 in the robustness section.[12]

Similar to regression models, a DEA analysis needs to be "well-specified" in the sense that relevant variables should be included in the specification. In case of regression a minimum number of observations is required for estimation; statistical inference (e.g., hypothesis testing) requires additional observations and/or bootstrap techniques for small samples. Due to the DEA's non-parametric nature, minimum sample size has no formal statistical basis. However, DEA's discriminatory power depends on the relative numbers of inputs, outputs and DMUs in the sample. As a rule of thumb, the number of DMUs should be at least 2-3 times higher than the inputs and outputs combined (Banker et al., 1989; Golany & Roll, 1989). In our case the number of DMUs is at least 7 times higher than the combined inputs and outputs.

[12] A robustness check with CS3 instead of CS2 is also performed with the results being qualitatively similar; hence this is not reported for brevity.

Table 11 *Test mapping per group*

Measures	Administered test	Category	Bilinguals	Greek Monolinguals
Accuracy (y_1) Response Speed (y_2)	BDST	Working memory	✓	✓
	Counting recall	Working memory	✓	✓
	Colour shape	Shifting	✓	✓
	Non-verbal Stroop	Inhibition	✓	✓
	ANT	Inhibition/Attention	✓	✓
Non-verbal intellectual ability (x_1)	KBIT-2		✓	✓
Grammar skill (x_2)	DVIQ		✓	✓
	TROG-2		✓	—
Expressive vocabulary skill (x_3)	PWFT		—	✓
	CELF-4		—	—
Receptive vocabulary skill (x_4)	Greek receptive vocabulary		—	✓
	BPVS		—	—

Notes. The table presents the outputs and inputs of the technical efficiency analysis, with information on the mapping of the tests in each group.

4.3.4 Second stage analysis

The technical efficiency estimate from the previous step may be used as the dependent variable in subsequent analysis. We investigate differences in the technical efficiency of monolingual and bilingual children in a second stage analysis. We use three estimation methods: i) an ANCOVA, which is widely used in the literature; ii) a regression with bootstrap corrected standard errors that corrects for potential small sample bias (Cameron & Trivendi, 2005); and iii) a k-means nearest-neighbour matching technique. We opt for the k-means nearest-neighbour as it is a non-linear, non-parametric technique that matches observations with similar characteristics. The advantage of k-means nearest-neighbour matching is that it does not rely on a formal model (like propensity score does); thus, being more flexible. Like the propensity score approach, it can match observations on both categorical and continuous variables. However, when matching on continuous covariate, a bias-correction term is necessary (Abadie & Imbens, 2006, 2011). More information is provided in Technical Appendix A.

We allow for three formulations in each estimation method, hereafter referred to as Specifications A to C respectively. These specifications are progressively less restrictive as they allow for decreasing similarities between the participants. In particular, specification A controls for differences with respect to non-verbal intellectual ability, grammar skill, expressive and receptive vocabulary skills and age. Specification B further adds SES to specification A, while specification C further adds language use to specification B.

4.4 Results

4.4.1 Descriptive statistics

Table 12 and presents key descriptive statistics for the variables utilised in the analysis. The mean, standard deviation and median for the bilinguals and monolinguals is reported alongside an ANOVA between-group test. Lack of statistical significance in the F-statistic suggests no group differences between the bilinguals and monolinguals.[13]

[13] The data are available at: https://bangoroffice365-my.sharepoint.com/:f:/r/personal/elp4ae_bangor_ac_uk/ Documents/%27The%20Executive%20Function%20of%20Bilingual%20and%20Monolingual%20Children-%20A%20Technical%20Efficiency%20Approach%27%20data%20and%20code?csf=1&web=1&e=HeKyPF

Table 12 *Descriptive statistics*

Measure	Test		Bilinguals (n=32)			Greek Monolinguals (n=38)				
		Units	Mean	SD	Median	Mean	SD	Median	F-stat	η^2
Backward digit span (ACC)		%	0.624	0.097	0.628	0.668	0.080	0.667	4.47**	0.062
Counting recall (ACC)		%	0.494	0.144	0.464	0.478	0.139	0.500	0.22	0.003
Colour shape (ACC)		%	0.821	0.083	0.836	0.830	0.086	0.848	0.18	0.003
Stroop (ACC)		%	0.894	0.117	0.933	0.900	0.109	0.947	0.06	0.001
ANT (ACC)		%	0.931	0.089	0.965	0.954	0.067	0.992	1.56	0.022
Backward digit span (RT)		ms	933.30	289.95	956.08	807.11	271.59	792.27	3.53	0.049
Counting recall (RT)		ms	2394.90	1215.61	2149.13	1887.87	1179.38	1523.10	3.12	0.044
Colour shape (RT)		ms	921.67	186.50	923.48	962.89	147.44	984.83	1.07	0.015
Stroop (RT)		ms	861.46	298.93	792.22	784.92	195.46	741.64	1.65	0.024
ANT (RT)		ms	912.30	255.63	865.50	861.81	189.42	866.88	0.90	0.013
Non-verbal intellectual ability	KBIT-2	%	61.75	15.35	64.13	60.93	14.35	58.70	0.05	0.001
Grammar skill	DVIQ	%	82.96	15.05	87.10	92.19	6.12	93.55	11.96***	0.150
Expressive vocabulary skill	PWFT	%	45.56	25.97	52.00	83.05	8.28	84.00	70.84***	0.510
Receptive vocabulary skill	GreekRecVoc	%	44.20	20.74	46.24	70.46	11.75	71.68	44.16***	0.394
Grammar skill	TROG-2	%	71.72	18.78	72.50	—	—	—	—	—
Expressive vocabulary skill	CELF-4	%	57.86	20.50	56.48	—	—	—	—	—
Receptive vocabulary skill	BPVS	%	63.73	15.16	61.90	—	—	—	—	—
Age		Years	9.14	2.24	8.90	9.77	1.69	9.91	1.81	0.026
SES		%	76.56	19.31	75.00	58.55	12.79	56.25	21.76***	0.242
Greek proficiency		%	79.69	23.07	90.00	96.32	7.86	100.00	17.39***	0.204
English proficiency		%	92.50	10.78	100.00	48.68	28.30	55.00	68.24***	0.501
Other proficiency		%	14.38	24.62	0.00	12.89	25.56	0.00	0.06	0.001
Greek language use		%	49.90	22.73	51.14	94.77	7.88	96.51	129.80***	0.656
Music		Binary	0.50	0.51	0.50	0.32	0.47	0.00	2.47	0.035
Years in Greek school		Years	0.47	1.11	0.00	5.00	1.80	5.00	153.54***	0.693
Years in complementary school		Years	3.43	3.47	2.57	2.75	0.00	0.00	69.55***	0.506
Total Greek education		Years	3.94	2.39	4.00	5.00	1.80	5.00	4.49**	0.062

Notes. The table shows descriptive statistics for the executive function tests (accuracy and response times) and other variables of the dataset. n denotes the observations, SD denotes the standard deviation. F-stat and η^2 correspond to the between-subjects ANOVA tests. ***, **, * denote statistical significance at the 1, 5 and 10% significance level respectively.

A first inspection of the executive function accuracy and response times scores (also see Figure 2) does not suggest any between-group differences, with the exception of the accuracy score in the BDST task ($F(1, 68) = 4.47$, $p < .05$) but here explanatory variables such as SES and languages skills have not been included in the comparisons. A comparison of non-verbal intellectual ability and age between the two groups does not suggest any significant difference ($F(1, 68) = .05$, ns) and ($F(1, 68) = 1.81$, $p > .10$). A comparison of the Greek versions of the grammar ($F(1, 68) = 11.96$, $p < .001$), expressive vocabulary ($F(1, 68) = 44.16$, $p < .001$) and receptive vocabulary ($F(1, 68) = 70.84$, $p < .001$) tests suggests significant between-group differences (also see Figure 3), which is consistent with the findings of Bialystok and Craik (2010).

The bilinguals have significantly higher SES compared to the monolingual peers ($F(1, 68) = 21.76$, $p < .001$), higher English proficiency score ($F(1, 68) = 68.24$, $p < .001$) and lower Greek proficiency score ($F(1, 68) = 17.39$, $p < .001$). Proficiency in other languages is comparable in both groups ($F(1, 68) = .20$, ns)[14]. The two groups show a significant difference in terms of Greek language use, with the monolinguals using the Greek language significantly more ($F(1, 68) = 129.80$, $p < .001$) compared to the bilinguals, as perhaps expected. The proportion of participants that play a musical instrument is comparable between the two groups ($F(1, 68) = 2.47$, $p > .10$).[15] Years in Greek school is significantly higher for the monolinguals

[14] A few participants from either group have limited knowledge of other languages. This information is revealed to us via the parental questionnaire. The level of knowledge in these other languages is significantly inferior to the main languages under examination (i.e., English and Greek), with participants only knowing a handful of words. The level of knowledge between the Bilinguals and the Greek Monolinguals shows no significant difference between them, which suggests no potential heterogeneity induced by these participants in the analysis. As a robustness check we exclude these participants from the analysis, and the results remain qualitatively similar.

[15] We use the music binary variable (1 if a participant plays a musical instrument, zero otherwise) to proxy for unmeasured cultural differences between the groups. Other alternatives may be participation in individual/team

(F(1, 68) = 153.54, $p < .001$) as they have always been studying in a Greek school in Greece. The majority of the bilingual cohort (25 out of 32 participants) never attended a Greek school in Greece, while the remaining 7 attended one for a period of 1- 4 years.[16] Instead, the bilinguals attended a supplementary (Greek) school in England, which is additional to their formal English education.[17] The variable Total Greek Education shows the total exposure of a participant to the Greek educational system, whether formal in Greece, or informal (i.e., supplementary) in the UK. A between groups test reveals only mild difference (F(1, 68) = 4.49, $p < .05$) in favour of the Greek monolinguals.

The correlations between the accuracy scores, response times as well as age, SES, non-verbal intellectual ability, grammar, expressive and receptive vocabulary scores are reported in appendix Table A28. Positive and significant coefficients between all the accuracy scores of the tests are evidenced. This suggests a similarity in the performance of the participants across the tasks. The fact that inhibition tasks are positively correlated is in line with the Paap and Greenberg (2013) suggestions. In particular, we find significant correlation between Stroop and Colour Shape tasks in terms of accuracy scores ($r = .45$, $p < .01$) and of response times ($r = .57$, $p < .01$). However, we also document significant and positive correlations between working memory and inhibition tasks. For example, BDST and Stroop ($r = .57$, $p < .01$) that provides empirical support to the fact that the underlying cognitive processes may be interrelated or that the proxies used may not tap solely on these processes (task impurity problem). Negative and significant correlations between accuracy and RT scores as perhaps

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sports and/or other extracurricular activities. However, as western societies the English and the Greek share a similar cultural background; hence any such effect is expected to be minimal.

[16] Of these 7 participants that attended Greek school in Greece, 2 attended for one year, 1 for two years, 3 for three years and 1 for 4 years. Our technical efficiency results remain robust to the exclusion of these seven participants, with the results of this analysis being available from the authors upon request.

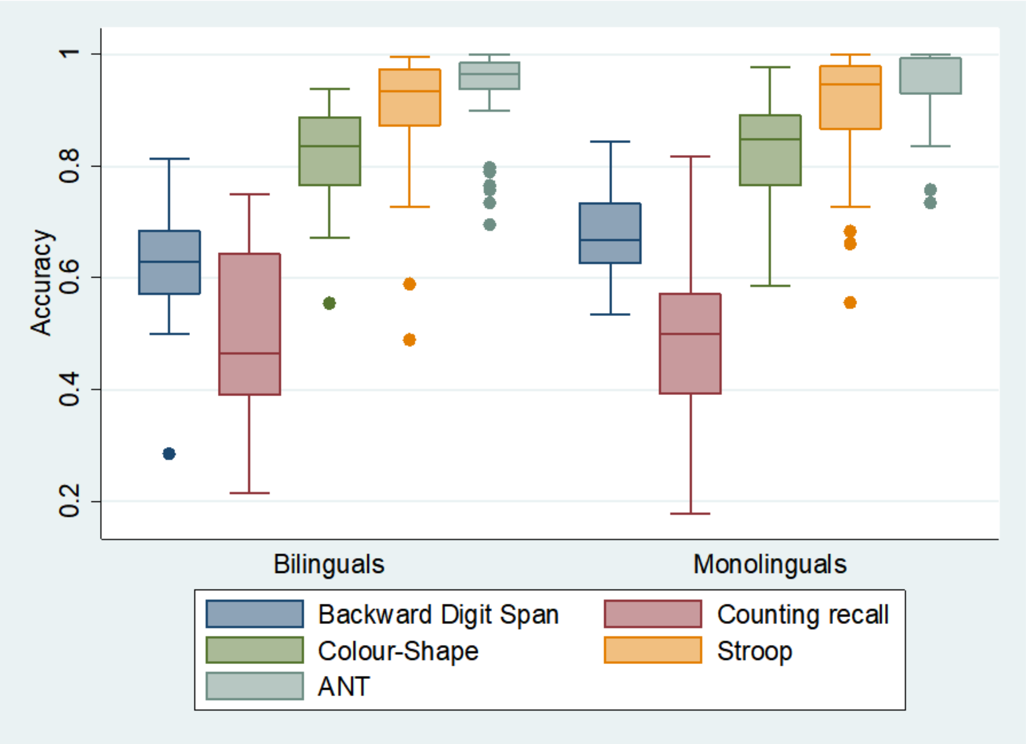
[17] This is in contrast to Greek pupils attending a Greek school in the UK, which follows and delivers the Greek curriculum in Greek.

expected, for example within the Stroop task we observe a negative and significant correlation ($r = -.41$, $p < .01$). All other variables have the expected relationship with accuracy and RT scores of the tasks, with the exception of SES that does not exhibit any significant relationship. For example, higher IQ is positively correlated with accuracy scores and negatively correlated with RTs.[18]

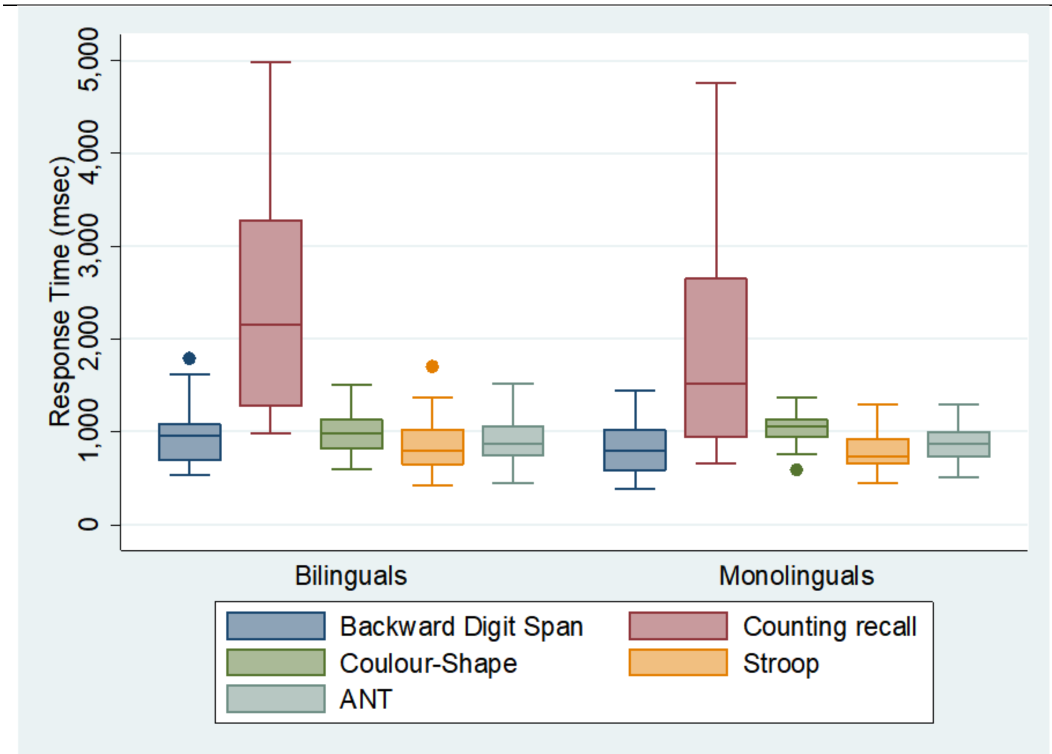
[18] Higher correlation between outputs and inputs tends to increase the average efficiency scores, while the within-outputs or within-inputs correlation does not have a significant effect on the average efficiency score (López, Ho, & Ruiz-Torres, 2016). In addition, the efficiency of a unit based on a DEA approach is determined by the unit's location relative to the frontier. Therefore, the *average* efficiency score is not as informative as the *relative* efficiency score between the two (or more) groups.

Figure 2 *Box-Plots of executive function metrics*

Panel A: Accuracy

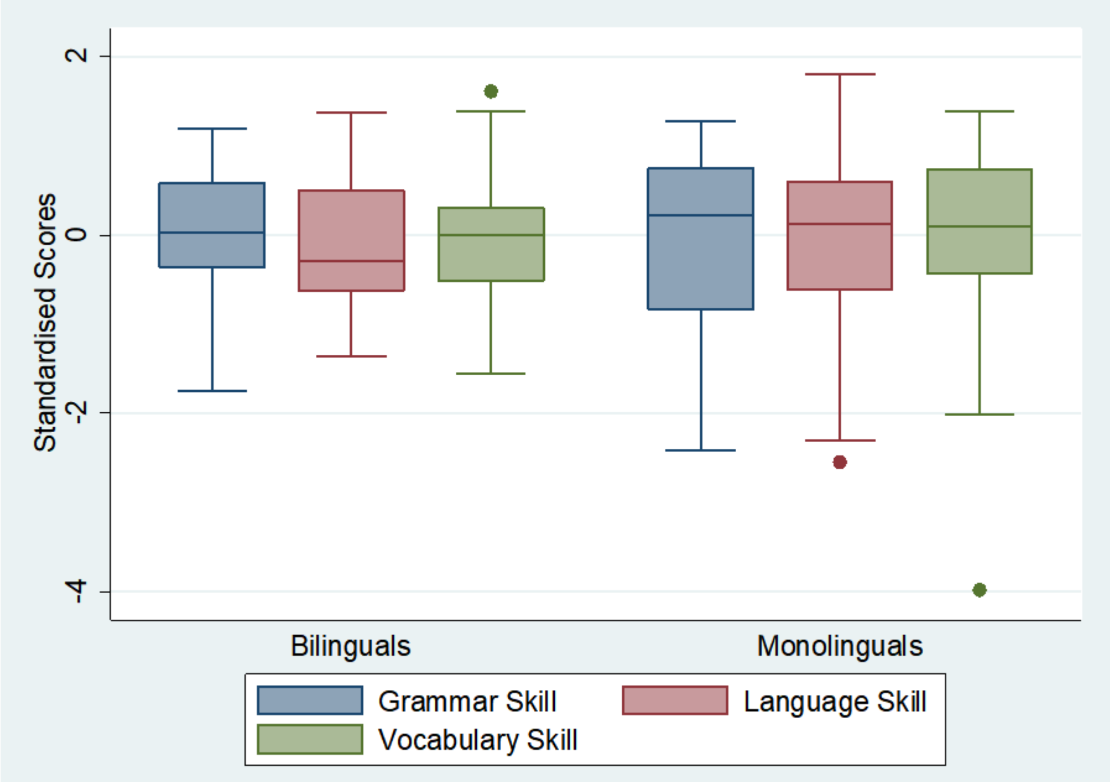


Panel B: Response Time



Notes. The figure reports box plots of accuracy and response time metrics for bilinguals and monolingual groups.

Figure 3 *Grammar, Language and Vocabulary skill standardised scores*



Notes. Standardised grammar, language and vocabulary skill metrics for bilinguals and monolingual groups.

4.4.2 Efficiency estimates

Table 13 presents the technical efficiency estimates of Bilinguals and Monolinguals. Under panel A we report technical efficiency estimates when using each executive function test's accuracy and response speed as outputs. In panel B, we combine the information from multiple executive function tests in two variants, namely the "Accuracy" and the "Response Speed". The former uses the accuracy scores of all five tests, while the latter uses their respective response speed. The "All" variant includes both the accuracy and the response speed from all five executive function tests. The choice of inputs is always the same, which are the non-verbal intellectual ability, grammar skill, expressive vocabulary skill, receptive vocabulary skill and age.[19] A battery of statistical tests is performed for the between-group differences. The estimated Cronbach's alpha ($a = .93$) indicates strong reliability of the technical efficiency variables.

[19] As a robustness check we have eliminated age from the list of input and the results remain qualitatively similar. Although these are not reported for brevity, they are available from the authors upon request.

Table 13 *Technical efficiency estimates by group*

	Monolinguals (n=38)			Bilinguals (n=32)							
Executive function test	Mean	SD	Median	Mean	SD	Median	Mean % gain	Anova F-test	T-test	MW-test	KS-test
						Panel A					
Backward digit span	0.756	0.107	0.738	0.837	0.137	0.844	10.25	7.78***	2.73***	2.96***	0.41***
Counting recall	0.645	0.092	0.623	0.755	0.145	0.732	15.75	14.78***	3.70***	3.60***	0.50***
Colour Shape	0.649	0.144	0.647	0.794	0.152	0.771	20.19	16.78***	4.08***	3.59***	0.40***
Non-verbal Stroop	0.642	0.126	0.617	0.760	0.151	0.721	16.86	12.78***	3.52***	3.67***	0.48***
ANT	0.622	0.111	0.601	0.755	0.157	0.744	19.36	17.12***	4.02***	3.83***	0.53***
Total	0.663	0.116	0.645	0.780	0.148	0.763	16.32				
						Panel B					
Accuracy	0.793	0.101	0.769	0.897	0.093	0.908	12.41	20.12***	4.52***	4.08***	0.46***
Response Speed	0.588	0.157	0.557	0.717	0.212	0.655	19.77	8.50***	2.84***	2.87***	0.37***
All	0.796	0.099	0.775	0.905	0.094	0.908	12.85	21.94***	4.70***	4.34***	0.49***

Notes. The table presents DEA technical efficiency estimates for the Monolingual and Bilingual groups of children of our sample. The outputs in each executive function task are: i) Accuracy, and ii) Response Speed. The outputs of all five executive function tasks are utilised in the "All" variant. The "Accuracy" and "Response Speed" variants use the accuracy scores and response speed scores of all executive function tasks respectively. Five inputs are utilised, namely: i) Non-verbal intellectual ability, ii) Grammar skill, iii) Expressive vocabulary skill, iv) Receptive vocabulary skill, v) Age. The weighting scheme for the Bilingual inputs is based on Composite score 2 (see section 4.3). For each group we present the mean, standard deviation and median of technical efficiency, the logarithmic percentage gain where a positive value indicates that Bilinguals are more efficient than monolinguals. A battery of tests is presented including an ANOVA F-test and a bootstrap t-test for the equality of means between the two groups, a Mann-Whitney (MW) test for the equality of medians between the two groups, a Kolmogorov-Smirnov (KS) test for the equality of the distribution of efficiency scores in the two groups. ***, **, * denote statistical significance at the 1, 5 and 10% significance levels respectively.

A cursory inspection of Panel A results suggests that Bilinguals exhibit higher technical efficiency by 16.32% on average compared to their monolingual counterparts. Depending on the executive function test, the gain ranges between 15.75% (Counting recall) ($F(1, 68) = 14.78$, $p < .001$) and 20.19% (Colour Shape) ($F(1, 68) = 16.78$, $p < .001$). For example, the average technical efficiency of bilinguals for the BDST executive function test is at 0.836 against the 0.756 of the monolingual cohort. This suggests that the bilinguals are about 10.25% better at utilising their available inputs than the monolinguals. Panel B results corroborate our previous findings, with bilinguals being around 12.85% more efficient than the monolinguals based on the "All" variant and the effect is significant ($F(1, 68) = 21.94$, $p < .001$). An investigation of the "accuracy" and "response speed" variants suggest that the higher efficiency scores of the bilinguals are mainly driven by their relatively faster responses compared to the monolingual group.

4.4.3 Second stage analysis

Table 14 presents the results of the second stage analyses. Panel A controls for age, non-verbal intellectual ability, grammar skill, expressive and receptive vocabulary skill. Panel B further controls for SES. Panel C further controls for language use. The "Margin" column reports the estimated marginal effect of the between-group differences, where a positive value indicates that the bilinguals exhibit superior technical efficiency compared to their monolingual peers.[20] The main finding is that after controlling for an extended array of controls, the superior technical efficiency of bilinguals found in Section 5.2 persist.

[20] The marginal effects under the ANCOVA and the regression estimation techniques are the same due to the similarity of these designs (Stuart, 2010). However, we show the marginal effect under the regression column for enhanced clarity to the reader.

Table 14 *Second-stage analysis*

	I (ANCOVA)			II (Bootstrap Regression)				III (k-means NN)		
Executive function test	Margin	F-stat	η^2	Margin	SE	t-stat	Adjusted R^2	Margin	SE	t-stat
Panel A: Specification A										
Backward digit span	0.056**	4.750	0.070	0.056**	0.026	2.120	0.348	0.071**	0.030	2.390
Counting recall	0.085***	20.750	0.247	0.085***	0.020	4.260	0.671	0.087***	0.020	4.350
Colour Shape	0.147***	16.700	0.210	0.147***	0.036	4.130	0.215	0.161***	0.045	3.580
Non-verbal Stroop	0.093***	16.190	0.204	0.093***	0.024	3.920	0.610	0.090***	0.023	3.960
ANT	0.105***	21.800	0.257	0.105***	0.024	4.400	0.631	0.107***	0.025	4.240
Accuracy	0.084***	18.360	0.225	0.084***	0.020	4.070	0.486	0.088***	0.023	3.790
Response Speed	0.089***	11.010	0.149	0.089***	0.028	3.180	0.687	0.092***	0.030	3.050
All	0.088***	21.610	0.255	0.088***	0.020	4.400	0.529	0.092***	0.022	4.120
Panel B: Specification B										
Backward digit span	0.033	1.370	0.022	0.033	0.030	1.100	0.366	0.073**	0.035	2.080
Counting recall	0.053***	7.490	0.107	0.053**	0.021	2.510	0.720	0.076**	0.037	2.040
Colour Shape	0.153***	13.810	0.182	0.153***	0.039	3.910	0.203	0.182***	0.049	3.710
Non-verbal Stroop	0.067**	6.890	0.099	0.066**	0.025	2.710	0.633	0.088**	0.042	2.130
ANT	0.082***	10.720	0.147	0.081***	0.025	3.240	0.647	0.098**	0.049	2.020
Accuracy	0.074***	11.150	0.152	0.074***	0.024	3.050	0.485	0.092***	0.028	3.210
Response Speed	0.078**	6.510	0.095	0.078**	0.032	2.470	0.685	0.127**	0.056	2.280
All	0.080***	14.010	0.184	0.081***	0.023	3.470	0.525	0.093***	0.028	3.290
Panel C: Specification C										
Backward digit span	0.043	0.870	0.014	0.043	0.046	0.920	0.398	0.024	0.076	0.310
Counting recall	0.011	0.140	0.002	0.011	0.032	0.370	0.727	0.036	0.047	0.780
Colour Shape	0.179***	6.890	0.101	0.179***	0.068	2.650	0.193	0.177*	0.107	1.660
Non-verbal Stroop	0.036	0.077	0.013	0.036	0.041	0.089	0.632	0.076	0.056	1.360
ANT	0.010	0.060	0.001	0.010	0.039	0.250	0.670	0.329	0.065	0.510
Accuracy	0.047*	1.660	0.026	0.047	0.038	1.220	0.484	0.103*	0.053	1.950
Response Speed	0.038	0.580	0.009	0.038	0.051	0.760	0.686	0.035	0.054	0.640
All	0.054**	2.320	0.036	0.054*	0.037	1.440	0.525	0.103**	0.052	1.970

Notes. The table presents second-stage results for the technical efficiency estimated in a previous section. The technical efficiency is the dependent variable from the previous step and three estimation techniques are used; i) ANCOVA, ii) Regression with bootstrapped standard errors, iii) k-means nearest-neighbours. The margin columns present the estimated coefficient (i.e., marginal effect) of the Bilingual binary variable, which takes the value 1 for Bilinguals, zero otherwise. Panel A controls for age, non-verbal intellectual ability, grammar skill, expressive and receptive vocabulary skills. Panel B further controls for SES. Panel C further controls for language use. ***, **, * denote statistical significance at the 1, 5 and 10% significance level respectively.

The results of the "All" variants are particularly interesting as these combine the information from all five executive function tests. The marginal effect across all estimation methods and specifications is positive and statistically significant ($\hat{\beta}_{II} = .054, p < .10$). This suggests that the bilinguals exhibit, on average, between 5.4% and 10.3% superior technical efficiency compared to their monolingual peers.

A comparison of Panel A and Panel C finds the former with more statistically significant coefficients. However, once we add all the covariates certain marginal effects drop from statistical significance at conventional levels. This is particularly the case for the individual executive function tests. In particular, the technical efficiency based on the BDST executive function test is statistically significant at Panel A ($\hat{\beta}_{II} = 0.056, p < .05$) but not at Panel C ($\hat{\beta}_{II} = 0.043, \text{ns}$), which highlights the importance of SES and language use in isolating the bilingual effect. This is in line with the comments in Paap (2018) about improper controlling of factors may reveal a bilingualism advantage.

4.5 Robustness tests

4.5.1 Comparison with conventional designs

In this section we compare the insights from the technical efficiency analysis presented in the main part of the paper to an ANCOVA analysis that is commonly used in similar studies. Table 15 reports the descriptive statistics (mean and standard deviation) of the accuracy scores and response times for the five executive function tests, including several derived measures such as: i) the absolute difference between the incongruent and congruent trials (Difference); ii) a simple average performance measure of the congruent and incongruent trials (Average); iii) the Local Shifting Cost (LSC) and Global Shifting Cost (GSC); iv) the Inhibition effect. For all executive function measures a series of between-groups ANCOVA analyses are performed with age, non-verbal intellectual ability, grammar skill, expressive vocabulary skill, receptive vocabulary skill, SES and language use as covariates.

Table 15 *Comparison with conventional designs – ANCOVA analysis*

Executive function test	Units	Bilinguals (n=32)		Greek Monolinguals (n=38)		ANCOVA	
		Mean	SD	Mean	SD	F-stat	η^2
Backward digit span (ACC)	%	0.624	0.097	0.668	0.080	6.50**	0.096
Backward digit span (RT)	ms	933.30	289.95	807.11	271.59	0.49	0.008
Counting recall (ACC)	%	0.494	0.144	0.478	0.139	4.32**	0.066
Counting recall (RT)	ms	2394.90	1215.61	1887.87	1179.38	0.00	0.000
Colour shape (ACCcong)	%	0.918	0.068	0.904	0.072	0.54	0.009
Colour shape (ACCincong)	%	0.725	0.124	0.756	0.123	0.07	0.001
Colour shape (ACCincong-cong)	%	0.193	0.113	0.148	0.104	0.02	0.000
Colour shape (ACCaverage)	%	0.821	0.083	0.830	0.086	0.26	0.004
Colour shape (RTcong)	ms	786.68	190.01	843.95	170.05	1.68	0.027
Colour shape (RTincong)	ms	1056.67	219.40	1081.82	166.10	1.57	0.025
Colour shape (RTincong-cong)	ms	284.69	145.37	259.95	130.90	0.15	0.002
Colour shape (RTaverage)	ms	921.67	186.50	962.89	147.44	2.23	0.035
LSC	ms	-161.33	142.34	-134.70	161.24	0.15	0.002
GSC	ms	-376.43	226.90	-330.86	209.02	0.06	0.001
Stroop (ACCcong)	%	0.935	0.104	0.929	0.101	1.37	0.022
Stroop (ACCincong)	%	0.825	0.231	0.824	0.211	0.02	0.000
Stroop (ACCbase)	%	0.921	0.095	0.948	0.066	3.55*	0.055
Stroop (ACCincong-cong)	%	0.154	0.207	0.115	0.160	0.66	0.011
Stroop (ACCaverage)	%	0.894	0.117	0.900	0.109	0.90	0.014
Stroop (RTcong)	ms	762.14	302.45	684.87	196.91	0.69	0.011
Stroop (RTincong)	ms	1027.67	333.47	958.86	308.02	0.29	0.005
Stroop (RTbase)	ms	812.15	304.88	718.23	185.53	0.96	0.015
Stroop (RTincong-cong)	ms	277.30	165.94	284.74	171.68	0.00	0.000
Stroop (RTaverage)	ms	861.46	298.93	784.92	195.46	1.41	0.023
Inhibition effect	ms	-265.53	184.75	-274.00	188.78	0.00	0.000
ANT (ACCcong)	%	0.949	0.068	0.970	0.048	0.75	0.012
ANT (ACCincong)	%	0.913	0.114	0.938	0.103	0.15	0.002
ANT (ACCincong-cong)	%	0.042	0.058	0.036	0.088	0.05	0.001
ANT (ACCaverage)	%	0.931	0.089	0.954	0.067	0.38	0.006
ANT (RTcong)	ms	863.15	243.77	824.74	182.19	2.71	0.043
ANT (RTincong)	ms	964.44	273.86	902.51	206.10	1.87	0.030
ANT (RTincong-cong)	ms	102.17	67.56	81.56	57.50	0.16	0.003
ANT (RTaverage)	ms	912.30	255.63	861.81	189.42	2.40	0.038

Notes. The table reports key means and standard deviations (SD) for the executive functions test of the bilingual and monolinguals groups. n denotes the sample size, ACC denotes the accuracy score, RT the response time in msec. "cong" and "incong" refer to the congruent and incongruent respectively; "incong-cong" is the absolute difference between the incongruent and congruent trials; "average" is the average of the congruent, incongruent and base trials. Local switching cost (LSC), Global switching cost (GSC) and Inhibition effect are explained in section 3.2.4). F-stat and η^2 correspond to the between-subjects ANCOVA analysis with age, non-verbal intellectual ability, grammar score, expressive and receptive vocabulary scores, SES and language use as covariates. ***, **, * denote statistical significance at the 1, 5 and 10 significance level respectively.

The results of this analysis suggest that there are no significant performance differences between bilingual and monolinguals. For example, and pertaining to the working memory, no conclusive significant difference is found with bilinguals performing better in the Count recall test ($F(1, 61) = 4.32$, $p < .05$), but worse in the BDST ($F(1, 61) = 6.50$, $p < .05$) compared to their monolingual counterparts. However, a drawback of an ANCOVA analysis is apparent in this case as it is not able to account for the multiple executive function tests (and their metrics) that are available. As an alternative we use a MANCOVA analysis that allows for multiple dependent variables at the same time, thereby allowing for more efficient use of the breadth of the administered executive function tests. We use the same control variables as in the ANCOVA case. With regards to the choice of the dependent variables we present a list of several models, labelled I - X, in Table 16, each using different metrics of each executive function score. In the MANCOVA models presented we include at least one dependent variable from each of the three categories of executive function, namely working memory, switching and inhibition. These results are reported in Table 16.

Table 16 *Comparison with conventional designs – MANCOVA analysis*

Executive function measures	I	II	III	IV	V	VI	VII	VIII	IX	X
Backward digit span (ACC)	YES	YES		YES	YES	YES	YES	YES	YES	YES
Backward digit span (RT)			YES				YES	YES	YES	YES
Counting recall (ACC)	YES	YES			YES	YES	YES	YES	YES	YES
Counting recall (RT)			YES	YES			YES	YES	YES	YES
Colour shape (ACCaverage)	YES								YES	YES
Colour shape (RTaverage)			YES	YES					YES	YES
LSC						YES	YES			
GSC		YES			YES			YES		
Stroop (ACCaverage)	YES								YES	YES
Stroop (RTaverage)			YES	YES					YES	YES
Inhibition effect		YES			YES	YES	YES	YES		
ANT (ACCaverage)	YES				YES	YES	YES	YES	YES	YES
ANT (RTaverage)		YES	YES	YES			YES	YES	YES	YES
Controls										
Age	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
IQ	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
GS, RVS, EVS	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
SES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
Language Use	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
Observations	70	70	70	70	70	70	70	70	70	70
Wilks Lambda	0.830	0.827	0.867	0.817	0.828	0.828	0.806	0.803	0.754	0.710
F-statistic	2.340^{*}	2.380^{**}	1.750	2.550^{*}	2.380^{**}	2.360^{*}	1.630	1.660	1.690	2.200^{**}

Notes. The table reports ten MANCOVA models (labelled I – X) where the dependent variables are metrics of each executive function score. "YES" denotes which dependent variables are used in each model. "average" is the average of the congruent, incongruent and base trials. Local switching cost (LSC), Global switching cost (GSC) and Inhibition effect are explained in section 3.2.4). Each MANCOVA model controls for age, non-verbal intellectual ability, grammar score (GS), receptive vocabulary score (RVS), expressive vocabulary score (EVS), SES and language use. The Wilks' Lambda and associated F-statistic relate to the between-groups comparison. ***, **, * denote statistical significance at the 1, 5 and 10% significance level.

Overall, the MANCOVA results suggest that there are significant differences between the two groups. For example, under Model I, the between group tests suggest significant differences in the executive function of the two groups ($F(1, 61)=2.34$, $p < .10$; Wilk's $\Lambda = 0.830$). Model X is of particular interest by featuring as dependent variables the same measures used in the technical efficiency analysis as outputs, while the controls variables correspond to the inputs. This model suggests of significant between group differences in the executive function ($F(1, 63) = 2.20$, $p < .05$; Wilk's $\Lambda = 0.710$). Hence, the qualitative conclusion obtained using the technical efficiency approach is verified by a MANCOVA analysis. A drawback of the MANCOVA compared to the technical efficiency is that subsequent analysis in the former case is more complex, as between-group marginal effects are unique in each dependent variable.

4.5.2 Comparison to an alternative dataset - The Antoniou et al. (2016) dataset

The effect of bilectalism and multilingualism on executive control is examined in Antoniou et al. (2016). In this section we revisit the Antoniou et al. (2016) dataset, and apply the technical efficiency approach in answering the same questions. The use of the particular dataset is motivated from the conceptual closeness of the investigated topic – i.e., executive function in bilingual/bilectal populations, as well as the number of administered executive function tests coupled with the identified need to arrive to a comprehensive measure that summarises all information. In particular, the authors administer six executive function tests on a sample of bilectal, multilingual and monolingual children. Subsequently they use a PCA technique to produce two composite measures, which they identify as representative of working memory and inhibition. The executive function tests in Antoniou et al. (2016) are the following: i) Backward digit span (BDST); ii) Corsi blocks forward (Corsi forward); iii) Corsi blocks backward (Corsi backward); iv) Soccer task (Stroop); v) Simon task; vi) Colour shape. For these tests the dataset provides either the number of correct trials (BDST, Corsi) or accuracy scores and response times (Soccer, Simon, Colour shape).

We apply the technical efficiency methodology as described in the main paper with the outputs being the percentage scores of each of the three working memory tests (BDST, Corsi forward, Corsi backward), and the accuracy scores of the Soccer, Simon and Colour shape tasks. Our choice of inputs is similarly motivated to our main analysis but also takes into account the availability of the data. In particular, we use three inputs: i) non-verbal intellectual ability (IQ), ii) general language ability, iii) vocabulary skill (PPVT), iv) age. We conduct our analyses on three samples, labelled S1-S3. The first (S1) compares bilectal and monolingual children, while the second (S2) compares bilectal, multilingual, and monolingual children. These two use the exact sample specifications of Antoniou et al. (2016) for a direct comparison.

In particular, there are 17 bilectal participants (Mean age = 7.6; SD = 0.9 years) that are speakers of Cypriot Greek and Standard Modern Greek, while the 25 monolingual participants (Mean age = 7.4; SD = 0.9 years) only speak Standard Modern Greek under S1. The background analysis in Antoniou et al. (2016) suggests that these two groups do not differ in age, gender or language comprehension, however the bilectals exhibit significantly lower expressive and receptive vocabulary scores. Under S2 there are 44 bilectal participants (Mean age=7.6; SD=0.9 years), 26 multilingual participants (Mean age = 7.6; SD = 0.9 years) and 25 monolingual participants (Mean age = 7.4; SD = 0.9 years). The background analysis in Antoniou et al. (2016) suggests that these three groups do not exhibit significant differences in age, gender or language comprehension, however there are significant differences in terms of SES and IQ. Our third (S3) analysis compares bilectal, multilingual and monolingual children and this time we use all the participants that are available in the Antoniou et al. (2016) dataset. Under S3 there are 64 bilectal participants (Mean age = 7.8; SD = 1.59 years), 47 multilingual participants (Mean age = 7.8; SD = 1.8 years) and 25 monolingual participants (Mean age =

7.6; SD = 0.9 years). These three groups do not exhibit statistically significant differences with respect to age ($F(2, 133) = .550$, $p > .10$), gender ($F(2, 133) = .370$, $p > .10$) and IQ ($F(2, 130) = 2.270$, $p > .10$). There are significant differences in terms of SES ($F(2, 130) = 10.43$, $p < .01$) and general language ability ($F(2, 133) = 6.830$, $p < .01$).

Table 17, Panels A-C presents the results of this analyses of S1-S3 respectively. In each group we report the mean and standard deviation of the technical efficiency as well as the working memory and inhibition composite measures of Antoniou et al. (2016) for comparison purposes. An ANCOVA between groups analysis is reported with age, IQ, general language ability and SES as control variables, in line with those used in Antoniou et al. (2016)

Table 17 *Comparison to alternative datasets – the Antoniou et al. (2016) dataset*

Panel A: Sample 1							
	Bilectals (n=17)				Monolinguals (n=25)		
	Mean	SD			Mean	SD	F-statistic
Working memory	0.039	0.653			-0.289	0.763	2.960*
Inhibition	0.123	0.730			-0.098	0.557	1.140
Technical Efficiency	0.988	0.031			0.955	0.057	3.120*
t-test	2.121**						
Panel B: Sample 2							
	Bilectals (n=44)		Multilinguals (n=26)		Monolinguals (n=25)		
	Mean	SD	Mean	SD	Mean	SD	F-statistic
Working memory	-0.033	0.712	0.208	0.658	-0.289	0.763	2.630*
Inhibition	0.126	0.561	0.198	0.465	-0.098	0.557	1.640
Technical Efficiency	0.950	0.090	0.979	0.035	0.896	0.091	7.010***
t-statistic	2.401**		4.308***				
Panel C: Sample 3							
	Bilectals (n=64)		Multilinguals (n=47)		Monolinguals (n=25)		
	Mean	SD	Mean	SD	Mean	SD	F-statistic
Working memory	-0.027	0.800	0.036	0.882	-0.289	0.763	1.060
Inhibition	0.021	0.622	-0.004	0.675	-0.098	0.557	0.620
Technical Efficiency	0.950	0.089	0.949	0.146	0.842	0.124	6.100***
t-statistic	4.595***		3.118***				

Notes. The table reports mean and standard deviation (SD) of the technical efficiency estimates in each of the bilectals, multilinguals and monolingual groups using the dataset of Antoniou et al. (2016), where n denotes the sample size. The working memory and inhibition are the composite scores as these are defined in Antoniou et al., (2016) and are reported here for comparison purposes. Panel A compares the bilectals to the monolinguals, while Panel B compares bilectals, multilinguals and monolinguals. These two use the exact sample specifications of Antoniou et al. (2016). Panel C compares bilectals, multilinguals and monolinguals using a more extended dataset. The ANCOVA F-statistic presented is for the group categorical variable, where a statistically significant difference between the respective groups is indicated. The covariates used in the ANCOVA are: age, IQ, general language ability and SES. The t-statistic is for the between-groups mean comparison test of the technical efficiency of the respective group to the monolingual. ***, **, * denote statistical significance at the 1, 5 and 10% significance levels.

For S1, the technical efficiency analysis shows the bilectals to be about 3.2 percentage points more efficient than their monolingual counterparts with the difference between the groups being significant ($F(1,36) = 4.53$, $p < .05$). Antoniou et al. (2016) use a 2x2 mixed ANCOVA design for the working memory and inhibition components and find the bilectals to outperform the monolinguals.

The technical efficiency analysis on S2 uncovers significant differences between the groups ($F(2,88) = 7.01$, $p < .01$). Specifically, the multilinguals are the most efficient group with an average efficiency score of .979, followed by the bilectals at .95 and the monolinguals at 0.89. The difference between multilinguals and monolinguals is significant ($F(1,45) = 10.21$, $p < .01$), while a similar conclusion is reached for bilectals and monolinguals ($F(1,63) = 8.91$, $p < .01$). No significant difference is found between the bilectals and the multilinguals ($F(1,64) = 1.40$, $p > .10$). Antoniou et al. (2016) use a 2x3 mixed ANCOVA design and find that bilectals and multilinguals significantly outperform the monolingual group in terms of executive function. However, no significant difference between the bilectals and multilinguals is observed.

The technical efficiency analysis on S3 shows a similar conclusion to S2 with both multilinguals and bilectals being more efficient than their monolingual counterparts. The between groups ANCOVA analysis suggests that the difference is statistically significant ($F(2, 129) = 6.10$, $p < .01$). A 2x3 (working memory versus inhibition by group: multilinguals versus bilectals versus monolinguals) ANCOVA, in the spirit of Antoniou et al. (2016), does not suggest any significant difference in the three groups ($F(2, 121) = 1.145$, $p > .10$).

Overall, we confirm the results of the Antoniou et al. (2016) using our technical efficiency approach and offer some more insights in terms of the main advantages of a technical efficiency approach. Compared to the PCA, technical efficiency provides a single ratio, which ranges by construction between zero and unity, and has a clear interpretation. By contrast, the PCA requires a degree of subjectivity in terms of the number of retained components (or factors), with the Kaiser's criterion being one of the many used in such analysis (Antoniou et al., 2016). An inherent difficulty in the PCA related to the interpretation of the factors. Another advantage of the technical efficiency is that by construction it accounts for differences between the groups in the form of inputs. For example, the PCA analysis is followed by an ANCOVA that accounts for certain differences between the two groups in several metrics. By contrast, several of these metrics may be used as inputs in the technical efficiency analysis. As a consequence, simple unconditional t-tests on the technical efficiency estimates have certain merit. An inspection of the t-statistics reported in Table 17 yields the same qualitative conclusion as the more complex ANCOVA set up.[21]

4.5.3 The balanced bilinguals assumption

In the main analysis when creating the grammar and vocabulary scores for the bilinguals we used what we termed as composite score 2 (see section 4.3 for more details). Here we compare to the naïve and restrictive strategy where the main assumption is that bilinguals are balanced between the two languages, namely Greek and English. As a consequence, the composite grammar skill score would be a simple average of the respective grammar skill tasks for Greek and English languages (CS1). Admittedly this may seem a strong assumption particularly in cases where some participants may have had limited exposure to the new language. However, as this strategy is less computationally demanding, there is a certain merit in examining the impact of the results from adopting it.

[21] As a further robustness check we run a second-stage analysis similar to that of section 4.3.4, using the same control variables as in the ANCOVA that is presented. The results of this analysis do not challenge the findings here and are omitted for brevity but are available from the authors upon request.

Table 18 replicates Table 13 with the only difference being that bilinguals are now assumed to be balanced using the composite score we explain above. A cursory inspection of the results suggests that the qualitative nature of the story holds, with bilinguals having higher technical efficiency than their monolingual counterparts. However, this gap in efficiency appears less pronounced compared to our main analysis. In particular, for the overall results, bilinguals are now about 11.6% more efficient. Hence the assumption of balanced bilingualism in this instance reduces the efficiency advantage of the bilinguals by approximately 10% compared to the main analysis (see Table 13). Individual executive function tasks show higher variability. For instance, the bilinguals in the BDST task show a 17.7% lower gain in their efficiency scores to the monolinguals compared to the results of Table 13. Overall, the implicit assumption of balanced bilinguals that appears in the calculation of the composite scores has an important effect.

Table 18 *Technical efficiency estimates by group – Balanced Bilinguals Assumption*

	Monolinguals			Bilinguals							
Executive function test	Mean	SD	Median	Mean	SD	Median	Mean % gain	Anova F-test	T-test	MW-test	KS-test
Panel A											
Backward digit span	0.754	0.108	0.736	0.821	0.147	0.834	8.58	4.87**	2.21**	2.37**	0.34**
Counting recall	0.644	0.092	0.620	0.742	0.145	0.709	14.12	11.75***	3.42***	3.33***	0.48***
Colour Shape	0.649	0.143	0.655	0.782	0.164	0.761	18.62	13.10***	3.62***	3.06***	0.36**
Non-verbal Stroop	0.637	0.126	0.613	0.738	0.157	0.727	14.82	9.05***	3.01***	2.97***	0.48***
ANT	0.618	0.112	0.600	0.724	0.162	0.707	15.82	10.37***	3.22***	2.97***	0.43***
Total	0.660	0.116	0.645	0.762	0.155	0.748	14.25				
Panel B											
Accuracy	0.790	0.101	0.766	0.879	0.118	0.904	10.65	11.53***	3.39***	3.08***	0.41***
Response Speed	0.580	0.159	0.547	0.692	0.222	0.689	17.64	6.00**	2.44**	2.28**	0.32*
All	0.793	0.100	0.770	0.891	0.121	0.942	11.62	13.74***	3.70***	3.35***	0.44***

Notes. The table presents DEA technical efficiency estimates for the Monolingual and Bilingual groups of children of our sample. The outputs in each executive function task are: i) Accuracy, and ii) Response Speed. The outputs of all five executive function tasks are utilised in the "All" variant. The "Accuracy" and "Response Speed" variants use the accuracy scores and response speed scores of all executive function tasks respectively. Five inputs are utilised, namely: i) Non-verbal intellectual ability, ii) Grammar skill, iii) Expressive vocabulary skill, iv) Receptive vocabulary skill, v) Age. The weighting scheme for the Bilingual inputs is based on Composite score 1 (see section 4.3). For each group we present the mean, standard deviation and median of technical efficiency, the logarithmic percentage gain where a positive value indicates that Bilinguals are more efficient than monolinguals. A battery of tests is presented including an ANOVA F-test and a bootstrap t-test for the equality of means between the two groups, a Mann-Whitney (MW) test for the equality of medians between the two groups, a Kolmogorov-Smirnov (KS) test for the equality of the distribution of efficiency scores in the two groups. ***, **, * denote statistical significance at the 1, 5 and 10% significance levels respectively.

4.6 Discussion and conclusion

In this paper we introduce a novel approach to evaluate performance in the executive functioning skills of bilingual and monolingual children. This approach is based on the frontier methodology that measures the relative efficiency of a decision-making unit (DMU) compared to the best practice, in what is termed as *technical efficiency*. Technical efficiency may be viewed as a composite performance indicator, which combines information from multiple indicators, represented by inputs and outputs, over a set of decision-making units (DMUs). Technical efficiency estimates are obtained via DEA and are used to benchmark the DMUs, with the efficient DMUs described as “best-practice”. Hence, it is a particularly useful in performance evaluation situations where there are several alternative metrics. It is worth pointing out that an efficient DMU has the best composite performance (i.e., is technically efficient) using all the available information reflected in inputs and outputs. By contrast, the complex nature of executive function may be insufficiently captured by analysing single metrics in isolation; often leading to mixed conclusions. An alternative approach might be to construct a weighted average of several metrics. However, an issue here is that an assumption on the weighting scheme would be needed. An additional challenge is when different measurement units are present across the metrics. By contrast, DEA optimally selects the weights thereby letting the data speak for themselves, while it can handle a variety of data subject to only two restrictions. First, DEA applications require that the factors only appear either as input or output. While this is clearly visible in the case of raw data; ratios may be more challenging if for example inputs and outputs share a common denominator. Subject to the above rule, DEA can accommodate both raw data and ratios in inputs/outputs (Cook et al., 2014; Cooper et al., 2000; Dyson et al., 2001). Second, all outputs need to be quantities where “more-the-better” is applicable; the converse is true for the inputs. In our research the executive function tests’ accuracy and response time is an example where a transformation is required to ensure this condition is met. Technical efficiency brings several important benefits to the discipline. Most importantly, it can take into account multiple tasks and multiple metrics, which define the outputs. By construction it accounts for differences with respect to key covariates, dubbed as inputs. Being a non-parametric, linear programming technique means that it is flexible, does not rely on distributional assumptions and is not computationally intensive.

We demonstrate the application of the frontier methodology in the context of bilingualism, by focusing on executive function tasks of 32 Greek/English bilingual children that are compared against 38 Greek monolingual children. Using the accuracy and response times of five executive function tasks spanning working memory, inhibition and shifting, we find the bilingual cohort to be around 6.5% more efficient compared to the Greek monolinguals; a statistically significant difference. This suggests that the bilinguals outperform their monolingual counterparts in terms of executive function, after controlling for differences in terms of age, non-verbal intellectual ability, grammar skill, expressive vocabulary skill, receptive vocabulary skill, SES, and language use. The results are robust to a number of alternative specifications of technical efficiency (e.g., using only the accuracy metric), alternative specification of control variables (e.g., with/-out SES, language use), estimation techniques (e.g., ANCOVA, bootstrap regression, k-means nearest-neighbours). To identify the benefits of technical efficiency analysis, we subject our dataset to a conventional ANCOVA / MANCOVA series of analyses. The ANCOVA clearly suggests no distinct evidence of a bilingual superior performance, across a wide range of metrics that are in line with the recent literature. However, the MANCOVA approach owing to its multivariate nature, is able to pick up differences between the two groups. In particular, the MANCOVA and the technical efficiency with the same dependent variables are able to provide similar results; thus, highlighting the merits of technical efficiency. We also apply the technical efficiency approach to an alternative, yet related, dataset sourced from Antoniou et al. (2016). Using our technical efficiency approach we are able to replicate the qualitative conclusions of the Antoniou et al. (2016), which uses PCA. We also comment on the advantages of technical efficiency relatively to PCA; namely the more intuitive nature of the efficiency score, and the fact that it controls by construction for several differences between the two groups. Future research may incorporate technical efficiency analysis along the lines outlined here, expand into more tasks that would cover additional aspects of executive function.

Chapter 5 - Language skills in Greek-English bilingual children attending Greek supplementary schools in England.

Abstract

Many parents in the U.K. enrol their children in Greek supplementary schools so the children can learn and maintain the Greek language and culture in parallel with English mainstream education. Despite fears about the effects of this heritage language (Greek) use on children's skills in the majority language (English), research on these somewhat hidden schools to date is limited and qualitative in nature. The current study is the first quantitative study which examines the effect of attending a Greek supplementary school on the vocabulary and grammar scores of Greek-English bilingual children. We administered a battery of language tests in both languages to 31 Greek-English bilingual children, aged 5-13 years, and closely looked at the participants' language history using parental questionnaires. Using multiple regression analyses we examine the relationship between relevant variables, such as language use and years in supplementary school and we find that the higher the use of Greek, the higher the scores in the Greek language tasks, although no significant relationship was detected between years in supplementary school and the development of language skills. Crucially, use of Greek does not negatively predict scores in the English language tasks. Implications of our results and future directions are discussed.

Keywords: heritage language, supplementary school, Greek, bilingualism, language skills, language use

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5.1 Introduction

From July 2018 to June 2019, the estimated number of Greek nationals who were residents in the U.K., was 74,000 (Office for National Statistics, 2019), 43,000 more compared to 2009, a rise which was primarily a result of the 2010 government-debt crisis in Greece (Karatsareas, 2020; 2021a). By the end of 2020, 102,330 applications from Greek citizens residing in the U.K. were approved for the EU Settlement Scheme in order to obtain settled and pre-settled status (Pratsinakis et al., 2021). More than a quarter of this population have children, 47,9% of whom were born in the U.K. (Pratsinakis et al., 2021). Many of these parents wish to provide their children the opportunity to attend Greek supplementary schools in the U.K. in order to learn and maintain their heritage language in parallel with their English mainstream education.

The amount and nature of language exposure seems to be vital in the development of language skills (e.g., Hoff et al., 2012). Though vocabulary and grammar skills have been assessed in several bilingual populations speaking a majority and minority language (e.g., Hoff, 2018) in relation to a number of associated variables such as age, language exposure and socioeconomic status (SES), and despite this rise in Greek nationals and their children in the U.K. (Karatsareas, 2021a, 2021b), to the best of our knowledge no other study has explored the role of the exposure to a supplementary educational setting on the Greek and English language skills of Greek-English bilingual children.

In this study we address the role of supplementary educational setting on the Greek and English language skills of Greek-English bilingual children. We aim to investigate Greek and English receptive and expressive vocabulary skills as well as the receptive grammar skills in relation to a number of related variables such as age, language use and SES, of an understudied group of Greek-English bilingual children living in England and attending both English mainstream and Greek supplementary schools.

5.1.1 Supplementary schools

Supplementary schools, also known as complementary, heritage, or Saturday schools, support and maintain the language and culture of many immigrant communities in countries such as the U.S.A., the U.K., Canada, South Africa and Australia. These schools have been called 'hidden' schools by Aravossitas (2016) since the language of immigrant communities in such countries is categorised as non-official and is often not supported or is ignored by the authorities.

More specifically in the U.K., the educational system for over half a century has recognised the existence of children whose parents speak another language, such as Turkish, Chinese or Greek, namely heritage language speakers, and has provided a range of languages at GCSE and A level (Wei, 2006). This preparation of pupils to sit examinations in the various community languages in which these or other, foreign language qualifications are offered, is the key aspect of supplementary schools. These qualifications are viewed as formal recognition and legitimisation of their languages (Matras & Karatsareas, 2020). There are an estimated 3000-5000 such schools in England (NRCSE, 2020).

The main reason for the existence of these schools in the U.K. was the wish to maintain the language and customs of the country of origin by minority ethnic community members as well as maintain their cultural identity and traditions, linked in many cases to religion (Creese et al., 2006). As a result, isolation is reduced amongst minority ethnic groups, an aim which is particularly evident in Greek (Pillas, 1992), Turkish (e.g., Lytra, 2011), Chinese (Creese et al., 2007) and newly arrived refugee family (Rutter, 1998, 2003) supplementary schools. The first group of supplementary schools emerged in the late 1960s for children of Afro-Caribbean families, because of their dissatisfaction with mainstream education and how it failed to reflect the culture of the Afro-Caribbean community as well as due to the limited representation of the

Afro-Caribbean community in education and positions of authority (Chevannes & Reeves, 1987).

A second wave of supplementary schools occurred in the late 1970s and early 1980s by Muslim communities originating from South Asia and Africa. These schools were established for religious reasons closely intertwined with language, in line with Anglican, Catholic or Jewish communities, who were able to have their own schools. During the 1990s, and after controversy regarding the education of Muslim children, the education of their teachers and the official recognition and support of the two first Muslim schools, a number of other immigrant communities began to establish their own supplementary schools in order to maintain their language and culture. For example, the Chinese, the Turkish, and the Greek communities founded a noteworthy number of schools in England and Scotland for their British-born generations (Wei, 2006). These schools included weekend or afternoon classes outside of normal school hours and they were truly complementary since their founders did not ask for separate mainstream education in their languages. In the current study we will be focusing on a Greek supplementary school in the U.K.

5.1.2 The Greek community and Greek educational provision in the U.K.

Due to historical and political circumstances in the past, many Greek speaking individuals from Greece and Cyprus moved to the U.K. The majority of these Greek-speaking communities in the U.K. used to consist mostly of people of Greek Cypriot origin (Paraskevopoulos, 2012), who use both standardised and non-standardised varieties of Greek and English in contrast to individuals from the Greek mainland who mostly use the Standard Greek variety (Karatsareas, 2021b). Immigrants from the Greek mainland created churches and Greek supplementary schools, which were later used by Greek Cypriot migrants to maintain a cultural identity (Metis, 1993). The motivation underlying the establishment of these communities and as an extension of these schools is that of ethnicity, as per Raveau's (1987) definition of ethnicity: '…the awareness - felt or recognized - of belonging to a group related to a historical or mythical past that can be projected into a possible or utopian common destiny. It is expressed in terms of seven indicators of participation or recognition: biogenetic, territorial, linguistic, economic, religious, cultural and political' (Raveau, Galap, Lirus, & Lecoutre, 1977, as cited in Raveau, 1987, p. 105). In this case, the aim of the Greek supplementary schools is to preserve, shape and communicate the Greek identity, language and culture (Cyprus Ministry of Education, Culture, Sport and Youth, 2019) in the Greek-speaking community in the U.K.

Until the beginning of the 21st century, the Greek population in the U.K. consisted of prosperous people involved with shipping and banking, an increasing population of Greek professionals, such as academics, lawyers and doctors, and a big number of university students (Pratsinakis et al. 2020). There were 10-12,000 bankers and shippers by 2006, who were mostly concentrated in London (Harlaftis, 2006). The Greek student population was 22,485 in 2002/2003 with two thirds pursuing undergraduate studies (Koniordos, 2017). However, due to changes in the entry criteria for Greek universities, the rise of undergraduate tuition fees for EU students and the consequences of the crisis on Greek salaries (Karatsareas, 2021b) this number decreased to 9,920 in 2018/2019 (Higher Education Statistics Agency, 2020). In 2015/2016, around three quarters of Greek students were postgraduate students (Koniordos, 2017). It is estimated that between the period of 1998 to 2007, a total of 550,000 Greek citizens (7.3% of the active population) migrated abroad in order to engage in high skilled professional jobs (Rompolis, 2007). In 2001 35,000 Greek born people were residing in the U.K. and 36,769 in 2011 (Pratsinakis et al., 2021).

From July 2018 to June 2019, the estimated number of Greek nationals who were residents in the U.K., excluding students living in halls, was 74,000 (Office for National Statistics, 2019), 43,000 more compared to 2009. This is a massive rise compared to an estimate of 26,000 in 2008, 33,000 in 2012, 42,000 in 2013, 54,000 in 2014, and 62,000 in 2016. Between 28 August 2018 to 30 June 2020, 76,590 Greek nationals had a successful EU Settlement Scheme application for pre-settled (47,590 Greek nationals had less than 3 years in the UK) and settled status (29,000 Greek nationals had over 5 years in the UK without any absence over 6 months in a 12-month period; GOV.UK, 2020). In December 2020, 102,330 applications were made from Greek nationals to get pre-settled or settled status (Pratsinakis et al., 2021). This rise can be explained by the unemployment rate in Greece, which grew from 7.7% in September 2008 to a record high, 27.8% in September 2013, with the youth unemployment rate of 59.5 % at its peak in the first quarter of 2013 (European Parliament, 2015). Greek scientists living abroad stated that Greece cannot guarantee their future as a scientist, and they could not progress in the career in Greece. Due to the economic crisis, they had no choice but to leave their country for a better future (Theodoropoulos et al., 2014), a better work environment, a job that would fit their skills and ambitions or offer them opportunities for professional development, higher salaries, financial independence and a lack of meritocracy in Greece, a better future for their children or reuniting with partners (Pratsinakis et al., 2021, p. 14). This is the so-called "new" Greek migration, that is, the rise in the migration of first-generation Greek nationals and their children to the U.K. due to the 2010 government-debt crisis. The U.K. was the second most popular destination, after Germany, as a result of this crisis (Pratsinakis et al., 2021).

It is evident from these numbers that some of these people may have brought their children to the U.K. or may have created families in the U.K. Indeed, based on Pratsinakis (2019; as cited in Karatsareas 2021a) 57% who were parents migrated with their whole family, 31% formed their families in the U.K., and 73% of the migrants left Greece with their families. More than a quarter of the Greek migrants in the U.K. have children, of which 47,9% where born in the U.K. Some of them might create families in the future since more than 44,6% of this adult population is aged under 35. At the moment, especially outside London, there is a rise in first generation Greek nationals and their children compared to Greek Cypriot second and third generation residents in the U.K. attending Greek supplementary schools. The dynamic has changed recently, namely children born in Greece that possibly have attended Greek mainstream schools for some years, have relocated to the U.K. with their parents, due to the 2010 government-debt crisis (also see Karatsareas, 2020), or have been born in the U.K. and are acquiring Greek as a first language from first generation Greek speaking parents. Also, parents who had migrated to Greece from other countries, such as Albania, Georgia, Ukraine, Bulgaria, during the previous two decades and have moved to the U.K. due to the 2010 government-debt crisis are choosing to use their second language, Greek in the home. The above children together with children of Greek Cypriot origin residing in the U.K. (Karatsareas, 2021b) attend supplementary schools creating classrooms of diverse skills and needs (Lytra, 2019). This new wave of Greek speakers has distinct characteristics compared to the Greek-speaking populations that arrived in the U.K. in previous decades and reside until now. 75% of these new migrants has an undergraduate degree and the majority has pursued postgraduate and doctoral studies (Pratsinakis et al., 2021). Another particularly crucial factor is that these new Greek migrants intend to stay, since 48% of those who migrated with their families to the U.K. after 2010 do not intend to return to Greece or intend to return after they retire (Pratsinakis et al., 2021). This percentage rises to 71% for those residing in London (Pratsinakis, 2019) and decreases to 25% for those without children. These numbers underline the importance of supplementary school in the maintenance of the Greek language and culture for these families.

The official Greek state is responsible for the provision of Greek Education to children of Greek origin who live outside of Greece all over the world (Ministry of Education and Religious Affairs, 2019). In the U.K., the Ministry of Education, Culture, Sport and Youth of Cyprus and the Greek Ministry of Education and Religious Affairs together with the Greek communities and the Greek Orthodox Church of Great Britain are responsible of this provision (Paraskevopoulos, 2012), although there is variability in the sharing of these responsibilities. This provision includes preparing and providing teaching material and assigning staff on secondment to schools worldwide. The teachers and managers of these schools are members of the community themselves. In some schools, there might be teachers who are sent by the communities' countries of origins for a specific period (e.g., 5 years) to serve in the supplementary schools. The operation of supplementary schools is linked to the language policies and practices in the home countries (Matras & Karatsareas, 2020). There are positive outcomes of attending these schools, such as achieving good results in A Level examinations in the U.K., something evident within the Greek community (Karadjia-Stavlioti, 1997).

There are several Greek bilingual education establishments in the U.K with the aim of maintaining the Greek identity. Most specifically, Greek communities run their own part time supplementary schools in churches and community centres or in classrooms rented out from mainstream schools during the weekend or in the afternoon. Classes usually take place on Saturday or Sunday mornings and/or weekday evenings (Matras & Karatsareas, 2020; Pantazi, 2008). The schools are run by the Greek Embassy in London, the Unified Forum for the Greek Education in the United Kingdom, the Greek Independent Schools of London, Private Greek schools (Nostos, n.d.) and Cyprus Educational Mission, a London-based unit of the Ministry of Education and Culture of the Republic of Cyprus (Matras & Karatsareas, 2020; Pantazi, 2008). These authorities act as a link between the home country and diaspora. There are also mainstream schools, namely the Greek Nursery, Primary School and High School of London, where pupils are taught via the Greek medium, based on the Greek curriculum with daily classes in the English language. There are also two independent Greek-English Orthodox bilingual schools, one primary and one high school in North London (Hellenic Education Office, 2016). The total number of these establishments is 108 (Nostos, n.d.). Based on a 1997 report, 10,230 children of Greek heritage were attending 70 supplementary schools. Most of these schools were in north London, where the majority of the Greek community is concentrated (Karadjia-Stavlioti, 1997). However, information is spread across various outdated websites, with no dates and no central information point for Greek-speaking U.K. residents.

Since 2013/2014 there has been an increase in enrolments due to this post-2010 wave of Greek migrants. There were 5300 enrolments in 2012/2013 and 6071 in 2018/2019 (Republic of Cyprus, Ministry of Education and Culture as cited in Karatsareas 2021a). Based on the Cyprus Education Mission (2019), during 2019/2020, 64 Greek supplementary schools operated in the U.K. 5972 students attended Greek supplementary schools in a total of 25 schools in London and 39 schools in other parts of the U.K. (CEM, 2020, as cited in Voskou, 2021).

5.1.3 Previous studies

In other bilingual education settings, such as Immersion education classrooms, there has been a strand of literature exploring the effect of the educational context on language skills (e.g., Bialystok & Barac, 2012; Goriot et al., 2018; Rhys & Thomas, 2013; Simonis et al., 2020), whereas no research to our knowledge has quantitatively explored the effects of exposure to a supplementary education context on both language skills of bilingual children.

Bialystok (2008) mentions the importance of the context where bilingualism or L2 acquisition occurs, such as the educational context; however, studies often neglect this factor. Children attend different types of educational programs throughout their everyday lives and acquire information in different acquisition contexts. Due to immigration, many children for whom English is not their first language attend state schools in the U.K. In addition to state schools, they might attend heritage language programs or supplementary schools after mainstream school, usually twice a week, to maintain their home language and culture (see Paraskevopoulos, 2012). However, the supplementary school educational setting that bilinguals attend and its relation to language skills, such as vocabulary and grammar, is an aspect that has not been researched thoroughly to the best of our knowledge.

A small number of quantitative studies have investigated the role of the educational setting in bilingual language development. Bialystok et al. (2010) investigated English receptive vocabulary and observed that bilingual children in English medium schools with a non-English language at home were comparable to monolingual counterparts in their responses regarding words associated with schooling while comprehension of words primarily associated with home was better in monolinguals. However, research rarely controls for which language is used in school, even though vocabulary size is a predictor of children's performance on tests of academic achievement such as spelling, reading and arithmetic (Smith, Smith, & Dobbs, 1991).

A few studies to date have compared bilinguals who are instructed in different languages to assess the effects on language (e.g., Barac & Bialystok, 2012). More specifically, Barac and Bialystok (2012) investigated the role of cultural background, language similarity and language of education on the language and cognitive effects of bilingualism. They compared 78 bilingual, six-year-old children, whose two languages were English plus Chinese, French, or Spanish, to a group of 26 English monolingual children. Their findings suggest that cognitive benefits of bilingualism are not affected by language of schooling, cultural backgrounds and language similarity. In contrast, the scores in the grammar, vocabulary and metalinguistic awareness tasks were affected by language similarity and language of schooling. The groups did not differ in the amount of language exposure and production in the home. All children lived in an English-speaking community; however the Spanish and Chinese bilingual groups were educated in English and the French bilingual group in French. The Spanish bilingual group outperformed the French bilingual group on all three tasks and the Chinese bilingual group on the vocabulary and metalinguistics awareness task. Only the Spanish-English bilingual children performed comparably to English monolinguals in the English receptive vocabulary and grammar task while the performance of all other bilingual groups was lower than the monolingual group, indicating that both language similarity and language of schooling play a role in linguistic tasks.

The amount and nature of language exposure have been shown to play a crucial role in the development of language skills (e.g., De Houwer, 2009; Gathercole & Thomas, 2009; Hoff et al., 2012). Children acquiring two languages, who have less exposure to each of the two languages, compared to monolingual control groups, have often been shown to acquire each language at a slower rate (e.g., Hoff et al., 2012). However, language dominance might shift towards the majority language after the children enter school and vocabulary and grammar skills might be affected in different ways. Thordardottir (2011) investigated vocabulary acquisition and its relation to the amount of bilingual exposure in five-year old simultaneous French-English bilingual children in Canada, finding a strong relationship. Duursma et al. (2007) found similar results in Year 5 children's minority language, Spanish, in the U.S.A. In order to support Spanish vocabulary skills, both Spanish support in the home as well as in the classroom was necessary (Duursma et al., 2007). Similarly, Chondrogianni and Marinis (2011) found that L2 receptive vocabulary and complex syntax skills of 6-to-9 year old sequential Turkish-English bilingual children attending mainstream schools in the U.K. were predicted by use of English in the home and maternal English proficiency. Length of exposure to the L2 and maternal English proficiency predicted general grammatical abilities.

During the last few years, there have been qualitative studies including various Arabic, Chinese, Bengali, Bulgarian, Urdu, Polish, Ukrainian, Greek supplementary schools or establishments in the U.K. and around the world, focusing on classroom practices such as translanguaging, (e.g., Creese & Blackledge, 2010; Faltzi, 2011; García & Wei, 2015, Hua et al., 2020; Liu, 2020), on teacher, parent and pupil identities and perspectives towards supplementary education (e.g., Androulakis et al., 2016; Archer et al., 2009; Creese et al., 2006; Gkaintartzi et al., 2015; Karatsareas, 2018; Kirsch, 2019; Liao & Larke, 2008; Panagiotopoulou et al., 2019; Sook Lee & Oxelson, 2006; Strand, 2007), on language provisions and pedagogy (e.g., Alexandrova-Kirova, 2017; Cummins, 2006; Gaiser & Hughes, 2015; Pantazi, 2006, 2008; Reed et al., 2020; Walters, 2011) and on social change and history pedagogy (Voskou, 2018; 2019; 2021). However, no quantitative study to date has investigated the effect of amount of exposure to a supplementary school setting on language skills.

Regarding the Greek heritage school situation, and after this mass movement from mainland Greece to the U.K., there has been only one study assessing how language use might affect receptive and expressive vocabulary and grammar skills in Greek-English bilingual pupils in the London, Reading and Oxford area (Papastefanou et al., 2019). However, this study does not test if length of exposure to the Greek supplementary school setting has a relationship to the performance in these language tasks. More specifically, Papastefanou et al. (2019) tested 40 Greek-English bilingual children in Year 1 and Year 3 on vocabulary, phonological awareness, morphological awareness, morphosyntax, and decoding in both languages. The results showed that as a group, the children were Greek dominant before the age of 4 but English dominant now and confirm that language dominance could change even before children enter school and affects language and literacy skills equally. Language use and test scores were strongly correlated in the heritage language, Greek, which highlights the importance of parental language use in the heritage language. The Greek language had no negative effect on children's language and reading performance in English.

5.1.4 The Present Study

In this study we will be addressing the role of supplementary educational setting on the Greek and English language skills of Greek-English bilingual children. To the best of our knowledge no other study has explored this. We aim to investigate Greek and English receptive and expressive vocabulary skills as well as the receptive grammar skills of Greek-English bilingual children living in England and attending both English mainstream and Greek supplementary schools in the North of England, which has not been previously studied. Studying this population is of increasing importance, since there is a rise in first generation Greek nationals and their children who have moved to the U.K. with their parents due to the 2010 government-debt crisis (also see Karatsareas, 2020). We aim to examine the relationship between variables linked to bilingualism, such as general lifetime language use, and vocabulary and grammar skills both in the majority (English) and heritage language (Greek). To address these aims we administered a battery of tests in both languages and closely looked at the participants' language backgrounds.

The research questions were:

1. What variables predict performance in Greek and English language tasks?

2. Does the length of attending a supplementary school affect the performance in language tasks in the majority (English) and heritage (Greek) language?

5.2 Method

5.2.1. Participants

The performance of 31 Greek-English bilingual children, 63-153 months old (*M* = 105.39, *SD* = 27.03), was tested. These are largely the same children as in Chapter 3. All children attended a Greek supplementary school and mainstream English school. Details of the group are presented in Table 19. Mean age of acquisition (AoA) for Greek was 8 months (*SD* = 1.22) and for English 1 year and 4 months (*SD* = 1.76). 10 children were simultaneous bilinguals and 21 were early sequential bilinguals. The children lived in England and were recruited if at least one of their parents spoke the Greek language with them. Eight children had one English speaking and one Greek speaking parent and 23 children had only Greek speaking parents. Three additional children were exposed to a third language, in addition to Greek and English and were excluded from the analysis. Children that were included in the analysis had to have similar educational experiences (mainstream English education and Greek supplementary school). As a result, five additional children were excluded because they had attended Greek mainstream school in Greece prior to arriving to the UK, namely three children for three years, one child for two years and one child for one year. Also, children's scores were included in the analysis if their nonverbal intelligence score was within normal range (over 80; K-BIT-2, Kaufman & Kaufman, 2004). In this case, all children had standardised scores over 80 (*M* = 104.84, *SD* = 10.65, Range = 85 - 124). Children's language proficiency was reported by the parents for English (*M* = 95.81, *SD* = 8.07) and for Greek (*M* = 74.52, *SD* = 21.58). The SES was average and above average. Based on parental and teacher reports the children did not have any hearing, behavioural, emotional, or mental impairment which were exclusion criteria.

Please see 3.4 Method section in Chapter 3 for further information about the educational background of these bilingual children, the ethics procedure, the materials and procedure.

Table 19 *Participant information: parent questionnaires and scores on language and IQ tests (raw scores reported for tests)*

Variable		**Descriptive scores**
Age	*N*	31
	M (SD)	104 *(28.72)*
	Range	63 – 153
Sex		19f 12m
Years in supplementary school	*M (SD)*	3.78 *(2.63)*
	Range	.25 - 9
English Proficiency	*M (SD)*	95.81 *(8.07)*
	Range	80 - 100
Greek Proficiency	*M (SD)*	74.52 *(21.58)*
	Range	20 - 100
K-BIT-2	*M (SD)*	104.84 *(10.65)*
	Range	85 - 124
Language Use	*M (SD)*	44.61 *(21.96)*
	Range	0 - 76.79
Total of Mum and Dad languages	*M (SD)*	4.35 (1.33)
	Range	3 - 9
SES	*M (SD)*	77.42 *(16.90)*
	Range	37.5 - 100

Note: Age = participants' age in months; f = female and m = male; English and Greek proficiency = percentage of proficiency from parental report; K-BIT-2 = non-verbal intelligence standardised score; Language Use = Percentage of language use with 0% being only English and 100% being only Greek; SES = the average percentage of mother and father education.

5.3 Results

5.3.1 Test performance

The performance of the children in the receptive and expressive vocabulary tasks and the receptive grammar tasks are presented in Table 20 and Figure 4.

Figure 4 *Performance in English and Greek tasks (out of 100 scale)*

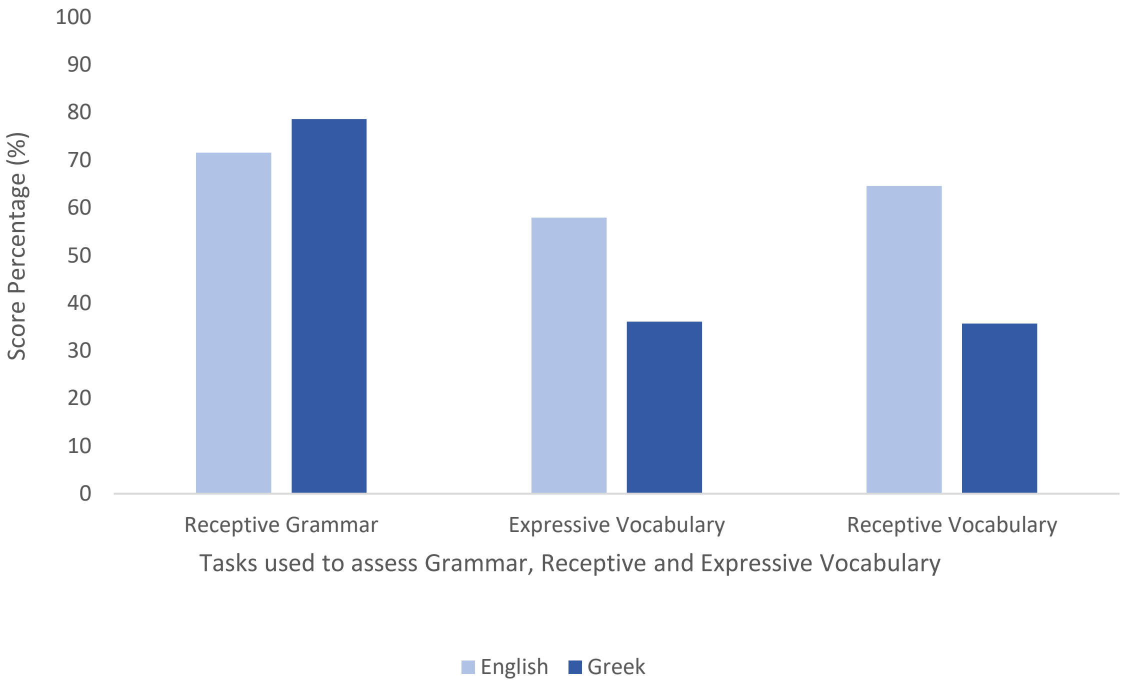

Table 20 *Descriptive Statistics – Performance in tests (out of 100 scale)*

Variable		**Score**
PWFT	*M (SD)*	36.06 *(22.96)*
	Range	0 - 82
Adapted PPVT	*M (SD)*	35.67 *(18.76)*
	Range	10.98 – 75.14
CELF-4	*M (SD)*	57.89 *(24.24)*
	Range	9.26 – 100
BPVS3	*M (SD)*	64.52 *(16.47)*
	Range	34.52 - 89.88
DVIQ	*M (SD)*	78.56 *(15.12)*
	Range	38.71 – 96.77
Trog-2	*M (SD)*	71.51 *(18.67)*
	Range	20 - 95

Note: PWFT = Greek expressive vocabulary score; Adapted PPVT = Greek receptive vocabulary score; CELF-4 = English expressive vocabulary score; BPVS3 = English receptive vocabulary score; DVIQ = Greek receptive grammar score; Trog-2 = English receptive grammar score. All scores are out of 100%.

5.3.2 Multiple Regression Analysis

A multiple regression was run using the following variables: age in months, total number of parental languages, SES, language use, English proficiency (parental report), and years in supplementary school. Greek proficiency based on the parental report was highly correlated with language use, so language use was only used in the model.

The risk of multi-collinearity was checked by calculating the collinearity statistics of variance inflation factor (VIF) and tolerance (see Table 21). VIF and tolerance values did not indicate any multicollinearity concern (VIF < 10 and tolerance > .10 for all variables) (Hair et al., 1998; Tabachnick & Fidell, 2001). All the VIFs of the model's predictors ranged from 1.390 to 5.439, therefore the effect of multicollinearity fell within acceptable limits. Tolerance was above .184 in all cases.

Greek tasks

A multiple regression was run to predict Greek receptive grammar skill (DVIQ; see Table 22). Language use added significantly to the prediction, p = .001 and significantly predicted the Greek receptive grammar score in the DVIQ, $F(6, 24) = 3.36$, $p = .030$, $R^2 = .456$ (Adjusted $R^2 = .321$).

A second multiple regression was run to predict Greek receptive vocabulary skill (adapted PPVT; see Table 23). Language use statistically significantly predicted the Greek receptive vocabulary score in the PPVT, $F(6, 24) = 6.55$, $p < .001$, $R^2 = .621$ (Adjusted $R^2 = .526$).

A third multiple regression was run to predict Greek expressive vocabulary skill (PWFT; see Table 24). Language use significantly predicted the Greek expressive vocabulary score in the PWFT, $F(6, 24) = 4.96$, $p = 002$, $R^2 = .554$ (Adjusted $R^2 = .442$).

English tasks

A multiple regression was run to predict English receptive grammar skill (TROG; see Table 25). Age in months added statistically significantly to the prediction, $p < .001$. This variable statistically significantly predicted English receptive grammar skill in TROG, $F(6, 24) = 14.12$, $p < .001$, $R^2 = .779$ (Adjusted $R^{2\,=}$ .724).

A second multiple regression was run to predict English receptive vocabulary skill (BPVS; see Table 26). Age in months added statistically significantly to the prediction, $p < .001$. This variable statistically significantly predicted English receptive vocabulary skill in BPVS, $F(6, 24) = 31.89$, $p < .001$, $R^2 = .889$ (Adjusted $R^{2\,=}$ .861).

A third multiple regression was run to predict English expressive vocabulary skill (CELF; see Table 27). Age in months added statistically significantly to the prediction, $p = .032$. This variable statistically significantly predicted English expressive vocabulary skill in CELF, $F(6, 24) = 3.66$, $p = .010$, $R^2 = .478$ (Adjusted $R^{2\,=}$ .347).

Table 21 *Collinearity Statistics*

Independent Variables	Tolerance	VIF
SES	0.535	1.868
Years in supplementary school	0.184	5.439
English proficiency	0.778	1.286
Language use	0.647	1.545
Mum & dad languages total	0.720	1.390
Age in months	0.190	5.268

Note: English proficiency = percentage of English proficiency from parental report; Language Use = Percentage of language use with 0% being only English and 100% being only Greek; SES = the average percentage of mother and father education.

Table 22 *Regression for DVIQ*

Model	*B*	SE *B*	*t*	*p*
Age in months	0.15	0.18	0.83	.418
Total number of parental languages	-1.77	2.02	-0.88	.388
SES	-0.35	0.18	-1.89	.071
Language use	0.50	0.13	3.84	.001
English proficiency	-0.18	0.32	-0.55	.589
Years in supplementary school	1.36	2.02	0.67	.506
Constant	87.15	35.25	2.47	.021

Table 23 *Regression for adapted PPVT*

Model	*B*	SE *B*	*t*	*p*
Age in months	0.16	0.19	0.85	.404
Total number of parental languages	-0.53	2.09	-0.25	.802
SES	0.04	0.19	0.22	.829
Language use	0.57	0.13	4.23	.000
English proficiency	-0.08	0.33	-0.24	.811
Years in supplementary school	3.09	2.09	1.48	.153
Constant	-11.11	36.52	-0.30	.764

Table 24 *Regression for PWFT*

Model	*B*	SE *B*	*t*	*p*
Age in months	0.05	0.25	0.21	.835
Total number of parental languages	2.76	2.77	1.00	.329
SES	-0.09	0.25	-0.36	.721
Language use	0.75	0.18	4.25	.000
English proficiency	0.17	0.44	0.39	.700
Years in supplementary school	3.24	2.78	1.17	.254
Constant	-36.65	48.49	-0.76	.457

Table 25 *Regression for TROG*

Model	*B*	SE *B*	*t*	*p*
Age in months	0.75	0.14	5.26	.000
Total number of parental languages	1.59	1.59	1.00	.327
SES	0.22	0.15	1.54	.136
Language use	-0.05	0.10	-0.45	.659
English proficiency	0.30	0.25	1.18	.249
Years in supplementary school	-3.13	1.59	-1.97	.060
Constant	-45.62	27.74	-1.65	.113

Table 26 *Regression for BPVS*

Model	*B*	SE *B*	*t*	*p*
Age in months	0.52	0.09	5.83	.000
Total number of parental languages	1.75	0.99	1.74	.095
SES	-0.03	0.09	-0.38	.710
Language use	-0.04	0.06	-0.68	.501
English proficiency	0.24	0.16	1.52	.142
Years in supplementary school	-0.17	1.00	-0.17	.865
Constant	-15.06	17.38	-0.87	.395

Table 27 *Regression for CELF*

Model	*B*	SE *B*	*t*	*p*
Age in months	0.65	0.29	2.28	.032
Total number of parental languages	-1.62	3.17	-0.51	.614
SES	0.05	0.29	0.18	.861
Language use	0.19	0.20	0.96	.348
English proficiency	0.61	0.50	1.21	.237
Years in supplementary school	-1.49	3.17	-0.47	.643
Constant	-68.19	55.38	-1.23	.230

5.4 Discussion

The overall aim of this study was to explore language in a group of Greek-English bilingual children attending a supplementary school in England together with English mainstream school. More specifically, we aimed to explore what variables predict performance in Greek and English language tasks and if the length of attending a supplementary school affects the performance in language tasks in the majority (English) and heritage (Greek) language. In order to pursue this, we assessed the children's receptive and expressive vocabulary as well as their receptive grammar in both languages, in order to investigate which variables such as years in supplementary school, general language use throughout the lifetime, SES, total number of languages spoken by the parents and parental report of proficiency affect these scores. This is the only study to date that investigates this relationship between exposure to a supplementary school setting and scores in both languages.

Our first aim was to investigate the variables that can predict these vocabulary and grammar scores. We performed a multiple regression analysis for each task. Language use significantly affected the scores in all Greek language tasks, namely the higher the use of Greek, the higher the scores in the Greek vocabulary and grammar tasks. This is in line with Papastefanou et al. (2019) who found that Greek expressive vocabulary was related to the Greek language use in and out of the home. Papastefanou et al. (2019), who tested 40 Greek-English bilingual children in Year 1 and Year 3, found that language use and expressive vocabulary test scores were strongly correlated in the heritage language, Greek, which highlights the importance of parental language use in the heritage language.

On the other hand, language use did not significantly predict scores in the English vocabulary and grammar tasks. Age was a significant predictor in the model, which was expected since these are standardised tasks and children perform better as they grow older.

Similarly, Duursma et al. (2007) found parental use of English in the home was not a predictor for English language proficiency of 96 Year 5 Latino English language learners.

The fact that higher scores in Greek language tasks were dependent on the use of Greek highlights that parents wishing to maintain Greek should use Greek in and out of the home. Importantly, the fact that English scores were not affected by Greek language use may help allay fears that heritage language could affect the development of mainstream language negatively. This is in line with studies failing to find evidence that maintaining a home language endangers the acquisition of the majority language (Poarch & Bialystok, 2017).

Our second aim was to investigate if the length of attending a supplementary school affects the performance in language tasks in the majority (English) and heritage (Greek) language. We found no significant negative relationship between attending a supplementary school and the development of English vocabulary and grammar skills. One might expect that years in supplementary school would be a positive predictor for the scores in Greek vocabulary and grammar tasks, however this was not found. One interpretation could be that the tests used are designed for monolingual Greek speakers and not bilingual ones and may not accurately reflect the proficiency of the bilingual children in each language. Secondly, it might be an issue of amount of input. Children attended supplementary school 2.5 – 3.5 hours per week where they were taught via the Greek medium. This possibly is sufficient to maintain these skills but not develop them.

5.5 Implications, Future Directions and Limitations

Since some Greek-English pupils in the UK sit GCSEs or A Levels in the Greek and English language, this study has further implications in regard to academic achievement. During the last few years, this rise in first generation Greek nationals and their children who have moved to the U.K. with their parents due to the 2010 government-debt crisis (also see Karatsareas,

2020) has changed the Greek population attending these supplementary schools, calling for future changes in the curriculum followed in these schools. More research is needed into the amount and nature of educational input needed to develop children's academic skills.

Further support and encouragement could be provided to parents in using the heritage language with their children based on the fact that no significant negative relationship was found between attending a Greek supplementary school or using more Greek (heritage language) in the home, and the development of English vocabulary and grammar skills.

We used non-standardised tasks to assess Greek receptive vocabulary and grammar skills in the children as well as English tests which are not standardised for bilingual children. As a result, tests in Greek and English were not comparable. Future development of tests is needed in Greek and English which should also include bi-mutilingual children (Babatsouli, 2019; Marinis et al., 2017). Also, standardised Greek tests assessing language skills are lacking or are outdated, and a large study would allow test standardisation and the establishment of quantitative norms.

The finding that years in supplementary school was not a predictor for the scores in Greek vocabulary and grammar tasks could be further investigated by comparing scores from Greek-English bilingual children who attend Greek supplementary schools with Greek-English bilingual children who attend a Greek-English bilingual school and with those who do not. This was not possible in this study but is an important future direction to further understand this result.

Finally, the relatively small sample size of this study is one of its limitations. Nevertheless, this is the only study to date that investigates this relationship between exposure to a supplementary school setting and scores in both languages.

Our findings, together with previous research on heritage/Greek language education abroad on this emergence of a new emigration wave (e.g., Aravossitas & Sugiman 2019; Baros et al., 2019, Karatsareas, 2021a, b; Voskou, 2021), highlight the need for further investigation of this understudied and constantly changing Greek- speaking population. This significant rise in the emigration of couples and families from Greece after the 2010 crisis (Pratsinakis, 2019) underlines how important it is to explore what the opportunities and challenges are that "new" Greek migrants create to Greek language education abroad. This cannot be done without identifying the language skills of these children and how these develop. Due to this increase of Greek migration not only to the U.K. but around the world, as Lytra (2019, p. 238) stresses, "Greek schools, their leaders and teachers are called upon to adapt and change in response to the increased heterogeneity and complexity of children and their families' multilingual repertoires, educational experiences, expectations and aspirations.". Cushing, Georgiou, and Karatsareas (2021) and Pantazi (2010) call for modified teaching approaches and practices, acknowledging student needs and identities, and closer links between community and mainstream educational settings.

5.6 Conclusion

In the current study we aimed to explore the role of supplementary educational setting on the Greek and English language skills of Greek-English bilingual children and which variables predict performance in Greek and English language tasks. While there are many qualitative studies exploring supplementary schools, to the best of our knowledge, no other study has explored if and how the length of attending a supplementary school affects the performance in language tasks in the majority (English) and heritage (Greek) language. In order to pursue this, we assessed the children's receptive and expressive vocabulary as well as their receptive grammar in both languages, and via a questionnaire parents provided information about their children's years in supplementary school, children's general language use throughout the lifetime, their SES, their total number of spoken languages and their children's proficiency scores.

Findings suggest that more use of Greek is a significant predictor of higher scores in Greek tasks while at the same time it is not a negative significant predictor of scores in English tasks. At the same time, we did not find a significant negative relationship between attending a supplementary school and the development of English vocabulary and grammar skills. These findings provide support for parents/wider family to use Greek in and out of the home. Parents might be hesitant in using the heritage language in and out of the home so as not to disadvantage their child, however the current study suggests that use of Greek does not negatively affect English scores, while it enhances Greek language scores.

Finally, years in supplementary school did not significantly predict scores in Greek vocabulary and grammar tasks. Future intervention studies can further investigate the curriculum used and amount of exposure/time that these children attend Greek supplementary schools in order to enhance their vocabulary and grammar in Greek.

Chapter 6 - General Discussion

The current thesis sought to enhance our understanding of the link between bilingualism and EFs as well as the link between language skills and exposure to a supplementary school setting of an understudied group of Greek-English bilingual children living in England and attending both English mainstream and Greek supplementary schools. More specifically, the aims of this thesis were to i) investigate the performance of Greek-English bilingual children in EF tasks compared to their monolingual Greek and monolingual English counterparts, after closely matching them on relevant variables (Chapter 3), ii) to propose a novel approach to evaluate the EF performance of bilingual and monolingual children (Chapter 4), and iii) to explore how the exposure to a Greek supplementary school might affect scores in language tasks and which variables are predictors of scores in language tasks of expressive/receptive vocabulary and receptive grammar in both languages (Chapter 6). This final chapter will present an additional general discussion of the key findings linked to the existence of a bilingual advantage, touching on theoretical, educational and future research implications.

6.1 Review of results in Chapter 3 and links to EF hypotheses

In Chapter 3 we present data resulting from testing 22 Greek-English bilingual children, 63-108 months of age, on a battery of EF tasks compared to 25 English and 15 Greek monolingual counterparts. Despite numerous previous studies investigating the EF skills of bilingual children (Valian, 2015 for an example overview), presented in Chapter 2 of this thesis, the field has not reached an agreement due to mixed findings. Bearing in mind the challenging nature of matching bilinguals due to many variables playing a role discussed in Chapter 2, we used k-means nearest neighbour methods to match the bilingual to the monolingual children on age, SES, non-verbal intelligence, gender, musical ability, and proficiency in both languages. We used a factor analysis on four indicators of language proficiency to reveal one factor which we interpreted as proficiency in English and proficiency in Greek.

Our main results are the following and are discussed below:

A comparison was performed between the Greek-English bilingual group and the English monolingual group. In this case, the Stroop (conflict) effect was significantly smaller for the bilingual group compared to the English monolingual one. This was a significant indicator of increased inhibitory skills in the bilingual group. Also, the bilingual group was faster in the BDST assessing working memory (updating). In all other components, no significant differences were found between these two groups. These findings extend previous research (see e.g., Lowe et al., 2021) that identify a bilingual advantage in some EF components. In this case, after controlling for many variables and closely matching the groups, we reported a bilingual effect in inhibition and working memory. The findings presented in Chapter 3 are consistent with the Bilingual Inhibitory Control Advantage (Hilchey & Klein, 2011) and the Adaptive Control Hypothesis (Green & Abutalebi, 2013). A bilingual effect in monitoring and updating might lead to a faster response time and a smaller conflict effect (Costa et al., 2009). However, no bilingual effect was reported in the colour-shape task (shifting) and conflict index of the ANT task (inhibition), findings which do not support the Bilingual Executive Processing Advantage (Hilchey & Klein, 2011). Based on findings with children attending intensive L2 immersion programmes (e.g., Purić et al., 2017), working memory might be one of the first EFs to be taxed. Inhibitory processing also seems to be significantly increased in childhood since the brain is regularly inhibiting the non-target language during the day. The majority of these bilingual children have to switch between the two languages during the day, namely use English in school and Greek at home. However, our findings are not in line with the Adaptive Control hypothesis (Green & Abutalebi, 2013) according to which in a single-language context (in this case the bilingual children use Greek and English in different contexts, e.g., at home and at school), EFs would not be boosted. Based on Paap's (2018) Controlled Dose hypothesis, this bilingual advantage might be present due to the fact that the bilinguals are still in the process of learning how to control their languages and are constantly monitoring and inhibiting.

However, if a so-called bilingual advantage was the result of enhanced inhibitory abilities in bilinguals, then a significant conflict effect should have also been found in the ANT task. Huizinga et al. (2006) state that various EF components may develop asynchronously. As discussed in Chapter 3, some researchers report a better performance of bilinguals in the ANT task (e.g., Kapa & Colombo, 2013; Pelham & Abrams, 2014), not found in our study, and others are suggesting that better performance is restricted to higher monitoring conditions and certain designs (e.g., Costa et al., 2009). Perhaps, the children's version of the ANT used in the current study required other skills too. Similarly, although the bilinguals were faster than the English monolinguals in the BDST, they were comparable in the second working memory task (Counting recall task), possibly due to BDST also involving executive-attentional resources (e.g., Elliot, Smith, & McCulloch, 1997). At the same time, these differences in results tapping into EF components which revealed significant differences between these two groups, which, based on other researchers, might be linked to EF tasks used being not ideal and even though they tap the same EF subsection that does not mean that they might tap on other skills as well (Laine & Lehtonen, 2018). Also, this dissociation between tasks might also be linked to the lack of theory on the bilingual advantages and the lack of clarity in the division of EF (Laine & Lehtonen, 2018). the non-target language.

Based on these mixed results and as a step forward, we propose to approach this bilingual advantage debate on EF in a holistic approach, using a novel methodology which allows us to jointly consider EF accuracy and response times across different tasks in the following chapter, Chapter 4.

When we performed the comparison of the Greek-English bilingual group to the second monolingual control group consisting of Greek monolingual children, no significant difference was found in any of the EF tasks, replicating previous findings in the literature (e.g., Antón et al., 2014) in showing no significant bilingual effect in EFs. One possible interpretation is that there is a sampling issue, namely the monolingual group was not truly monolingual since due to the Greek educational system, all children are exposed to English at least one hour a week starting Year 1, two hours a week in Year 2 and three hours a week in Year 3 (Greek Ministry of Education and Religious Affairs, 2016). In this case, it is possible that the children in our Greek monolingual group switch languages based on the communicative context and train their EF similarly to the bilingual group. However, even this minimal exposure to English as an L2 might have increased EF. It has been shown in other studies (Papastergiou, Sanoudaki, & Collins, 2019; Purić et al., 2017) that children attending L2 education programs have shown advantages in working memory. Future studies could test more children that fall in this minimal exposure categories to investigate these skills.

6.2. Review of results in Chapter 4 and comparison to Chapter 3 results

In Chapter 4 we aimed to closely match Greek-English bilingual children to monolingual Greek and monolingual English children and explore their performance in EF tasks and to introduce a new approach to investigate this EF performance, namely the *technical efficiency (TE*). The frontier methodologies allowed us to jointly consider multiple tests and metrics in a new measure; the TE. This technique is widely used in areas of banking, economics, finance and management but it is non-existent in the fields of linguistics and psychology. The TE analysis allowed us to look at accuracy and response time scores of more than one executive function tests jointly as one total score. Our results show that the bilingual individuals are 6.5% more efficient than their monolingual counterparts in EFs. This suggests that the bilinguals are more efficient in the use of their skills than monolingual counterparts, after controlling for differences in terms of age, intellectual ability, grammar skill, vocabulary skill, language skill, SES, and language use, a result which is contradictory to the one we found in Chapter 3 comparing younger Greek monolinguals to younger Greek-English bilinguals. Ideally, we would want to use the same Chapter 3 sample (19 Greek-English bilingual children and 15 Greek monolingual children, 25 English monolingual children) in Chapter 4. However, the size of the sample in Chapter 4 and therefore the participants tested had to be larger due to test requirements. In this case, the discrepancy between the findings in these two chapters could possibly be linked to the differences in the groups of bilinguals and monolinguals included, where in Chapter 3 participants ranged from 6-9 years of age and in Chapter 4 they ranged from 6-13 years of age. Perhaps these differences could be linked to language characteristics of these older bilingual children. More specifically in Chapter 4, 11 bilingual children were simultaneous bilinguals and 21 were sequential, and in Chapter 3, 5 were simultaneous and 14 sequential bilinguals. There were also more bilinguals in Chapter 4 exposed to their L2 later in childhood than the younger group included in Chapter 3, which has been shown to play a role in interference control tasks for example by Donnelly et al. (2019) who found that the effect sizes for interference cost were larger for late than for early age of acquisition comparisons. This is consistent with the hypothesis that late learned L2 might incur more interference than early learned ones (Bak, Vega-Mendoza, & Sorace, 2014). It might also be possible that these older bilinguals, due to more challenging classroom demands in English and extra-curricular activities, might require more cognitive effort and control to switch between the two languages. Analysis-specific reasons might be another factor explaining this discrepancy in results.

The methodological benefits of the TE are evident after performing a conventional ANCOVA / MANCOVA series of analyses. The ANCOVA showed no evidence of a bilingual superior performance and in the two WM components revealed contradictory results with bilinguals performing better in the counting recall task but worse in the BDST compared to their monolingual counterparts. This is contradictory to the finding in both Chapters 3 and 4, in line with mixed findings in the field (e.g., Arizmendi et al., 2018) which has now reached an impasse (Antoniou et al., 2021) and might be linked to task reliability, also discussed about Chapter 3 results. Poor reliability of tasks can lead to variability in the results across studies (Arizmendi et al., 2018). Other potential factors that might contribute are different strategy use, and task impurity. This can be improved by using multiple measures of each EF component under investigation. However, a drawback of an ANCOVA analysis is apparent in this case as it is not able to account for the multiple executive function tests (and their metrics) that are available, whereas the MANCOVA approach owing to its multivariate nature, was able to pick up differences between the two groups. At the same time, we applied our technical efficiency approach to the Antoniou et al. (2016) dataset, which was able to replicate the findings based on PCA. Contrary to certain data reduction techniques (e.g., PCA) that rely on the correlation between the variables, TE does not require the outputs/inputs to be highly correlated and controls by construction for several differences between the two groups. It is evident that our novel approach can control by construction for several differences between the groups, highlighting its applicability in the research of bilinguals where a large number of factors needs to be taken into consideration. At the same time, it is a non-parametric, linear programming technique which provides flexibility as it does not rely on distributional assumptions and is not computationally intensive.

New approaches, such as a variety of innovative methodological techniques and cross-sectional or longitudinal designs, to investigate how bilingualism shapes cognition, moving beyond traditional methods and taking into consideration individual differences and nuanced experiences, are needed and are at present invited by experts in the field (Antoniou, Pliatsikas, and Schroeder, 2021). TE is an innovative way of jointly viewing EF skills, and future studies in bilingualism may incorporate this methodology, expanding into more tasks that would cover additional aspects of executive function.

6.3. What is the role of supplementary education and use of the home language in English and Greek language skills?

After investigating cognitive skills of this understudied group of Greek-English bilingual children, in Chapter 5 we aimed to identify the predictor variables of Greek and English language tasks and examine the effect of exposure to a supplementary school on the performance in language tasks in the majority (English) and heritage (Greek) language. To the best of our knowledge, while there are many qualitative studies focusing on supplementary schools, this is the only study to date that investigates this relationship between exposure to a supplementary school setting and vocabulary and grammar scores in both languages. Studying this population is of increasing importance, since there is a rise in first generation Greek nationals and their children who have moved to the U.K. with their parents due to the 2010 government-debt crisis (Karatsareas, 2020; 2021a).

Our findings highlighted the significant role of Greek language use (heritage language) in order to perform better in Greek receptive and expressive vocabulary tasks and grammar tasks. This finding is in line with previous research in majority and minority/heritage language skills (e.g., Papastefanou et al., 2019). At the same time, higher language use of the Greek language was not a negative predictor of scores in English vocabulary and grammar tasks. This finding is of great importance for parents who might fear that speaking to their children in their heritage language might be detrimental. What should be kept in mind is to provide equal opportunities to children to use and receive language input in both languages from highly proficient users of the language (Hoff, 2018). Other factors could affect the academic performance of bilingual children such as the extent of parental involvement in school and the parents' ability (Hill & Taylor, 2004) and willingness to support children's education (Poarch & Bialystok, 2017).

In terms of the exposure to a supplementary school, it was found that these 2.5 to 3.5 hours a week are not a predictor of both English and Greek language skills. This is a positive finding for the development of English (majority language) vocabulary and grammar skills; it indicates, however, that these hours are not enough to significantly affect Greek language skills. This result might be due to various factors. The Greek tests used to assess receptive vocabulary and receptive grammar were not standardised. Also, the standardised task used to assess expressive Greek vocabulary was designed for use with monolingual Greek populations, not bilingual populations. As a result, they might not yield representative scores for these language skills in this bilingual population, even though they have been used by published research assessing Greek bilingual participants (e.g., Antoniou et al., 2016). This highlights the need for the creation of standardised tests providing bilingual norms for Greek and English.

Studies investigating vocabulary skills in bilingual children (see Lauro, Core, & Hoff, 2020) have identified two extra factors as predictors of children's language outcomes, namely phonological memory and child birth order. Phonological memory is the ability to temporarily hold speech-related information (numbers, sounds, words) in memory, which is linked to foreign language learning success in the classroom (Service, 1992) and to L2 learning among immigrant children and children from immigrant families (Farnia & Geva, 2011; Paradis, 2011; Verhagen, Leseman, & Messer, 2015). In addition, Lauro, Core and Hoff (2020) have found that child birth order is a significant predictor of Spanish expressive vocabulary or a general first born advantage (Hoff, 2006). These factors could also be included in future research.

The findings reported in Chapter 5 have important implications for the mother tongue education policies for Greek pupils in Great Britain. In December 2020, 102,330 applications were made from Greek nationals to get pre-settled or settled status (Pratsinakis et al., 2021) compared to an estimate of 26,000 Greek nationals in 2008. These people might have brought their children to the U.K. or may have created families while residing in the U.K. and this setting may have created a new reality with different prospects and challenges in the Greek language education in the U.K. As a result, there is a need for change in the educational practices adopted in Greek supplementary schools in the U.K. Over the last decade, teachers might work in many schools and may be responsible for three or even four different classes, including pupils of different language levels within the same class (Georgiadis & Zisimos, 2010). There are other challenging issues such as the curriculum which is followed, the diversity of language backgrounds of the pupils and the dated books used in class (Georgiadis & Zisimos, 2010; Voskou, 2019). There are different matters that should be considered in language education which should be considered, such as teaching Greek as a foreign language and teaching the language for heritage learners (Aravossitas & Oikonomakou, 2020), stronger links between heritage and mainstream educational settings, as well as taking into consideration Greek language students' needs and, of course, identities in the U.K.

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Appendices List

Item 1: Parent/Guardian Information Sheet and Consent forms (English and Greek)

Item 2: School Information Sheet (English and Greek)

Item 3: Head teacher consent form (English and Greek)

Item 4: Ethics Approval

Item 5: Questionnaires for parents/guardians (English and Greek)

Item 6: Technical Appendix A

List 1: Parent/Guardian Information Sheet and Consent forms (English and Greek)

Information letter to parents for PhD Study

PhD Supervisor: Dr Eirini Sanoudaki

PhD Student: Athanasia Papastergiou

Email: e.sanoudaki@bangor.ac.uk

elp4ae@bangor.ac.uk

PRIFYSGOL BANGOR UNIVERSITY

Study Title: Executive Function in Bilingual Children and the Role of Language Use and Education

Dear Parent/Guardian,

My name is Eirini Sanoudaki and I am a Lecturer in the School of Linguistics and English Language at Bangor University. My PhD student Athanasia Papastergiou and I are currently working on a research project looking at how cognitive abilities are influenced by bilingualism and education. This research has important implications for bilingual education programs. My graduate student, Athanasia Papastergiou will conduct the work. Athanasia has been awarded a fully-funded PhD studentship to conduct research on this topic.

Background

According to previous research the development of the executive-function system is the most crucial cognitive achievement in early childhood. Children gradually master the ability to control attention, inhibit distraction, monitor sets of stimuli, expand working memory, and shift between tasks. However, previous research findings on the executive function of bilinguals are not consistent especially with children in fully-bilingual communities, such as Wales, compared to bilinguals who live in other communities. In addition, based on previous findings the length of time in a bilingual educational setting might influence executive functioning. The purpose of this research is to address these two issues.

What's involved?

All children will complete the following assessments: a Language and Social background questionnaire about their language background and demographic information which will be completed with the help of parents/guardians, a computer-based executive function test, a standardised test of linguistic ability and a standardised test of intelligence ability. Each session will take no longer than 30-40 minutes per child. These measures are all age-appropriate and have been used in previous research with this age range. We find that children typically enjoy these tasks, which will be timetabled so as not to disrupt your child's learning programme.

Consent, confidentiality and feedback

Our research is conducted within the guidelines of Bangor's University Research Ethics Committee to ensure that it meets ethical guidelines and poses minimal risk to participants. I would like to assure you that all the data collected will be treated as highly confidential and anonymous. We will not use any names and every child will be assigned an anonymisation code before data input. We will require your child's date of birth (year and month will suffice) and the parents/guardians socioeconomic status, because we will be comparing different groups of children. Both Athanasia and I have an enhanced DBS check.

We have also obtained consent from the school's headteacher before beginning the study and we will coordinate with teachers to ensure minimal disruption within the classroom. Finally, we will, of course, ask your child whether they agree to participate before beginning. If they do not agree, they will just continue normal school activities. After taking part in the study, children will be given a letter to take home outlining in more detail the purpose of the study.

Although the school has most kindly allowed me access, I will not include your child if you object to their participation. If you do NOT wish your child to take part please let us know by either:

1. Returning a signed copy of the slip below

2. Contacting us by email at elp4ae@bangor.ac.uk

If you are happy for your child to take part, you do not need to do anything. Unless we receive a signed copy of the slip below by …/…/2016 we will assume you are happy for your child to take part.

In the event of any queries or problems to do with this research, please contact me Dr Eirini Sanoudaki (email e.sanoudaki@bangor.ac.uk; tel: +44 (0)1248 388638), or the School of Linguistics & English Language Head of Department, Dr Peredur Davies (email: p.davies@bangor.ac.uk; tel: +44 (0)1248 382198). If you have any queries for Athanasia, please email elp4ae@bangor.ac.uk.

Many thanks for your time,

Dr Eirini Sanoudaki

I DO NOT give permission for my child to participate in Athanasia's Papastergiou project.

Name of pupil………………………………………………………………

Signature of parent / guardian………………………………………………

<u>Γράμμα στους γονείς/κηδεμόνες για διδακτορική μελέτη</u>

Υπεύθυνη Καθηγήτρια Διδακτορικού: Δρ Ειρήνη Σανουδάκη

Διδακτορική Φοιτήτρια: Αθανασία Παπαστέργιου

Email: e.sanoudaki@bangor.ac.uk

elp4ae@bangor.ac.uk

PRIFYSGOL BANGOR UNIVERSITY

Εκτελεστική Λειτουργικότητα Δίγλωσσων Παιδιών για το Ρόλο της Χρήσης της Γλώσσας και της Εκπαίδευσης

Αγαπητοί γονείς/κηδεμόνες,

Ονομάζομαι Ειρήνη Σανουδάκη και είμαι Λέκτορας στη Διγλωσσία και στη Γλωσσολογία στο Τμήμα Γλωσσολογίας και Αγγλικής Γλώσσας στο Πανεπιστήμιο του Bangor. Η διδακτορική μου φοιτήτρια Αθανασία Παπαστέργιου και εγώ, μελετάμε το πως οι γνωστικές δεξιότητες επηρεάζονται από τη διγλωσσία και την εκπαίδευση. Το συγκεκριμένο πρότζεκτ θα έχει προεκτάσεις σε δίγλωσσα εκπαιδευτικά προγράμματα. Η Αθανασία έχει απονεμηθεί πλήρη διδακτορική υποτροφία για να διεξάγει έρευνα σχετική με αυτό το αντικείμενο.

Ερευνητικό Πλαίσιο

Σύμφωνα με μελέτες η ανάπτυξη του συστήματος εκτελεστικής λειτουργικότητας είναι το πιο καίριας σημασίας γνωστικό επίτευγμα στη νηπιακή ηλικία. Με τον όρο εκτελεστική λειτουργικότητα περιγράφεται ένα σύμπλεγμα γνωστικών διαδικασιών το οποίο περιλαμβάνει δεξιότητες όπως η οργάνωση, η πειθαρχία, η αυτορρύθμιση, το να θυμάται κανείς τι έχει να κάνει, η διαχείριση του χρόνου, η προσοχή και ο έλεγχος της παρόρμησης. Σταδιακά τα παιδιά κατακτούν την ικανότητα να ελέγξουν την προσοχή, να μην αποσπώνται, να επεκτείνουν τη λειτουργική μνήμη, και να εναλλάσσονται μεταξύ δραστηριοτήτων. Όμως, τα ευρήματα πρόσφατων μελετών σχετικά με την εκτελεστική λειτουργικότητα των δίγλωσσων παιδιών δεν είναι σταθερά ειδικά με παιδιά που κατοικούν σε κοινωνίες δίγλωσσες όπως της Ουαλίας συγκρινόμενα με δίγλωσσα παιδιά που κατοικούν σε μονόγλωσσες κοινωνίες. Επίσης, ο χρόνος που περνά ένα παιδί σε ένα δίγλωσσο εκπαιδευτικό πρόγραμμα μπορεί να επηρεάσει την εκτελεστική λειτουργικότητα. Ο σκοπός της παρούσας μελέτης είναι να ερευνήσει τα δύο παραπάνω ζητήματα.

Τι περιλαμβάνει?

Όλα τα παιδιά που θα πάρουν μέρος θα συμπληρώσουν τις παρακάτω δραστηριότητες: ένα ερωτηματολόγιο σχετικά με τη χρήση της γλώσσας/των γλωσσών που χρησιμοποιούν οι γονείς/κηδεμόνες τους και τα ίδια που θα συμπληρωθεί από τους γονείς/κηδεμόνες, σύντομες δραστηριότητες εκτελεστικής λειτουργικότητας βασισμένες σε υπολογιστή που περιλαμβάνουν παιχνίδια με αριθμούς, βέλη, χρώματα και δύο σταθμισμένες δραστηριότητες γλωσσικής ικανότητας. Η ώρα που θα απασχοληθούν τα παιδιά δεν θα ξεπεράσει τα 40 λεπτά. Όλες οι δραστηριότητες είναι ηλικιακά κατάλληλες και έχουν χρησιμοποιηθεί σε προηγούμενες μελέτες με αυτές τις ηλικίες, που τις βρίσκουν αρκετά διασκεδαστικές. Αυτό θα έχει προγραμματιστεί έτσι ώστε να μην δημιουργήσει αναστάτωση στη μαθησιακή διαδικασία.

Συγκατάθεση, εμπιστευτικότητα και ανατροφοδότηση

Η μελέτη διεξάγεται σύμφωνα με τις οδηγίες και τους κανόνες της Επιτροπής Ηθικής του Τμήματος Γλωσσολογίας και Αγγλικής Γλώσσας του Πανεπιστήμιο του Bangor ώστε να επιβεβαιωθεί ότι η μελέτη τηρεί όλους τους κανόνες ηθικής.

Θα ήθελα να σας διαβεβαιώσω ότι τα δεδομένα που θα συγκεντρωθούν θα αντιμετωπιστούν με εμπιστευτικότητα. Ενδιαφερόμαστε μόνο για τα συνολικά δεδομένα και όχι για την ατομική απόδοση του κάθε παιδιού. Δεν θα χρησιμοποιηθεί κανένα όνομα στην κωδικοποίηση των δεδομένων: Θα δοθεί ένα κωδικός σε όλα τα παιδιά που θα χρησιμοποιηθεί στα φύλλα απάντησης τους και έτσι τα δεδομένα θα είναι ανώνυμα. Θα χρειαστούμε την ημερομηνία γέννησης του παιδιού σας (χρόνος και μήνας θα είναι αρκετά) και το κοινωνικοοικονομικό υπόβαθρο των γονιών γιατί θα συγκρίνουμε διαφορετικές ομάδες παιδιών.

Έχουμε πάρει τη συγκατάθεση του διευθυντή του σχολείου και θα έρθουμε σε συνεννόηση με το διευθυντή και τους δασκάλους ώστε να επιβεβαιώσουμε ότι δε θα υπάρξει αναστάτωση στο μάθημα. Επίσης τα παιδιά θα ερωτηθούν αν θέλουν να πάρουν μέρος και θα δοθεί η δυνατότητα στα παιδιά να αποσυρθούν ανά πάσα στιγμή. Αν δε θελήσουν να πάρουν μέρος θα συνεχίσουν τις σχολικές τους δραστηριότητες.

Αν και το σχολείο σας έχει με μεγάλη ευγένεια συμφωνήσει να πάρει μέρος σε αυτήν τη μελέτη, δεν θα συμπεριλάβουμε το παιδί σας στη μελέτη αν δεν επιθυμείτε το παιδί σας να πάρει μέρος στη μελέτη.

Αν ΔΕΝ θέλετε το παιδί σας να πάρει μέρος παρακαλώ:

1. Επιστρέψτε τη φόρμα υπογεγραμμένη στο κάτω μέρος ή

2. Επικοινωνήστε με email στο elp4ae@bangor.ac.uk

Αν δέχεστε το παιδί σας να πάρει μέρος τότε δεν χρειάζεται να κάνετε κάτι. Αν δε λάβουμε κάποια φόρμα μέχρι και μέχρι τις …/…/2016 θα θεωρήσουμε ότι συμφωνείτε.

Σε περίπτωση τυχόν ερωτήσεων ή προβλημάτων σχετικά με τη μελέτη, σας παρακαλώ όπως επικοινωνήσετε με την επιβλέπων της μελέτης Dr Eirini Sanoudaki (email e.sanoudaki@bangor.ac.uk; tel: +44 (0)1248 388638), ή τον Πρόεδρο του Τμήματος Γλωσσολογίας και Αγγλικής Γλώσσας, Dr Peredur Davies (email: p.davies@bangor.ac.uk; tel: +44 (0)1248 382198). Αν έχετε ερωτήσεις για την Αθανασία παρακαλώ στείλτε email στο elp4ae@bangor.ac.uk.

ΔΕΝ δίνω την άδεια το παιδί μου να πάρει μέρος στο πρότζεκτ της Αθανασίας Παπαστέργιου

Όνομα παιδιού……………………………………………………………………………...

Υπογραφή γονέα/κηδεμόνα…………………………………………………………..

List 2: School Information Sheet (English and Greek)

PRIFYSGOL BANGOR UNIVERSITY

<u>Letter to schools for PhD study</u>

Email: e.sanoudaki@bangor.ac.uk

elp4ae@bangor.ac.uk

The Headteacher

Executive Function in Bilingual Children and the Role of Language Use and Education

Dear Sir/Madam,

I am a Bilingualism and Linguistics expert in the School of Linguistics and English Language at Bangor University. I am writing to request the school's help with a project looking at the executive function and the role of language use and education. My graduate student, Athanasia Papastergiou will conduct the work. Athanasia has been awarded a fully-funded PhD studentship to conduct research on this topic.

Background

According to previous research the development of the executive-function system, located in the prefrontal cortex, is the most crucial cognitive achievement in early childhood. Children gradually master the ability to control attention, inhibit distraction, monitor sets of stimuli, expand working memory, and shift between tasks. However, previous research findings on the executive function of bilinguals are not consistent especially with children in fully-bilingual communities, such as Wales, compared to bilinguals who live in other communities. In addition, based on previous findings the length of time in a bilingual educational setting might influence executive functioning. The purpose of this research is to address these two issues.

What's involved?

All children will complete the following assessments: a background information questionnaire about their bilingual language use, a computer-based executive function test, a standardised test of linguistic ability. Each session will take no longer than 30-40 minutes per child. These measures are all age-appropriate and have been used in previous research with this age range.

Consent, confidentiality and feedback

If your school agrees to take part in this study, we need to obtain consent from the head teacher, who will inform the parents of the details of the research. If parents do not wish their children to take part in the research they can withdraw them at any time. Please note that, in addition, children will be given the opportunity to withdraw at any time.

I would like to assure you that all the data collected will be treated as confidential. We are interested in only the group data and not the performance of any one child. No names will be entered on the database: all children will be assigned an anonymisation code that will be used on their response sheets.

The data will be written up as part of Athanasia's PhD thesis and may also be written up for publication in a research journal. In all instances, only group means will be presented; we will not present the data for any individual child.

When we have analysed and interpreted our findings, we will send you a summary of the results and their implications. Our research is conducted within the guidelines of the School of Linguistics and English Language Ethics Committee at Bangor University. In the event of any queries or problems to do with this research, please contact me Dr Eirini Sanoudaki (email e.sanoudaki@bangor.ac.uk; tel: +44 (0)1248 388638), or the School of Linguistics & English Language Head of Department, Dr Peredur Davies (email: p.davies@bangor.ac.uk; tel: +44 (0)1248 382198). If you have any queries for Athanasia, please email elp4ae@bangor.ac.uk.

We very much hope that you will agree to participate in this work. Athanasia will ring you soon to find out if the school is willing to participate in this work. As stated above, if you agree to participate, you will need to complete a consent form which we will send to you.

Yours sincerely,

Dr Eirini Sanoudaki

<u>Γράμμα για Διδακτορική Μελέτη</u>

Email: e.sanoudaki@bangor.ac.uk

elp4ae@bangor.ac.uk

PRIFYSGOL BANGOR UNIVERSITY

Εκτελεστική Λειτουργικότητα Δίγλωσσων Παιδιών για το Ρόλο της Χ της Εκπαίδευσης

Αξιότιμε Κυρία Διευθύντρια/Κύριε Διευθυντή,

Ονομάζομαι Ειρήνη Σανουδάκη και είμαι Λέκτορας, ειδικός στη Διγλωσσία και στη Γλωσσολογία στο Τμήμα Γλωσσολογίας και Αγγλικής Γλώσσας στο Πανεπιστήμιο του Bangor. Γράφω για να ζητήσω τη βοήθεια του σχολείου σχετικά με τη μελέτη της διδακτορικής μου φοιτήτριας, Αθανασίας Παπαστέργιου, που μελετά την εκτελεστική λειτουργικότητα και το ρόλο της χρήσης της γλώσσας και της εκπαίδευσης. Η Αθανασία έχει απονεμηθεί πλήρη διδακτορική υποτροφία της Οικονομικής και Κοινωνικής Ερευνητικής Επιτροπής - Κέντρου Διδακτορικής Εκπαίδευσης Ουαλίας (ESRC-DTC Wales) για να διεξάγει έρευνα σχετική με αυτό το αντικείμενο.

Ερευνητικό Πλαίσιο

Σύμφωνα με μελέτες η ανάπτυξη του συστήματος εκτελεστικής λειτουργικότητας είναι το πιο καίριας σημασίας γνωστικό επίτευγμα στη νηπιακή ηλικία. Με τον όρο εκτελεστική λειτουργικότητα περιγράφεται ένα σύμπλεγμα γνωστικών διαδικασιών το οποίο περιλαμβάνει δεξιότητες όπως η οργάνωση, η πειθαρχία, η αυτορρύθμιση, το να θυμάται κανείς τι έχει να κάνει, η διαχείριση του χρόνου, η προσοχή και ο έλεγχος της παρόρμησης. Σταδιακά τα παιδιά κατακτούν την ικανότητα να ελέγξουν την προσοχή, να μην αποσπώνται, να επεκτείνουν τη λειτουργική μνήμη, και να εναλλάσσονται μεταξύ δραστηριοτήτων. Όμως, τα ευρήματα πρόσφατων μελετών σχετικά με την εκτελεστική λειτουργικότητα των δίγλωσσων παιδιών δεν είναι σταθερά ειδικά με παιδιά που κατοικούν σε κοινωνίες δίγλωσσες όπως της Ουαλίας συγκρινόμενα με δίγλωσσα παιδιά που κατοικούν σε μονόγλωσσες κοινωνίες. Επίσης, ο χρόνος που περνά ένα παιδί σε ένα δίγλωσσο εκπαιδευτικό πρόγραμμα μπορεί να επηρεάσει την εκτελεστική λειτουργικότητα. Ο σκοπός της παρούσας μελέτης είναι να ερευνήσει τα δύο παραπάνω ζητήματα.

Τι περιλαμβάνει?

Όλα τα παιδιά που θα πάρουν μέρος θα συμπληρώσουν τις παρακάτω δραστηριότητες: ένα ερωτηματολόγιο σχετικά με τη χρήση της γλώσσας/των γλωσσών που χρησιμοποιούν οι γονείς/κηδεμόνες τους και τα ίδια, πέντε σύντομες δραστηριότητες εκτελεστικής λειτουργικότητας βασισμένες σε υπολογιστή που περιλαμβάνουν παιχνίδια με αριθμούς, βέλη, χρώματα και δύο σταθμισμένες δραστηριότητας γλωσσικής ικανότητας. Η ώρα που θα απασχοληθούν τα παιδιά δεν θα ξεπεράσει τα 40 λεπτά. Όλες οι δραστηριότητες είναι κατάλληλες ηλικιακά και έχουν χρησιμοποιηθεί σε προηγούμενες μελέτες με αυτές τις ηλικίες, που τις βρίσκουν αρκετά διασκεδαστικές.

Συγκατάθεση, εμπιστευτικότητα και ανατροφοδότηση

Αν το σχολείο σας συμφωνήσει να πάρει μέρος σε αυτήν τη μελέτη, θα χρειαστούμε να πάρουμε τη συγκατάθεση από το διευθυντή, ο οποίος θα ενημερώσει τους δασκάλους και γονείς/κηδεμόνες για το περιεχόμενο της έρευνας. Αν οι γονείς/κηδεμόνες δεν επιθυμούν το παιδί τους να πάρει μέρος στη μελέτη μπορούν να τα αποσύρουν ανά πάσα στιγμή. Επίσης τα θα δοθεί η δυνατότητα στα παιδιά η δυνατότητα να αποσυρθούν ανά πάσα στιγμή.

Θα ήθελα να σας διαβεβαιώσω ότι τα δεδομένα που θα συγκεντρωθούν θα αντιμετωπιστούν με εμπιστευτικότητα. Ενδιαφερόμαστε μόνο για τα συνολικά δεδομένα και όχι για την ατομική απόδοση του κάθε παιδιού. Δεν θα χρησιμοποιηθεί κανένα όνομα στην κωδικοποίηση των δεδομένων: Θα δοθεί ένα κωδικός σε όλα τα παιδιά που θα χρησιμοποιηθεί στα φύλλα απάντησης τους και έτσι τα δεδομένα θα είναι ανώνυμα.

Τα ανώνυμα δεδομένα θα χρησιμοποιηθούν ως μέρος της διδακτορικής διατριβής της Αθανασίας και μπορεί να χρησιμοποιηθούν για τυχόν δημοσιεύσεις σε κάποιο επιστημονικό περιοδικό. Σε κάθε περίπτωση, μόνο οι ομαδικοί μέσοι όροι θα παρουσιαστούν και δε θα παρουσιαστούν δεδομένα για κάθε παιδί ξεχωριστά.

Όταν θα έχουμε αναλύσει και ερμηνεύσει τα αποτελέσματα θα σας στείλουμε την περίληψη τους. Η μελέτη διεξάγεται σύμφωνα με τις οδηγίες και τους κανόνες της Επιτροπής Ηθικής του Τμήματος Γλωσσολογίας και Αγγλικής Γλώσσας του Πανεπιστήμιο του Bangor. Σε περίπτωση τυχόν ερωτήσεων ή προβλημάτων σχετικά με τη μελέτη, σας παρακαλώ όπως επικοινωνήσετε με την επιβλέπων της μελέτης Dr Eirini Sanoudaki (email e.sanoudaki@bangor.ac.uk; tel: +44 (0)1248 388638), ή τον Πρόεδρο του Τμήματος Γλωσσολογίας και Αγγλικής Γλώσσας, Dr Peredur Davies (email: p.davies@bangor.ac.uk; tel: +44 (0)1248 382198). Αν έχετε ερωτήσεις για την Αθανασία παρακαλώ στείλτε email στο elp4ae@bangor.ac.uk.

Ελπίζουμε ότι θα συμφωνήσετε να πάρετε μέρος σε αυτήν τη μελέτη. Η Αθανασία θα σας τηλεφωνήσει σύντομα για να σας ρωτήσει αν θέλετε να πάρετε μέρος στη μελέτη. Όπως αναφέρθηκε και παραπάνω, αν συμφωνήσετε να πάρετε μέρος, θα χρειαστεί να συμπληρώσετε μια φόρμα συγκατάθεσης την οποία θα σας στείλουμε.

Με εκτίμηση,

Δρ Ειρήνη Σανουδάκη

List 3: Head teacher consent form (English and Greek)

HEAD TEACHER CONSENT FORM

Έντυπο Παροχής Συγκατάθεσης του Διευθυντή

Title of Study: Executive Function in Bilingual Children and the Role of Language Use and Education

Τίτλος Μελέτης: Εκτελεστική Λειτουργικότητα των Δίγλωσσων Παιδιών και ο Ρόλος της Χρήσης της Γλώσσας και της Εκπαίδευσης.

Please read the following statements and, if you agree, tick the box to confirm agreement/

Παρακαλώ διαβάστε τις παρακάτω προτάσεις και, αν συμφωνείτε, σημειώστε με √ για να επιβεβαιώσετε συμφωνία:

1) The above study has been fully explained to me and I have had the opportunity to ask questions. ________

Η παραπάνω μελέτη μου έχει πλήρως εξηγηθεί και είχα τη δυνατότητα να κάνω ερωτήσεις. ________

2) Parents/guardians of each child participating in this study have been fully informed about the nature of this study.

Οι γονείς/κηδεμόνες κάθε μαθητή που συμμετέχει στην έρευνα έχουν ενημερωθεί πλήρως για τη φύση αυτής της μελέτης. ________

3) Parents/guardians have been given a reasonable period of time to withdraw their child from participating in the study.

Έχει δοθεί αρκετός χρόνος στους γονείς να αποσύρουν το παιδί τους από τη συμμετοχή τους στη μελέτη. ________

4) Children will be given the opportunity to withdraw at any point during the task.

Θα δοθεί η δυνατότητα στα παιδιά να αποσυρθούν σε οποιαδήποτε φάση της μελέτης.

5) I am willing to act *in loco parentis* in regard to consenting children whose parents have not contacted me (to indicate opt-out) about the study.
Δέχομαι να δράσω 'σε θέση γονέα/κηδεμόνα' όσον αφορά στη συμμετοχή μαθητών των οποίων οι γονείς/κηδεμόνες δεν έχουν επικοινωνήσει (για να αποσύρουν το παιδί τους) για την έρευνα.

Signature/Υπογραφή:

Name of Head Teacher	Date	Signature
Ονοματεπώνυμο Διευθυντή	**Ημερομηνία**	**Υπογραφή**

Please keep one copy of the consent for your records. In the event of any queries or problems to do with this research, please contact the supervisor Dr Eirini Sanoudaki (email e.sanoudaki@bangor.ac.uk; tel: +44 (0)1248 388638), or the School of Linguistics & English Language Head of Department, Dr Peredur Davies (email: p.davies@bangor.ac.uk; tel: +44 (0)1248 382198). If you have any queries for Athanasia, please email elp4ae@bangor.ac.uk.

Παρακαλώ κρατήστε ένα αντίγραφο της συγκατάθεσης για τα αρχεία σας. Σε περίπτωση τυχόν ερωτήσεων ή προβλημάτων σχετικά με τη μελέτη, σας παρακαλώ όπως επικοινωνήσετε με την επιβλέπων της μελέτης Dr Eirini Sanoudaki (email e.sanoudaki@bangor.ac.uk; tel: +44 (0)1248 388638), ή τον Πρόεδρο του Τμήματος Γλωσσολογίας και Αγγλικής Γλώσσας, Dr Peredur Davies (email: p.davies@bangor.ac.uk; tel: +44 (0)1248 382198). Αν έχετε ερωτήσεις για την Αθανασία παρακαλώ στείλτε email στο elp4ae@bangor.ac.uk.

List 4: *Ethics Approval*

PRIFYSGOL
BANGOR
UNIVERSITY

Ysgol Ieithyddiaeth ac Iaith Saesneg
Prifysgol Bangor

School of Linguistics and English Language
Bangor University

Myfyrwraig/*Student*: Papastergiou, Athanasia (LX-1502), December 11th 2015

Mae'r astudiaeth PhD hon wedi cael ei chadarnhau o ran agweddau moesegol, yn dilyn ymgynghoriad gyda'r arolygwr a swyddog Moeseg yr Ysgol, ac yn ogystal mae wedi cael ei chadarnhau gan bwyllgor Moeseg Coleg y Celfyddydau a'r Dyniaethau. Mae rhyddid i'r fyfyrwraig a enwir uchod barhau gyda chasglu'r data a gweithio ar y traethawd hir.

This PhD study has been approved with regards to ethical concerns, following consultation with the supervisor and the School Ethics officer, and furthermore has been approved by the Ethics committee of the College of Arts and Humanities. The student named above is now free to continue with collecting the data and working on the dissertation.

Dr Marco Tamburelli
Swyddog Moeseg yr Ysgol / Uwch Ddarlithydd mewn Dwyieithrwydd
School Ethics officer / Senior Lecturer in Bilingualism

List 5: Questionnaires for parents/guardians (English and Greek)

Reference Code ____________________________

Language and Social Background Questionnaire (to be completed by parents)

1. Today's date: ______________________________
day **month** **year**

2. Completed by: Mother ☐ Father ☐ Other ☐ (please specify) ________________________

Part A – Background

The following information refers to your CHILD:

3. First name: ____________________________ Last name: ________________________________

4. Date of birth ______________________________ **5.** Sex: ____________ **6.** Grade: _________
day **month** **year**

7. Country of birth: _______________________________ **8.** Handedness: left ☐ right ☐

The following information refers to the PARENTS:

10. Country of birth of MOTHER: ______________________________________

If not born in the U.K., when did the mother come to the U.K.? (Month/Year) ______________________

What language(s) did the mother grow up speaking? ____

List the languages known by the mother, *in order of fluency (most fluent to least fluent)*:

____

11. Country of birth of FATHER: ______________________________________

If not born in U.K., when did the father come to U.K.? (Month/Year) ______________________

What language(s) did the father grow up speaking? ____

List the languages known by the father, *in order of fluency (most fluent to least fluent)*:

____

Please indicate the highest level of education and occupation for each parent:

12. MOTHER	**13.** FATHER
1.______No qualifications	1.______No qualifications
2.______High school graduate	2.______High school graduate
3.______Some college or college diploma	3.______Some college or college diploma
4.______Bachelor's degree	4.______Bachelor's degree
5.______Graduate or professional degree	5.______Graduate or professional degree
Occupation: ________________________	**Occupation:** ________________________

Part B – Child's Language and Educational Experience

14. Does your child ***understand*** any language other than English? **yes** ☐ **no** ☐

If **yes**, how would you rate your child's understanding of English, Greek, and of any other language(s)?

Name other language(s)	Poor	Fair	Moderate	Good	Excellent
______________________	☐	☐	☐	☐	☐
______________________	☐	☐	☐	☐	☐
______________________	☐	☐	☐	☐	☐

15. Does your child ***speak*** any language other than English? **yes** ☐ **no** ☐

If **yes**, how would you rate your child's speaking in English, Greek, and in any other language(s)?

Name other language(s)	Poor	Fair	Moderate	Good	Excellent
______________________	☐	☐	☐	☐	☐
______________________	☐	☐	☐	☐	☐
______________________	☐	☐	☐	☐	☐

16. Does your child attend any language or school program other than regular school? **yes** ☐ **no** ☐

If **yes**, which program?________________________ Since when?_______/________/_______

How often? Every day ☐ Once a week ☐ Other: ____________________________

17. From what age has your child attended English school? ________________________________

18. Has your child attended a foreign language institute (frontistirio); ____ **If yes** for how many years? ______

19. Has your child attended Greek regular school? _____ **If yes** from what age?_________________

20. Which language did your child first speak?

English ☐ Greek ☐ Other language(s) ☐ Both/All at the same time ☐

21. Age when your child began acquiring Greek: ___________________________

22. Age when your child began acquiring English: ___________________________

23. Age when your child began acquiring another language: ___________________________

24. Is there's another relative (e.g., grandparent) who lives in the home? **yes** ☐ **no** ☐

If yes, what are the languages spoken by that relative? ___________________________

25. Does your child play a musical instrument? **yes** ☐ **no** ☐

Part C – Language in the home

For each of the following, please indicate with a check mark (√) the use of language in your home for that activity. If a question does not apply to your family, please indicate by writing N/A.

Questions about the CHILD

	All English			Half English/Half other language(s)			Only in the other language(s)
Language **CHILD** speaks to:	1	2	3	4	5	6	7
1. Mother	☐	☐	☐	☐	☐	☐	☐
2. Father	☐	☐	☐	☐	☐	☐	☐
3. Siblings	☐	☐	☐	☐	☐	☐	☐
4. Maternal grandparents	☐	☐	☐	☐	☐	☐	☐
5. Paternal grandparents	☐	☐	☐	☐	☐	☐	☐
6. Other relatives (aunts, uncles etc.)	☐	☐	☐	☐	☐	☐	☐
7. Friends	☐	☐	☐	☐	☐	☐	☐
Language **CHILD** uses for:							
8. Reading	☐	☐	☐	☐	☐	☐	☐
9. Listening to the radio/music	☐	☐	☐	☐	☐	☐	☐
10. Watching TV/DVD	☐	☐	☐	☐	☐	☐	☐
11. Searching the internet (e.g., Google, Facebook)	☐	☐	☐	☐	☐	☐	☐
Overall, language your **CHILD** uses to speak:							
12. At home	☐	☐	☐	☐	☐	☐	☐
13. Within your community/local environment	☐	☐	☐	☐	☐	☐	☐

Questions about the FAMILY

Language spoken **IN THE HOME** to the child by:	1	2	3	4	5	6	7
14. Mother	☐	☐	☐	☐	☐	☐	☐
15. Father	☐	☐	☐	☐	☐	☐	☐
16. Siblings	☐	☐	☐	☐	☐	☐	☐
17. Maternal grandparents	☐	☐	☐	☐	☐	☐	☐
18. Paternal grandparents	☐	☐	☐	☐	☐	☐	☐
19. Other relatives (aunts, uncles etc.)	☐	☐	☐	☐	☐	☐	☐
20. Neighbours/friends/ other caregivers	☐	☐	☐	☐	☐	☐	☐

Language spoken **IN THE HOME** between:

21. Parents/Spouses	☐	☐	☐	☐	☐	☐	☐
22. Siblings	☐	☐	☐	☐	☐	☐	☐
23. Maternal grandparents	☐	☐	☐	☐	☐	☐	☐
24. Paternal grandparents	☐	☐	☐	☐	☐	☐	☐
25. Other relatives (aunts, uncles etc.)	☐	☐	☐	☐	☐	☐	☐
26. Neighbours/friends	☐	☐	☐	☐	☐	☐	☐

Language used **IN THE HOME** for:

27. Reading	☐	☐	☐	☐	☐	☐	☐
28. Listening to the radio/music	☐	☐	☐	☐	☐	☐	☐
29. Watching TV/DVD	☐	☐	☐	☐	☐	☐	☐
30. Searching the internet (e.g., Google, Facebook)	☐	☐	☐	☐	☐	☐	☐
31. Reading stories to the child	☐	☐	☐	☐	☐	☐	☐

End of Questionnaire

Thank you for your participation

Reference Code ________________________

Ερωτηματολόγιο
(να συμπληρωθεί από τους γονείς/κηδεμόνες)

1. Ημερομηνία: __________/__________/__________
ημέρα μήνας χρόνος

2. Συμπληρώθηκε από: Μητέρα ☐ Πατέρα ☐ Άλλον ☐ (παρακαλώ διευκρινίστε) ____________________

Μέρος Α– Υπόβαθρο

Οι παρακάτω πληροφορίες αναφέρονται στο παιδί σας:

3. Όνομα: ______________________________ Επώνυμο: ______________________________

4. Ημερομηνία γέννησης ______/_______/_______ **5.** Φύλο: __________ **6.** Τάξη:__________
μέρα μήνας χρόνος

7. Τόπος Γέννησης: ______________________________ **8.** Επικρατές χέρι: αριστερό ☐ δεξί ☐

Οι παρακάτω πληροφορίες αναφέρονται στους γονείς:

10. Τόπος γέννησης της **ΜΗΤΕΡΑΣ**:____________________________________

Αν δεν γεννήθηκε στο Ηνωμένο Βασίλειο, πότε ήρθε η μητέρα στο Ηνωμένο Βασίλειο; ________/________
Μήνας Χρόνος

Με ποιες γλώσσες μεγάλωσε η μητέρα;____

Βάλτε σε σειρά τις γλώσσες που γνωρίζει η μητέρα, *σε σειρά ευχέρειας*
(από μεγαλύτερη ευχέρεια στη μικρότερη ευχέρεια):____

____

11. Τόπος γέννησης του **ΠΑΤΕΡΑ** :____________________________________

Αν δεν γεννήθηκε στο Ηνωμένο Βασίλειο, πότε ήρθε πατέρας στο Ηνωμένο Βασίλειο; ________/________
Μήνας Χρόνος

Με ποιες γλώσσες μεγάλωσε ο πατέρας;____

Βάλτε σε σειρά τις γλώσσες που γνωρίζει η μητέρα, *σε σειρά ευχέρειας*
(από μεγαλύτερη ευχέρεια στη μικρότερη ευχέρεια)____

____

Παρακαλώ βάλτε **X** στο υψηλότερο εκπαιδευτικό σας επίπεδο και συμπληρώστε το επάγγελμα του κάθε γονιού:

12. ΜΗΤΕΡΑ	**13.** ΠΑΤΕΡΑΣ
1.______ Δεν τελείωσα το Δημοτικό	1.______ Δεν τελείωσα το Δημοτικό
2.______ Απόφοιτος Δημοτικού	2.______ Απόφοιτος Δημοτικού
3.______ Απόφοιτος Γυμνασίου	3.______ Απόφοιτος Γυμνασίου
4.______ Απόφοιτος Λυκείου	4.______ Απόφοιτος Λυκείου
5.______ Πτυχίο Ανώτερης σχολής	5.______ Πτυχίο Ανώτερης σχολής
6.______ Πτυχίο Ανώτατης σχολής	6.______ Πτυχίο Ανώτατης σχολής
7.______ Μεταπτυχιακό Δίπλωμα	7.______ Μεταπτυχιακό Δίπλωμα
8.______ Διδακτορικό Δίπλωμα	8.______ Διδακτορικό Δίπλωμα
Επάγγελμα: ________________________	**Επάγγελμα:** ________________________

Μέρος Β – Γλωσσική Εμπειρία Παιδιού

14. Το παιδί σας ***καταλαβαίνει*** άλλη γλώσσα/ες εκτός από Αγγλικά; **ναι** ☐ **όχι** ☐

Πώς θα βαθμολογούσατε την **κατανόηση** του παιδιού σας στα Αγγλικά, στα Ελληνικά και σε κάποια άλλη γλώσσα/ες;

Ονόματα γλωσσών	Ανεπαρκής	Μικρή	Μέτρια	Καλή	Άριστη
________________________	☐	☐	☐	☐	☐
________________________	☐	☐	☐	☐	☐
________________________	☐	☐	☐	☐	☐

15. Το παιδί σας ***μιλάει*** άλλη γλώσσα/ες εκτός από Αγγλικά; **ναι** ☐ **όχι** ☐

Πώς θα βαθμολογούσατε την ομιλία του παιδιού σας στα και Αγγλικά, στα Ελληνικά και σε κάποια άλλη γλώσσα/ες;

Ονόματα γλωσσών	Ανεπαρκής	Μικρή	Μέτρια	Καλή	Άριστη
________________________	☐	☐	☐	☐	☐
________________________	☐	☐	☐	☐	☐
________________________	☐	☐	☐	☐	☐

16. Το παιδί σας παρακολουθεί κάποιο άλλο γλωσσικό ή σχολικό πρόγραμμα εκτός από το καθημερινό σχολείο; **ναι** ☐ **όχι** ☐

Αν **ναι**, ποιο πρόγραμμα;__________________________ Από πότε; _______/_______/_______

Πόσο συχνά; Κάθε μέρα ☐ Μία φορά την εβδομάδα ☐ Άλλο:__________________________

17. Από **ποια ηλικία** παρακολουθεί το παιδί σας Αγγλικό καθημερινό σχολείο; ______________________

18. Παρακολουθούσε το παιδί σας κάποιο φροντιστήριο ξένων γλωσσών; ____ **Αν ναι** για πόσα χρόνια; _____

19. Παρακολουθούσε το παιδί σας καθημερινό Ελληνικό σχολείο; _______ **Αν ναι** από ποια ηλικία; _______

20. Ποια γλώσσα μίλησε **πρώτα** το παιδί σας;

Αγγλικά ☐ Ελληνικά ☐ Άλλη γλώσσα ☐ Και τις δύο / Όλες ταυτόχρονα ☐

21. Σε ποια ηλικία το παιδί σας άρχισε να κατακτά τα Ελληνικά; ________________________

22. Σε ποια ηλικία άρχισε το παιδί σας να κατακτά τα Αγγλικά; __________________________

23. Σε ποια ηλικία άρχισε το παιδί σας να κατακτά κάποια άλλη γλώσσα;________________________

24. Ζει κάποιος άλλος συγγενής (π.χ., παππούς, γιαγιά) στο σπίτι; **ναι** ☐ **όχι** ☐

Αν **ναι**, τι γλώσσες μιλάει αυτός ο συγγενής? ____

25. Το παιδί σας παίζει κάποιο μουσικό όργανο; **ναι** ☐ **όχι** ☐

Μέρος Γ – Γλώσσα στο Σπίτι

Για κάθε μία από τις παρακάτω ερωτήσεις, παρακαλώ σημειώστε με το σύμβολο (√) τη χρήση γλώσσας στο σπίτι σας γι' αυτή τη δραστηριότητα. Αν κάποια ερώτηση δεν αφορά την οικογένειά σας, παρακαλώ σημειώστε N/A.

<u>Ερωτήσεις για το παιδί</u>

	Μόνο Αγγλικά		Μισά Αγγλικά/ Μισά Ελληνικά ή άλλες γλώσσες			Μόνο Ελληνικά ή άλλες γλώσσες	
Γλώσσα που μιλάει το **παιδί** σε:	1	2	3	4	5	6	7
1. Μητέρα	☐	☐	☐	☐	☐	☐	☐
2. Πατέρα	☐	☐	☐	☐	☐	☐	☐
3. Αδέρφια	☐	☐	☐	☐	☐	☐	☐
4. Παππούδες από τη μητέρα	☐	☐	☐	☐	☐	☐	☐
5. Παππούδες από τον πατέρα	☐	☐	☐	☐	☐	☐	☐
6. Άλλους συγγενείς (θείες, θείους, κτλ.)	☐	☐	☐	☐	☐	☐	☐
7. Φίλους	☐	☐	☐	☐	☐	☐	☐
Γλώσσα που χρησιμοποιεί το **παιδί** για:							
8. Ανάγνωση	☐	☐	☐	☐	☐	☐	☐
9. Ραδιόφωνο/Μουσική	☐	☐	☐	☐	☐	☐	☐
10. Τηλεόραση/DVD	☐	☐	☐	☐	☐	☐	☐
11. Ίντερνετ (π.χ., Google, Facebook)	☐	☐	☐	☐	☐	☐	☐
Γενικά, γλώσσα που μιλάει το **παιδί**:							
12. Στο σπίτι	☐	☐	☐	☐	☐	☐	☐
13. Μέσα στην κοινωνία/τοπικό περιβάλλον	☐	☐	☐	☐	☐	☐	☐

<u>Ερωτήσεις για την οικογένεια</u>

Γλώσσα που μιλάνε στο **παιδί**:	1	2	3	4	5	6	7
14. Μητέρα	☐	☐	☐	☐	☐	☐	☐
15. Πατέρας	☐	☐	☐	☐	☐	☐	☐

16. Αδέρφια	☐	☐	☐	☐	☐	☐	☐
17. Παππούδες από τη μητέρα	☐	☐	☐	☐	☐	☐	☐
18. Παππούδες από τον πατέρα	☐	☐	☐	☐	☐	☐	☐
19. Άλλοι συγγενείς (θείες, θείοι, κτλ.)	☐	☐	☐	☐	☐	☐	☐
20. Γείτονες/Φίλοι/Πάροχοι φροντίδας (π.χ., νταντά)	☐	☐	☐	☐	☐	☐	☐

Γλώσσα που χρησιμοποιείται στο **σπίτι** ανάμεσα σε:

21. Γονείς/Συζύγους	☐	☐	☐	☐	☐	☐	☐
22. Αδέρφια	☐	☐	☐	☐	☐	☐	☐
23. Παππούδες από τη μητέρα	☐	☐	☐	☐	☐	☐	☐
24. Παππούδες από τον πατέρα	☐	☐	☐	☐	☐	☐	☐
25. Άλλους συγγενείς (θείες, θείους, κτλ.)	☐	☐	☐	☐	☐	☐	☐
26. Γείτονες/Φίλους	☐	☐	☐	☐	☐	☐	☐

Γλώσσα που χρησιμοποιείται στο **σπίτι** για:

27. Ανάγνωση	☐	☐	☐	☐	☐	☐	☐
28. Ραδιόφωνο/Μουσική	☐	☐	☐	☐	☐	☐	☐
29. Τηλεόραση/DVD	☐	☐	☐	☐	☐	☐	☐
30. Ίντερνετ (π.χ., Google, Facebook)	☐	☐	☐	☐	☐	☐	☐
31. Ανάγνωση βιβλίων/παραμυθιών στο παιδί	☐	☐	☐	☐	☐	☐	☐

Τέλος Ερωτηματολογίου **Ευχαριστώ πολύ για τη συμμετοχή σας**

List 6: Technical Appendix A

APPENDIX Table A28 *Correlation matrix*

	BDST_ACC	Counting_ACC	ColourShape_ACC	Stroop_ACC	ANT_ACC	BDST_RT	Counting_RT	ColourShape_RT	Stroop_RT	ANT_RT	SES	IQ	GS	LS	VS
Counting_ACC	0.46 (0.00)	1.00													
ColourShape_AC	0.33 (0.01)	0.55 (0.00)	1.00												
Stroop_ACC	0.57 (0.00)	0.45 (0.00)	0.45 (0.00)	1.00											
ANT_ACC	0.52 (0.00)	0.52 (0.00)	0.56 (0.00)	0.65 (0.00)	1.00										
BDST_RT	-0.04 (0.73)	-0.06 (0.62)	-0.04 (0.72)	-0.05 (0.70)	-0.01 (0.94)	1.00									
Counting_RT	-0.24 (0.05)	-0.09 (0.46)	-0.27 (0.02)	-0.42 (0.00)	-0.48 (0.00)	0.02 (0.89)	1.00								
ColourShape_RT	-0.30 (0.01)	-0.37 (0.00)	-0.20 (0.10)	-0.33 (0.01)	-0.45 (0.00)	0.11 (0.36)	0.28 (0.02)	1.00							
Stroop_RT	-0.46 (0.00)	-0.51 (0.00)	-0.38 (0.00)	-0.41 (0.00)	-0.54 (0.00)	0.11 (0.38)	0.31 (0.01)	0.57 (0.00)	1.00						
ANT_RT	-0.58 (0.00)	-0.41 (0.00)	-0.40 (0.00)	-0.51 (0.00)	-0.65 (0.00)	0.19 (0.12)	0.38 (0.00)	0.61 (0.00)	0.64 (0.00)	1.00					
SES	-0.07 (0.55)	-0.07 (0.56)	0.05 (0.67)	-0.03 (0.82)	0.04 (0.73)	0.08 (0.50)	0.16 (0.18)	-0.04 (0.76)	0.08 (0.53)	0.02 (0.90)	1.00				
IQ	0.61 (0.00)	0.68 (0.00)	0.39 (0.00)	0.45 (0.00)	0.59 (0.00)	-0.06 (0.64)	-0.19 (0.11)	-0.54 (0.00)	-0.59 (0.00)	-0.61 (0.00)	0.00 (1.00)	1.00			
GS	0.41 (0.00)	0.49 (0.00)	0.41 (0.00)	0.42 (0.00)	0.43 (0.00)	-0.03 (0.80)	-0.21 (0.08)	-0.46 (0.00)	-0.43 (0.00)	-0.47 (0.00)	-0.01 (0.94)	0.57 (0.00)	1.00		
LS	0.25 (0.03)	0.26 (0.03)	0.32 (0.01)	0.22 (0.06)	0.26 (0.03)	0.04 (0.74)	-0.11 (0.37)	-0.35 (0.00)	-0.26 (0.03)	-0.27 (0.03)	0.16 (0.18)	0.38 (0.00)	0.40 (0.00)	1.00	
VS	0.52 (0.00)	0.54 (0.00)	0.52 (0.00)	0.35 (0.00)	0.53 (0.00)	0.07 (0.57)	-0.27 (0.03)	-0.51 (0.00)	-0.52 (0.00)	-0.51 (0.00)	0.04 (0.74)	0.67 (0.00)	0.64 (0.00)	0.61 (0.00)	1.00
Age	0.57 (0.00)	0.62 (0.00)	0.46 (0.00)	0.48 (0.00)	0.63 (0.00)	-0.12 (0.32)	-0.41 (0.00)	-0.66 (0.00)	-0.73 (0.00)	-0.71 (0.00)	-0.17 (0.16)	0.78 (0.00)	0.58 (0.00)	0.45 (0.00)	0.72 (0.00)

Notes. The table reports correlation coefficients and p-values in parentheses. BDST denotes the Backward digit span test, ACC denotes accuracy score, RT the response time. GS, LS, VS are the grammar score, language score, and vocabulary score (VS) respectively. SES is the socio-economic status.

Information about the k-means nearest neighbour matching

The k-means nearest neighbour matching relies on some distance function to quantify the closeness between two (or more) observations. In our context, for each observation of a bilingual child, the k-means nearest neighbour approach determines the "nearest" observation of a monolingual.

A distance function is used to define the closeness of the observations. In the general form we can denote this variable as x. Then the distance between two observations i, j where the i observations corresponds to a bilingual and the j observation corresponds to a monolingual is given as:

$$|x_i - x_j| = \frac{(x_i - x_j)(x_i - x_j)}{Cov(x, x)} \quad (1)$$

We can generalise this formula for p number of covariates using matrix algebra. Assume that $x = \{x_1, x_2, \dots, x_p\}$ and that each observation, i, has the following set of covariates $\mathbf{x}_i = \{x_{1,i}, x_{2,i}, \dots, x_{p,i}\}$. The distance between observations i, j is now given as:

$$\|\mathbf{x}_i - \mathbf{x}_j\| = \left((\mathbf{x}_i - \mathbf{x}_j)'\mathbf{S}^{-1}(\mathbf{x}_i - \mathbf{x}_j)\right)^{1/2} \quad (2)$$

where $\mathbf{S}$ is the variance-covariance matrix of the covariates.

Typical choices for $\boldsymbol{S}$ are:

$$\mathbf{S} = \begin{cases} \mathbf{I}_{\boldsymbol{p}} & \text{for the Euclidean case} \\ \dfrac{(\mathbf{X} - \bar{\mathbf{x}}'\mathbf{1}_{\boldsymbol{n}})'\boldsymbol{W}(\mathbf{X} - \bar{\mathbf{x}}'\mathbf{1}_{\boldsymbol{n}})}{\sum_i^n w_i - 1} & \text{for the Mahalanobis case} \end{cases} \quad (3)$$

where $\mathbf{1}_{\boldsymbol{n}}$ is an $n \times 1$ vector of ones, $\mathbf{I}_{\boldsymbol{p}}$ is the identity matrix of order p, same as the number of covariates used, w_i is the frequency weight for the i observation, $\bar{\mathrm{x}} = \sum_i^n w_i \mathrm{x}_i / \sum_i^n w_i$ denotes a weighted mean and $\mathbf{W}$ is an $n \times n$ diagonal matrix containing the frequency weights. Compared to the Euclidean case, the Mahalanobis may be preferred as it accounts for interactions between the covariates.

Coming back to observation i, we can define the following set of nearest-neighbor index:

$$\Omega(i)^x = \{j | t_j = 1 - t_i, \|\mathbf{x}_i - \mathbf{x}_j\| < \|\mathbf{x}_i - \mathbf{x}_l\|_{\mathbf{S}}, t_l = 1 - t_i \forall l \neq j\} \quad (4)$$

where i is the observation corresponding to a bilingual and for which we want to find a matching monolingual. j denotes the matching monolingual (is only one in this case) and l denotes another candidate monolingual. t denotes the treatment effect and takes the value 1 for bilinguals, zero otherwise. $\|\mathbf{x}_i - \mathbf{x}_j\|$ and $\|\mathbf{x}_i - \mathbf{x}_l\|$ denote the distance between i, j and i, l respectively and in the formula above we require that the distance between i, j is smaller than

i, l (since we select the matching j participant as our match). The notation $t_j = 1 - t_i$ and $t_l = 1 - t_i$ implies that for our i observation which is a bilingual (hence $t_i = 1$) needs to be matched with some monolingual observation for which $t_j = 1 - 1 = 0$ or $t_l = 1 - 1 = 0$

The above can be generalised for m matching observations to enhance reliability of the comparisons, as follows:

$$\Omega(i)_m^x = \left\{j_1, j_2, \ldots, j_m | t_{j_k} = 1 - t_i, \left\|\mathbf{x}_i - \mathbf{x}_{j_k}\right\|_\mathbf{S} < \left\|\mathbf{x}_i - \mathbf{x}_{j_k}\right\|_\mathbf{S}, t_l = 1 - t_i \forall l \neq j_k\right\} \tag{5}$$

For the prediction of the potential outcomes we use the following notation. $y_{1,i}$ is the potential outcome of the i observation that corresponds to a bilingual ($t = 1$). Conversely, $y_{0,i}$ is the potential outcome of the i observation that corresponds to a monolingual ($t = 0$). Only $y_{1,i}$ or $y_{0,i}$ is observed, never both. The k-means nearest neighbours can predict the potential outcome for the i observation as follows:

$$\hat{y}_{t,i} = \begin{cases} y_i \text{ if } t_i = t \quad \text{for } t \in \{0,1\} \\ \dfrac{\sum_{j \in \Omega(i)} w_j y_j}{\sum_{j \in \Omega(i)} w_j} \end{cases} \tag{6}$$

The first is the case where the outcome of the individual observation (y_i) is observed whether bilingual ($t = 1$) or monolingual ($t = 0$). The second case is the *counterfactual* outcome, which does not exist and is estimated as the outcome of the closest match (or matches). The following quantities of interest, namely the Average Treatment Effect (ATE) and the Average Treatment Effect on the Treated (ATET) can be defined as:

$$ATE = \tau_1 = E(y_1 - y_0) \tag{7}$$

$$ATET = \delta_1 = E(y_1 - y_0 | t = 1) \tag{8}$$