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an ERP approach

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Bilingualism and Cognition: An ERP Approach

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PhD Thesis

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Declaration

This Project is the work of the writer's own investigation, and was undertaken under the supervision of Professor Debra Mills. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidate for any degree.

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"You have brains in your head. You have feet in your shoes.
You can steer yourself any direction you choose." – Dr. Seuss

Contents Page

Thesis Summary

The topic of bilingualism and cognition has been well debated in recent years, particularly in relation to cognitive gains as a consequence of speaking multiple languages. There is a long established belief that the experience of learning a second language, be it simultaneously with another from birth or later in childhood/early adulthood, leads to advantages in executive functioning (Bialystok, 2005). However, it has also been proposed that the cognitive advantages seen previously in studies with bilingual populations are not clear cut and that other factors may be influencing the results (Gathercole et al., 2014; Hilchey and Klein, 2011; Paap and Greenberg, 2013). The studies presented in this thesis addressed bilingualism and its effects on cognition in both infant and young adult participants taken from the North Wales area and the Bangor University student population. The infant study addressed semantic priming and working memory, and the young adult studies addressed response inhibition and suppression. The results of these studies proved inconclusive and suggest that the topic of bilingualism and cognition is a complex one. There are many factors that need to be considered and controlled in future studies with bilingual populations including age of acquisition, amount of exposure, language dominance, socioeconomic status, proficiency, and general intelligence. The experience of acquiring multiple languages places demands on cognitive load, which perhaps in turn results in advantages on tasks requiring executive functioning. These advantages may also be gained from other experiences that place demands on cognitive load such as musical training, video gaming, and dancing. Experiences shape the brain and the process of unraveling which experiences lead to these changes is a multifaceted process that needs to be prudently approached.

1. General Introduction

Over the last three decades research regarding bilingualism has increased in popularity and interest. In the early years of addressing the effects of bilingualism, research focused on language ability. The relationship between bilingualism and language ability consistently showed that bilingualism was not a positive influence. Critics have since suggested that the methodology used is questionable and the results of these early studies did not control for other factors such as intelligence, proficiency or cultural differences, and that when these factors are taken into account the differences in language ability between bilinguals and monolinguals is minimal (Barac & Bialystok, 2011). More recent research has switched focus from language abilities to cognitive functions. More specifically researchers are interested in whether being bilingual altars brain development in such a way that it affects executive functions.

Primarily, the majority of the research in favor of an advantageous bilingual effect on executive functions comes from Professor Ellen Bialystok's lab. Her research has suggested that bilingual individuals produce superior performance than monolinguals on tasks that require conflict monitoring, suppression, inhibition, attention and working memory. The theory behind this beneficial effect comes from the Bilingual Advantage Hypothesis, which suggests the constant switching from one language to another and the control needed to inhibit interference from a competing language, requires daily use of these executive functions. Therefore, leading to an advantage on other tasks that also require these cognitive processes to complete successfully.

However, several researchers (Hilchey & Klein, 2011; Paap & Greenberg, 2013; Valian, 2015; Gathercole et al., 2014) have suggested that the bilingual advantage on these tasks is minimal and is dependent on other factors. These authors conclude that when factors such as proficiency, culture, socioeconomic status, age and IQ are controlled the effect of bilingualism diminishes.

Here, three studies are presented that aim to address these conflicting theories. Incorporating the use of ERPs, the aim of these studies is to establish whether the bilingual advantage is present on tasks that require semantic processing, working memory, inhibition, suppression and attention. The first study addresses semantic processing and working memory capacity in bilingual and monolingual infants. While the second and third studies use a Go/No-Go paradigm to address inhibition, suppression and attention processes in young monolingual and bilingual adults.

1.1 Bilingualism and linguistics

Historically, bilingual research has shown that a bilingual speakers vocabulary in each of their languages is not as large or as diverse as a monolingual speakers' knowledge of that language, even when a bilingual may be fluent in both of their languages and use them daily (Bialystok, 2009; Oller & Eilers, 2002; Perani et al, 2003; Bialystok, Luk, Peets & Yang, 2010). Several studies have shown that bilingual adults experience disadvantages on tasks that require rapid lexical access and retrieval. Bilinguals suffer from increased tip-of-the-tongue states (Gollan & Silverberg, 2001) along with longer naming times (Gollan, Montoya, Fennema-Notesine, & Morris, 2005), are slower and commit more errors in picture naming (Roberts, Garcia, Desrochers, & Hernandez, 2002), have reduced scores on letter and category fluency tests (Gollan, Montoya, & Werner, 2002), experience more interference in lexical decision making (Michael & Gollan, 2005) and have poorer word identification through noise (Rogers, Lister, Febo, Besing, & Abrams, 2006). This linguistic pattern appears to reflect more effortful language processing for bilinguals than for comparable monolinguals; specifically these linguistic shortfalls seem to be confined to conditions, which require the individual to rapidly retrieve specific lexical items but does not appear to be present in situations that require more general linguistic or conceptual processing (Bialystok, Craik, & Luk, 2008). For example, poorer word identification through noise (Rogers, Lister, Febo, Besing & Abrams, 2006) indicates less automatic access and retrieval to linguistic knowledge. Further, these deficits are observed even when a bilingual is performing a task, such as a picture-naming task, in their first and dominant language (Ivanova & Costa, 2008). It has been proposed that the reason for this linguistic deficit is due to a single common lexical storage system, where vocabularies for both languages are stored together (Bialystok, 2009).

The proposition of a joint lexical semantic system supports the theory that during daily language use, both of a bilingual's languages are active (Morton & Harper, 2007), even when only one is in use (Costa, 2005; Green, 1998; Jared & Kroll, 2001). It was shown by Guttentag, Haith, Goodman, & Hauch (1984) that there is a pattern of distributed activation during language processing in bilingual individuals, whereby bilinguals do not switch off activation of one language whilst simultaneously engaged in another. Indicating that both languages are active simultaneously during language processing. One advantage of this is that it allows bilinguals the ability to code-switch (completely switch to other language for a word or phrase) and borrow (a morpheme, word or short expression is taken from the other language and adapted morphosyntactically to the base language) from their two languages when they are in conversation with another bilingual (Grosjean, 1999). The ability to code-switch and borrow from each of the two languages is perhaps the most visible evidence for the theory of joint activation and conflict selection (Bialystok, 2009). Joint activation contributes to how lexical items are selected, and this could lead to both facilitation and interference depending on the relationship between the words being retrieved (Costa, 2005). As a consequence it is probable that when a bilingual individual is processing one of their two languages the non-target language must interfere with the production and comprehension of the target language (Morton & Harper, 2007) this leads to more effortful lexical choices, slower retrieval of items from the lexicon and less efficient performance (Bialystok et al, 2008).

It has been proposed that intrusions from the non-target language are inhibited, whilst simultaneously keeping the target language active (Bialystok, 2001). Due to the demands of coordinating two languages, bilingual individuals have daily practice using cognitive processes such as attention and inhibition. This is an on going continuous process (Green, 1998), which over time leads to more efficient inhibitory control of attention resources through extensive practice (Bialystok, 2001; Carlson & Meltzoff, 2008). Although the linguistic experiences of being bilingual appear to have a costly effect on language processes, they do seem to be beneficial for non-linguistic processes (Bialystok, 2009).

1.2 Bilingualism and Cognition

Inhibition is an instrumental aspect of executive functioning, which can be described as the process whereby thought and action are under conscious control (Posner & Rothbart, 2000). Other additional aspects of executive functioning include: resistance to interference, cognitive flexibility, working memory and planning ability – which are all believed to connect to inhibitory processes to some extent (Carlson & Meltzoff, 2008). It would therefore be logical to suggest that those bilinguals who are fluent in both languages and use them regularly will show generalised effects on cognitive performance. In particular bilingualism should lead to a beneficial effect on the process of executive control (Bialystok, 2009).

The bilingual advantage hypothesis proposes that the extensive practice of executive control that a bilingual gains, results in more efficient performance on tasks that require the ability to control attention to conflicting features of a problem (Bialystok, 2009). During completion of such tasks, inhibitory processes are a key component as the individual must be able to inhibit or suppress their attention to the irrelevant or misleading aspects of the stimulus. This allows the individual to direct attention to the appropriate aspects of the task, leading to a successful response (Carlson & Meltzoff, 2008).

Since the proposal of the bilingual advantage hypothesis, research has switched its attention from language ability to focus on possible cognitive processes affected by bilingualism, namely executive functions. During tasks that require efficient use of executive functions, it has been suggested that a bilingual individual should perform more efficiently than a monolingual because of their daily use of these processes to successfully manage their two languages (Bialystok, 2006). This resolution of conflict in lexical choice is thought to boost the central control system that monitors attention, which leads to that function being more robust in bilinguals (Bialystok et al, 2008).

Executive functions are essential in the process of overcoming automatic behaviour, which therefore allows an individual the ability to attend selectively; concentrate on a specific task; make goal orientated choices; inhibit attention to irrelevant stimuli; hold information in working memory, and reflect on higher order rules – all of which are responsible for improvements in control processes (Craik & Bialystok, 2006). Control of attention allows for selectively directing attention, particularly in misleading situations. In a situation that requires problem solving the individual must be able to intentionally focus on some aspects of information while ignoring other aspects. However, this selective attention process is more difficult when a salient response contradicts the most favourable one and must therefore be overruled – meaning that inhibition is a critical component of control (Bialystok & Martin, 2004). An important aspect of control is that it is involved in the process of most cognitive tasks, as the majority of these tasks require the ability to inhibit distracting information whilst also keeping relevant rules stored in working memory so that they can be followed successfully during completion of the task (Diamond and Taylor, 1996).

Many non-verbal control tasks have been used in assessing the extent of the effect of bilingualism on executive functions including, the flanker task (Mezzacappa, 2004; Yang, Shih & Lust, 2005; Costa et al., 2009), perceptual analysis (Bialystok & Shapero, 2005), Attention Network Task (Carlson & Meltzoff, 2008), Simon Task (Bialystok, 2006) and the Stroop Task (Bialystok, 2009; Naylor, Stanley, & Wicha, 2012). These studies have concluded that the bilingual advantage is isolated to situations that require inhibition of attention to a distracting response. There is a specific role for conflict inhibition in these tasks, as the bilingualism advantage did not generalise to all inhibitory processes. There is a difference between performance on tasks requiring inhibition of attention (Bilingual advantage present) and inhibition of an action or motor response (no Bilingual advantage).

These results robustly suggest that there is a cognitive difference in the ability to resolve conflicting attention demands between bilingual and monolingual speakers, which are connected to the cognitive exercise of holding two languages in mind (Carlson & Meltzoff, 2008).

A standard marker for inhibitory control is the difference in mean response time between trials that need conflict resolution and those that do not. On a subset of trials conflict occurs because task irrelevant stimuli is often paired in an incongruent manner with the task relevant stimulus. The smaller the subsequent interference effect (difference in response time between the congruent and incongruent trials) the greater the implied ability (Paap & Greenberg, 2013).

One such task is the Simon task, which requires the efficient use of many cognitive processes in order to complete it successfully. In order for the participant to perform the task efficiently, they must resolve conflict; engage with working memory; as well as monitor and switch between trial types and responses effectively (Bialystok, 2006; Miyake & Shah, 1999). The need for so many cognitive processes make this a good task for assessing the effect bilingualism has on executive functioning. A bilinguals' ability to move successfully between two languages enhances their capacity for switching between other cognitive domains, which explains the smaller Simon effect produced by bilingual participants compared to their monolingual peers (Bialystok et al., 2004; Bialystok, 2006). Bilinguals are better prepared for solving tasks that include misleading perceptual information and require them to ignore a salient perceptual cue so that they can direct their attention to the aspect of the task that requires a response. The Simon Task is a potent means for demonstrating the effect of stimulus response compatibility on performance (Bialystok, 2006), and has been the basis for many studies investigating attention processes and executive functions (Lu & Proctor, 1995). Successful performance on the Simon task requires that the participant is able to use cognitive processes (selective attention, inhibition, and response switching) effectively. Bilinguals perform the spatial conflict aspect of the Simon task more efficiently than monolinguals, as it incorporates the type of conflict resolved better by bilinguals (Bialystok, 2006). The results seen during the Simon task also support the proposition that bilingualism enhances working memory performance. The participant must keep arbitrary rules about stimuli and responses in mind in order to respond to the target accurately. This combination of remembering relevant rules and suppressing the predisposition to press the incorrect response key in incongruent trials places demands on working memory (Namazi, 2009). The proposition that bilingualism results in faster responses in conditions that place greater demands on working memory could be an additional explanation as to why bilingual participants outperform monolinguals on the Simon task.

Although the research appears to demonstrate a strong bias towards an advantage for bilingualism and cognitive control, there is an increasing belief that these advantages are not a true reflection of the effect bilingualism has on cognitive control. Contrary to these previous findings, there is now an approach that proposes that other factors, and not bilingualism, may have led researchers to propose the bilingual advantage hypothesis.

Several authors have suggested that the bilingual effects on cognitive functions is sporadic (Hilchey & Klein, 2011), or that there is no bilingual effect (Paap & Greenberg, 2013), and that other factors such as socio-economic status (SES), proficiency, age, and the type of bilingual being tested (early sequential versus late bilingual) may contribute to the effects seen when addressing bilingualism and executive functions (Gathercole et al., 2014; Paap & Greenberg, 2013; Hilchey & Klein, 2011; Adesope et al., 2011; Woodard & Rodman, 2007; Namazi & Thordardotti, 2010; Valian, 2015).

Several executive functions have come under scrutiny including inhibitory control, conflict monitoring and switching costs. Regarding inhibitory control, there have been reports of no bilingual advantage across 17 new tests using tasks such as the Simon task, the Stroop task, the Flanker task and the anti-saccade (Hilchey & Klein, 2011; Humphrey & Valian, 2012; Kousaie & Phillips, 2012a, 2012b; Paap & Greenberg, 2013). There have also been studies that have demonstrated that there is no global response time advantage on tasks assessing bilinguals' ability to monitor conflict on tasks such as the Simon task and the Flanker task (Humphrey & Valian, 2012; Kousaie & Phillips, 2012a; Paap & Greenberg, 2013; Prior & MacWhinney, 2010).

One of the most popular paradigms used to study bilingualism and executive functions is the Stroop task (Bialystok & Depape, 2009). In the Stroop tasks' simplest form, participants are shown names of colours and are asked to name the colour of the ink the word is written in, on a congruent trial the name of the colour and the colour of the ink match (i.e. 'red' written in red ink), however on an incongruent trial the name of the colour does not match the colour of the ink it is written in (i.e. 'red' written in blue ink). On the incongruent trials the participant must inhibit interference from the written word in order to name the colour of the ink. It has previously been found that bilinguals have faster response times and/or smaller interference effects than their monolingual peers (Badzakova-Trajkov, 2008; Bialystok et al., 2008; Gathercole et al., 2010). Conversely, it has also been shown that proficiency plays a role in the Stroop effect. When language background is controlled the performance of bilinguals is equivalent to monolinguals

(Rosselli et al., 2002). Further, language dominance also effects response times on the Stroop task – bilinguals are faster to respond in their dominant language, and it has been proposed that the effects seen in the colour naming Stroop may be related to vocabulary size (Rosselli et al., 2002). There is also an advantage in inhibitory control on the Stroop task when the bilinguals' second language fluency is better. A group of second language Spanish-English adults were tested using the colour naming Stroop and it was discovered that English fluency (the participants second language) predicted better speed on the Stroop incongruent trials independent of education; suggesting greater inhibitory control in bilinguals who have a higher fluency in their second language (especially when that is the language of the stimuli) (Suarez et al., 2014). Taken together the results of these Stroop tasks demonstrate that when a verbal task is used to analyse cognitive processes in bilinguals, other factors need to be considered and controlled such as proficiency, fluency, language dominance and the type of bilingual being tested, as they all contribute to performance on the Stroop task.

In another study, three experiments compared bilinguals to monolinguals on 15 indicators of executive functioning (Paap & Greenberg, 2013). The tasks used across the three studies included an anti-saccade, the Simon, a flanker and a colour-switching task; whereby the indicators of these tasks compared a neutral or congruent baseline to a condition that should require executive functioning. Groups were matched for intelligence, as they performed identically on the Ravens Advanced Matrices test. For each of the measures tested there was no main effect of group, and the interaction between group and condition was only significant for one indicator, which was indicative of a bilingual disadvantage. When the analysis controlled for parental education or only included highly proficient bilinguals the pattern of results was the same. This study reconfirms the issue that effects assumed to be indicators of executive function on one task, do not predict individual differences on that same indicator during a related task (I.e. inhibitory control on the flanker and the Simon tasks). Further, when studies only use one task to assess bilingualism and executive functioning there is no way of testing the convergent validity of the results obtained. Studies that have used multiple nonlinguistic interference tasks, find no bilingual advantage and little or no convergent validity (Fan et al., 2003; Humphrey & Valian, 2012; Keye et al., 2009; Kousie & Phillips, 2012a; Stins et al., 2005). Therefore, the lack of consistent cross-task correlations undermines the interpretation that these are valid indicators of domain general abilities (Paap & Greenberg, 2013).

If a coherent bilingual advantage in inhibitory control or any other executive function is present, it could be expected that the advantage would be present in two different tasks that subsequently correlate with each other. However, if the two do not correlate then the bilingual advantages observed are likely to be task specific, and therefore not indicative of a shared and domain general ability (Paap & Greenberg, 2013). There have been either weak or no correlations from the results obtained between the Simon, Stroop, and Flanker tasks, and this inconsistency places doubt on the use of such tasks when assessing executive functions (Paap & Greenberg, 2013). Additionally, Paap and Greenberg (2013) suggest that it is difficult to draw conclusions between studies as the coherence in the type/version of tasks used to measure executive function and the type of bilingual tested varies, leading to differences in results. Therefore, the reports of a bilingual advantage are not robust.

The results obtained in studies assessing bilingualism and executive function may be attributable to other factors, such as, Type I errors and task-specific performance differences on measures that lack convergent validity. Another possibility proposed is that demographic factors were not matched (Morton & Harper, 2007,2008; Morton, 2010; Tare & Linck, 2011). In many cases the language groups tested were drawn from different cultures and countries; some studies only had samples of 10-15 participants per language group; and the means calculated have been based on as few as 14 trials per condition. Therefore, the conclusions drawn from studies assessing bilingualism and executive function are vulnerable to interpretation (Paap & Greenberg, 2013).

There have been several studies that have found a bilingual advantage on tasks that require switching, whereby the bilingual group have demonstrated smaller switching costs (Garbin et al., 2010; Prior & MacWhinney, 2010; Prior & Gollan, 2011). However, when bilinguals and monolinguals were matched on demographic factors (age, education, pay grade, intelligence, and verbal ability) there were no group difference in switching costs, and a bilingual disadvantage on inhibitory control was found (Tare & Linck, 2011). It was concluded that factors other than bilingualism might be the driving factor behind the previously observed bilingual cognitive advantages (Tare & Linck, 2011).

In addition to demographic differences across language groups, it has also been proposed that cultural differences may contribute to the differences found between monolingual and bilingual groups. Typically, early/native bilinguals are bicultural, and the factors (i.e. SES) already known to guide and influence the development of executive functions will vary across cultures (Morton & Carlson, 2014). On a study that assessed six measures of executive functioning (Carlson & Choi, 2009), a significant bilingual advantage was found between a group of Korean-English bilinguals living in the United States and a matched sample of American monolinguals. However, the results obtained from the Korean-English bilinguals were indistinguishable from a group of matched Korean monolinguals. These results question the interpretation that bilingualism plays a strong role in the group differences seen in tasks assessing executive functioning, and they support the idea that cultural differences play a crucial role in the development of executive functioning (Carlson & Choi, 2009). Therefore, it is difficult to isolate the particular role bilingualism plays in the development of executive functions (Morton & Carlson, 2014).

Regarding previous studies that have found a bilingual advantage in older adults, and that have suggested that bilingualism delays the onset of AD symptoms; there is evidence to suggest that this is not a universal finding (Martyr et al., 2014). A study conducted with Welsh/English bilinguals and monolingual English older adults, found that across a range of executive control tasks covering the domains of working memory; set-shifting and switching; and inhibition and response conflict; only nine of the forty executive function indices where performed better by the bilinguals. Whereas the monolinguals performed better on 31 of the executive function indices assessed. This monolingual advantage was seen on tasks that required working memory, set shifting and switching, and mental speed, but this advantage was reduced when inhibition and management of response conflict were required. The two groups did not differ on cognitive reserve, and the amount of daily use of the bilinguals' two languages did not effect performance. The authors concluded that bilingualism did not contribute to an advantage on executive control tasks and did not result in an enhanced cognitive reserve among older adults in Wales (Martyr et al., 2014). Further, they suggested that in the Welsh context, bilingualism would not result in a delay in the onset of symptoms of AD.

In order to examine this hypothesis Clare and colleagues (2014) compared the age at the time of receiving an AD diagnosis in Welsh/English bilinguals and monolingual English patients, and assessed performance of a battery of executive control tasks. The bilingual group was 3 years older than the monolingual group at the time of diagnosis, but this difference was not significant. Also, the bilingual group was significantly more cognitively impaired at the time of diagnosis than the monolingual group. Performance on the tests only revealed a bilingual advantage when the task required the use of inhibition and response conflict, otherwise there were no differences between the monolingual and bilingual groups. It was concluded that although bilingual Welsh/English speakers with AD may demonstrate an advantage in inhibition and response conflict there are no clear advantages over monolingual English speakers in the domain of executive functions (Clare et al., 2014). Further, the authors point out that although there was a delay in onset of AD in the Welsh/English bilingual group, the difference in age among the Welsh sample is smaller than in other clinical populations (Clare et al., 2014).

Within the research area of bilingualism and cognitive advantages, particularly advantages in executive functions, it appears that there is no universal agreement. These studies highlight the need for rigorous testing and balanced population samples. Further, cultural and demographic differences between samples could contribute to the bilingual advantages seen in both young and older adults. In the next section, the effect bilingualism has on development during infancy and early childhood will be discussed.

1.3 Bilingualism and Development

During early childhood dramatic developmental changes in executive function occur. Executive function is an important subject in the study of child development because it has widespread implications for the organisation of behaviour and behavioural control. For instance, improvements in executive functions have a positive affect on language development, as well as insufficiencies in executive control have previously been linked to specific language impairment (Im-Bolter, Johnson, & Pascual-Leone, 2006; McEvoy, Rodgers, & Pennington, 1993). Further, enhancing executive functions early in development can lead to an enhancement in school performance and reduce the prevalence of psychopathology (Diamond & Lee, 2011; Liss et al., 2001; Pennington & Ozonoff, 1996). Individual differences and experiences related to executive function early in development can produce long-lasting effects, which can be prevalent into adulthood.

It has been suggested that the experience of bilingualism improves and perhaps even accelerates the development of cognitive control in children (Craik & Bialystok, 2006; Bialystok, 2001; Carlson & Meltzoff, 2008). A comprehensive review of the literature found that bilingual children outperform monolingual children on tasks that require selective attention and cognitive flexibility (Bialystok, 2001). During such tasks, inhibitory control is a key component as it allows for suppression of misleading aspects of a stimulus in order for successful attention to the relevant stimuli. Research with children has shown better control over their executive function for bilinguals' than their monolingual peers (Bialystok, 2005). A range of tasks have been used to assess executive functioning in children, and have resulted in advantages for bilingual children as young as 4 years of age (Bialystok & Martin, 2004).

One task that has become a well-established assessment of executive control in preschool children and has demonstrated a bilingual advantage is the Dimensional Change Card Sort (DCCS) task (Bialystok, 1999; Bialystok & Martin, 2004; Carlson &

Meltzoff, 2008). This is a task where there are two pairs of rules in conflict; successful completion of the task requires the child pay attention to one pair of rules at a time. The child is shown cards that contain pictures of two targets e.g. Red Rabbit and a Blue Boat, the child is then given a set of cards containing pictures of Red Boats and Blue Rabbits and is asked to sort the cards into two piles by one of the dimensions e.g. colour (or shape). Following this first phase the child is asked to resort the cards by the other dimension e.g. shape (or colour). It has been demonstrated that it is hard for preschool children, up to the age of 4/5 years, to successfully complete the second phase of the task as they continue to sort the cards by the first set of rules, even though they are able to correctly state the new rule. They are unable to switch their reasoning and attention to focus on the second pair of rules; the pre-switch phase still holds their attention (Bialystok, 1999; Bialystok & Martin, 2004; Carlson & Meltzoff, 2008).

In the Theory of Cognitive Complexity and Control (CCC) Zelazo and Frye (1998) suggest that preschool children are unable to solve problems that are based on conflicting rules as they lack the ability to consciously represent and execute the functions needed. Inhibition is also a process critical to CCC as solutions to these cognitive problems usually requires the child be able to overcome earlier responses, in other words they must suppress any overriding automatic responses. Successful completion of the DCCS task requires that the child be able to use higher order rules to make deliberate decisions about lower order rules, therefore the conflicting situation presented is only resolved once these higher order rules have been learned (Bialystok, 1999). In the absence of these higher order rules the preschool children rely on their association with other rules, in the majority of situations the child persists with the first rule that they learned as their association with that set of rules is stronger. During the completion of the second phase of the DCCS task preschool children are unable to reason that the second set of rules they are given are simply another version of the first set of rules that they have already employed. During the second phase the child is unable to attend to the feature of the target that is relevant and ignore the feature of the target that is now obsolete, but is still present (Bialystok, 2009). As the feature that is now obsolete was the focus of attention during the pre-switch phase it is still highly salient during the post-switch phase and is therefore likely that this feature is still used by the child to interpret the target.

This ability to switch focus during the sorting decision, while also attending to the new feature and inhibiting the irrelevant feature, which is likely to still be salient, is an aspect of executive control (Bialystok, 2009; Zelazo et al, 2003). Control on the post switch phase of the DCCS task seems to be more demanding because children rarely make mistakes on the pre-switch phase but they find the post-switch phase demanding. Bilingual children develop the ability to solve problems that contain conflicting or misleading cues at an earlier age than comparable monolingual children, and the representational demands of this task are similar to those used by bilinguals in representing their two languages. If there is a representational advantage for bilinguals it should be evident during the completion of the DCCS task (Bialystok & Martin, 2004). This is indeed true as bilingual children successfully master performance on the DCCS task earlier than monolingual children (Bialystok, 1999; Bialystok & Martin, 2004). It would therefore appear that there is a bilingual advantage on the DCCS task. Specifically this task demonstrates that bilingual children are especially advanced when the task requires conceptual inhibition, which is the process of inhibiting attention to previously relevant features of the task in order to focus attention on the newly relevant feature (Bialystok & Martin, 2004; Carlson & Meltzoff, 2008). Performance of bilingual preschool children on the DCCS task would suggest that even from an early age bilinguals are better able to solve problems that are based on conflict and attention (Bialystok, 1999).

In addition to the DCCS, a bilingual advantage for selectively attending to one cue whilst ignoring a conflicting cue has been shown for the Simon task (Martin-Rhee & Bialystok, 2008), the ambiguous figure task (Bialystok & Shapero, 2005), and the global-local task (Bialystok, 2010). A study conducted with 6-year-old English/Spanish bilinguals and English monolinguals, compared performance on a range of executive function measures to test the generality of the bilingual advantage (Carlson & Meltzoff, 2008). The main results showed a significant bilingual advantage on tasks that required the management of conflicting attention demands, but there was no advantage for tasks that required impulse control. These findings were robust even when controlling for socioeconomic factors. Further, these results support the notion that even in childhood, bilingualism provides an advantage in situations that require the control of attention in the presence of conflicting demands.

There is also evidence to suggest that bilingualism affects the development of working memory in children. In one study, 5-year-old children performed a Simon-type task that manipulated working memory demands. The results showed that bilinguals were faster than monolinguals to respond across all conditions, as well as being more accurate when responding to incongruent trials, which confirmed an advantage in executive functions (Morales, Calvo & Bialystok, 2013). In a second study, 5-to-7-year-old bilingual children outperformed their monolingual peers on a visuospatial span task. Particularly, bilingual children showed an advantage during conditions that included more demanding executive function. Both of these studies show that there is an advantage for bilingual children on tasks that require working memory, which is particularly salient when the task involved additional executive function demands (Morales et al. 2013).

In recent years research into the effects of bilingualism on development has been conducted with children younger than preschool age. A study conducted with 24-month-old monolingual and bilingual toddlers, carried out a battery of executive function tasks and the Bayley test, to establish whether the cognitive advantages previously seen in 4 year olds would also be present in children as young as 24 months old. The native bilingual children performed significantly better on the Stroop task, but there were no differences between the two groups on the other tasks in the battery. The authors concluded that even in children as young as 24-months, it is evident that bilingualism provides a cognitive advantage for tasks that require conflict resolution (Poulin-Dubois et al., 2011).

Developmental differences between bilingual and monolingual children have been shown in infancy. In a study with 7-month-old infants Kovács and Mehler (2009) found cognitive control differences between monolingual and bilingual infants on a task similar to the A-Not-B. Infants were given an auditory cue during the training phase, which signaled that a toy puppet would be presented in one of two locations. During the test phase, the infants heard a novel cue that signaled that a toy puppet would be presented in the second location. At test bilingual infants learned to redirect their gaze to the opposite side of the screen to receive the visual reward, where as monolingual infants continued to look at the previously rewarded side even though no reward appeared there any more. Ibanez-Lillo and colleagues also conducted a similar paradigm with 8-month-old Spanish-Catalan bilinguals. Their study found that both monolingual and bilingual infants were able to inhibit their attention to the incorrect location. The bilingual infants did appear to show a tendency to inhibit their attention earlier than the monolinguals (Ibanez-Lillo, Pons, Costa, & Sebastian-Galles, 2010). Another study compared monolingual and bilingual 6-month-olds on a visual habituation task (Singh et al., 2014). The results demonstrated that bilingual infants had greater adeptness for stimulus encoding as well as better recognition memory for the familiar stimuli compared to the monolingual infants. The authors concluded that there is a generalized cognitive advantage in bilingual infants, which is not specific to language, is early to emerge and has a broad scope (Singh et al., 2014). These differences found at such an early stage of development suggests that executive control could be influenced by exposure to multiple languages even before children become verbal.

During a deferred imitation task bilingual, not monolingual, 18-month-old infants were able to generalize (Brito & Barr, 2012). During the training phase of this deferred imitation task infants were shown, but were not allowed to touch, one of two perceptually different puppets: a yellow duck or a black and white cow. A mitten was placed on the right hand of the puppet, which had a bell inside (the bell was removed during the test phase). The experimenter then showed the infant a sequence of actions: (1) pull off mitten (2) shake mitten to ring bell (3) replace mitten. Following a 30-minute delay the infants were shown the puppet not used during the training phase and were encouraged to touch and explore the puppet. The bilingual infants generalized the actions they were shown in the training phase to the novel puppet, where as the monolingual infants did not. The bilingual infants demonstrated improved memory flexibility and generalization, which is a result of exposure to more than one language (Brito & Barr, 2012).

Therefore, is appears that over the course of early childhood, exposure to a second language and the development of bilingualism has been shown to be beneficial for completing tasks that require working memory processes, as well as tasks that place extra demands by introducing a conflicting cue.

1.4 Thesis Aims

The main aim of the Thesis was to establish whether the reported advantages for bilingual infants and young adults was also evident in the Welsh/English bilingual population. Over the course of the last 20 years research related to bilingualism and executive functions has delivered mixed results and mixed opinions. The purpose of the studies included in this Thesis was to contribute to the literature on bilingualism and executive functions from a cognitive neuroscience perspective, as the research that has been previously conducted with the use of EEG and other neuropsychological measures in this field is limited. Also, the research presented in this Thesis addresses bilingualism in infancy and young adulthood; two developmentally different populations. One population that has been extensively studied with regards to bilingualism and cognitive functions (young adults); and one population which is beginning to be studied on a more frequent basis, but still has a limited scope in the current literature (Infants). Over the course of the three studies presented in this Thesis; inhibition, suppression, attention and working memory are all addressed.

In the first study, which was conducted with 14-to-22-month old infants, the aim was to establish whether incorporating a working memory element to a word-picture semantic priming paradigm would result in different modulations of the N400 ERP component. This would in turn signify differences between monolingual and bilinguals on their ability to maintain an auditory word in working memory in order to complete the semantic priming task efficiently. If the bilingual infants have acquired more adept working memory processes as a result of exposure to two languages then it would be expected that they would elicit a greater N400 effect in conjunction with early differences in response to the initial onset of the word.

In the second study, young adults took part in a Go/No-Go paradigm that incorporated an additional suppression of irrelevant stimuli aspect. In this study it was expected that in relation to the central Go/No-Go task, the measures of response inhibition would not differ between groups. In addition to the central Go/No-Go task, there were stimuli appearing in the periphery that needed to be suppressed in order to focus on the central task. On this aspect of the task, it was predicted that the bilingual young adults would suppress their attention to the distracting irrelevant stimuli more efficiently.

The third study was a modification of the second, where attention was directly manipulated by incorporating an attended versus unattended element in relation to the location of the irrelevant stimuli. It was expected that the results of this study would provide conclusive evidence for an efficient suppression mechanism in the bilingual young adults that is not efficient in the monolingual young adults. Whereby the bilingual participants would attend successfully to the to-be-attended location and suppress their attention to the un-cued unattended location.

All three studies are conducted with the use of ERP methodology. The scope of research already conducted in conjunction with ERPs and the bilingual executive function question is sparse. The use of ERPs allows for collection of data at the neuronal level, whereby information about the latency and amplitude of an effect elicited in response to a particular stimulus can be measured. This methodology also allows for the recording of both overt and covert information. As well as providing information about the scalp distribution of the effect elicited.

In summary the aim of the studies presented in this Thesis are to address directly whether exposure to two languages impacts the development of executive functions with the use of ERPs. As well as addressing whether different types of bilingualism have differing degrees of effects on this development. This is an important research area as the implications of bilingualism are becoming more significant - considering that the world is constantly adapting to a more bilingual existence.

2. Event-Related Potentials

2.1 **Electroencephalography** *and Event-Related Potentials*

2.1.1 Electrical Activity at the Neuronal Level

There are two types of potential that occur due to electrical activity in a neuron, these are an action potential and a postsynaptic potential. Action potentials are discrete voltage spikes that travel from the beginning of an axon at the cell body to the axon terminals where neurotransmitters are released. Postsynaptic potentials are voltages that arise when neurotransmitters bind to receptors on the membrane of the postsynaptic cell. This causes ion channels to open or close and leads to a graded change in potential across the cell membrane. The potentials displayed in an event-related potential (ERP) waveform reflect postsynaptic potentials rather than action potentials.

When an individual encounters a stimulus, an excitatory neurotransmitter is released at the apical dendrites of a cortical pyramidal cell. Current then flows from the extracellular space into the cell, which yields a net negativity on the outside of the cell in the region of the apical dendrite. Simultaneously, current flows out of the cell body and basal dendrites, which yields a net positivity and in turn completes the circuit. The negative current at the apical dendrites and the positivity at the cell body create a tiny dipole.

The dipole from a single neuron is too small to record from a distant scalp electrode, however under certain conditions, the dipoles from many neurons will summate, which in turn leads to the possibility of recording the resulting voltage at the scalp. In order for the dipoles to summate and therefore be recordable at the scalp, they must have a similar orientation, receive the same input, and occur at approximately the same time across thousands or millions of neurons. However, if the neurons are not spatially aligned then the positivity of one neuron may be adjacent to the negativity of another resulting in cancellation of the voltage. Cancellation will also occur if the input received by one neuron is an excitatory neurotransmitter and the adjacent neuron receives an inhibitory neurotransmitter. Summation of dipoles is most likely to occur in cortical pyramidal cells that are aligned perpendicular to the surface of the cortex.

2.1.2 Cognitive Neuroscience and ERPs

Since the early years of cognitive psychology the techniques used to measure cognitive processes has evolved. In the beginning, cognitive processes were measured by collecting reaction times, which were extremely useful in understanding a range of functions, including perception, memory, and language. Technological advancement has led to a change within cognitive neuroscience, as the use of high-tech methods such as electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are being used as substitutes for reaction time measurements (Luck, 2000; Luck, 2005).

During neurotransmission postsynaptic potentials are generated, which passively travel through the brain and skull to the scalp. These postsynaptic potentials are measured using an electroencephalogram. The EEG is recorded using electrodes that are placed on the surface of the scalp. The signal from the electrodes placed on the scalp is amplified, and the voltage over time is plotted. This allows any changes in voltage to be analyzed. EEG in its raw form is a crude measure of brain activity as it denotes a composite of hundreds of different sources of neural activity, which in turn makes it difficult to isolate specific cognitive processes. However, within the EEG data there are neural responses associated with sensory, cognitive and motor events.

An event related potential (ERP) is when these responses are extracted from the EEG by averaging the data (Luck, 2005). When averaging the data, it is possible to time lock to specific stimulus events, which in turn allows the analysis of the voltage change created by that given stimulus event – creating positive and negative deflections known as ‘components’, ‘peaks’ or ‘waves’. Typically these components are labeled with a P or an N, to denote whether it is a positive or negative deflection, followed by a number that indicates the timing of the component. For example, the component labeled P100 is a positive peak whose onset is 60-90 ms post stimulus and peaks between 100 - 130 ms.

By measuring these components, it is possible to analyze amplitude and latency effects related to specific sensory, cognitive and motor events. Following a stimulus event, there are a series of components triggered, which reflect the sequence of neural processes generated by that particular stimulus. The series of components generated denotes both early sensory processes as well as decision and response related processes (Luck, 2000). By analysing the amplitude and latency of the components generated, the time course of the cognitive processes can be measured. Also, the distribution of the voltage of the components generated over the scalp can be used to estimate the neuroanatomical location of the cognitive processes.

The use of ERPs and fMRI provides a researcher with a multidimensional measure of cognitive processing. Allowing the researcher the ability to separate the subcomponents of cognition. A typical reaction time experiment is comprised of a stimulus followed by a response, however this does not allow the researcher the ability to observe the cognitive processing that is occurring between the onset of the stimulus and the participants response. During an ERP experiment, a continuous ERP waveform is elicited by the stimulus that makes it possible to observe the neural activity occurring between the stimulus and the response. It is also possible to use the distribution of the voltage over the scalp to isolate specific cognitive processes (Luck, 2000; Luck, 2005).

Another benefit of using ERP and fMRI is that the researcher is able to measure both overt and covert responses to stimuli. In certain studies the task requires the participant respond to a particular stimulus whilst providing no response to another stimulus, in this scenario the researcher may still wish to analyse the covert response to the un-responded stimuli. For example, in a study of attention the participants may be instructed to respond to attended stimuli but refrain from responding to unattended stimuli. With the use of ERPs it is possible to compare the cognitive processing involved during the attended and unattended trials.

2.2 Cognitive Processes and ERP Components

Within the realm of ERP analysis there are a variety of different components that can answer a question regarding cognitive functions. In the three experimental chapters noted here, the ERP components of concern are the P100, N200, P300 and the N400. Here I will discuss each component in turn.

2.2.1 Visual Attention and the P100

When required to detect a visual stimulus in the environment, the visual system relies on an uninterrupted straight line between the stimulus and the visual receptors. Although these receptors are spread out over millions of individual spatial locations they have poor temporal resolution. When perceiving the environment the eyes move continuously to align the fovea (region of highest resolution) with objects of interest. Mostly eye movements are sudden saccades, separated by periods of fixation. During saccades vision is suppressed. In brief, input into the visual system consists of a series of brief snapshots that contain a precise and explicit representation of the spatial organization of the world. Therefore, when faced with numerous objects simultaneously, an individual can only look at one of those objects to give that object preferential access to the fovea; these shifts of gaze are called overt attention (Luck & Kappenman, 2012).

Covert attention aids the process of overt attention by facilitating the processing of objects in a relevant spatial location before an overt shift of gaze is made to that location. Covert attention has different functional roles; it determines whether an object is a target, as well as precisely locating the object before gaze is shifted (Luck, 2009). Every visual saccade is preceded by a shift of covert attention (Deubel & Schneider, 1996; Hoffman &

Subramaniam, 1995). As well as covert shifts of attention that precede overt shifts of gaze, there are two other mechanisms of attention that are important to the visual system. The first is feature-based attention, which highlights objects containing relevant features that are good targets for future fixations. This process means that the visual system does not need to search for a relevant object by moving the eyes from location to location until the object required is found. The second mechanism is object-based attention, which allows visual processing to be determined by the shape of the attended object. This third process allows perceptual processes to expand across the entire target object without also engaging with objects located nearby (Luck & Kappenman, 2012).

A paradigm widely used in conjunction with ERPs, in the study of visuospatial attention, is the Hillyard sustained attention paradigm (Van Voohris & Hillyard, 1977; for reviews, see Hillyard et al, 1998; Mangun, 1995). In this paradigm, participants are instructed at the beginning of each trial block that they are required to attend to either the left or right visual field. A series of stimuli are presented and are equally likely to appear in both the left and right visual field, the participant is required to monitor the sequence of stimuli and respond when they detect a deviant within the series of standard stimuli. In this scenario the earliest widely replicated ERP effect of visuospatial attention is a larger P1 wave for stimuli appearing at the attended compared to unattended location. This P1 effect can also be seen in the Posner cueing paradigm (Eimer, 1994a, 1994b; Hopfinger & Mangun, 1998; Luck et al, 1994; Mangun & Hillyard, 1991).

The Posner cueing paradigm contains a cue and a target. The cue indicates the probable location of the target for that trial. There are valid (target appears at the cued location) and invalid trials (target appears at an uncued location). Unlike the Hillyard sustained attention paradigm, participants are required to respond to the target no matter where it appears. The results show that participants are faster and more accurate when responding to a valid compared to an invalid trial (Luck & Kappenman, 2012). Both the Hillyard sustained attention paradigm and the Posner cueing paradigm evoke larger P1 waves when stimuli are presented at the attended (valid) location compared to the unattended (invalid) location.

The latency of the P1 can vary, but typically the P1 wave and the P1 attention effect begins 70-100 ms after stimulus onset and peaks between 100-130 ms. The P1 has a scalp distribution that is maximal over the lateral occipital lobe, contralateral to the location of the stimulus eliciting the effect. Some studies have attempted to localize the P1, and these studies (sometimes using fMRI effects as well as ERP) suggest that the early portion of the P1 is generated in the dorsal extrastriate cortex (middle occipital gyrus), whereas the later portion is generated more ventrally from the fusiform gyrus. At least 30 distinct visual areas are activated in the first 100 ms after the onset of a visual stimulus, and it can be assumed that many of these areas presumably contribute to the voltages recorded in the P1 latency range. The P1 is sensitive to the direction of spatial attention (Hillyard, Vogel, Luck, 1998) and to the subjects' state of arousal (Vogel & Luck, 2000).

The P1 attention effects reflect a top-down modulation of the initial wave of sensory activity passing through the visual cortex (Hillyard et al., 1998). The finding that the P1 waveforms are larger for attended than unattended stimuli supports this interpretation. In essence the amplitude of the P1 evoked by a visual stimulus indicates to what extent that stimulus has been attended.

Historically, it has been proposed that feature-based attention does not typically produce the same P1 effect as spatial attention, and is later than spatial attention whilst also being contingent on it. Thus, feature-based attention is only applied to stimuli that have passed through the initial spatial filter stage (Hillyard & Münte, 1984; Luck & Kappenman 2012). This proposal supports the space-is-special hypothesis of attention (Moore & Egeth, 1998; Nissen, 1985; Treisman, 1988; Wolfe, 1994). However, in recent years it has been shown that under certain circumstances, feature-based attention can function as early as spatial attention as well as autonomously of spatial attention. Feature-based attention can influence P1 amplitude under circumstances that maximize competition between the attended and unattended feature values – simultaneous competition (Valdes-Sosa et al., 1998; Zhang & Luck, 2009). Although, simultaneous competition between location and features leads to early location independent effects of feature-based attention; this simultaneous competition does not necessarily need to be present to observe location-based P1 attention effects. Therefore, location may have a special status in attention (Luck & Kappenman, 2012).

2.2.2 *Inhibition and the N200*

Everyday functioning requires the ability to inhibit irrelevant information, including thoughts, behaviors and stimuli (Logan et al., 1984; Hasher & Zacks, 1988; Pires et al., 2014). Inhibition plays a central role in the control of cognitive domains (attention, memory and language) and situations requiring decision-making, conflict resolution, error correction and response inhibition (Norman & Shallice, 1986; MacLeod et al., 2003). Inhibition has both an automatic (implicit or unintentional) and controlled (explicit or intentional) nature (Piai et al., 2012; Ludowig et al., 2010; Nigg, 2000; Friedman & Miyake, 2004; Andres et al., 2008; Collette et al., 2009; Pires et al., 2014). Therefore, neural systems must not only initiate behaviors but also suppress them actively. It has been proposed that the N2 component is indicative of a response inhibition system.

A variety of paradigms have been used with ERPs to study inhibition, such as location and identity negative priming (NP), Stop-signal, Go/No-Go, Stroop Task Switching, the Eriksen Flanker Task, Spatial cueing tasks, Anti-saccade, Proactive Interference and Direct Forgetting (Kok, 1999; Pires et al., 2014). It has been widely accepted that these paradigms are related to different types of inhibition. The Stop-signal, Go/No-Go and Eriksen Flanker tasks are related to behavioral inhibition, whereas the NP, Stroop and Direct Forgetting are related to cognitive inhibition. Further, the Stop-signal and the Stroop are examples of tasks that engage with controlled inhibition, and the NP and Spatial cueing tasks engage with automatic inhibition (Nigg, 2000; Pires et al., 2014).

The N2 component is identified as being related to inhibition, it has a fronto-central negativity that peaks approximately 200-300 ms post-stimulus. It is an endogenous ERP component and has several subcomponents (Folstein & Van Petten, 2008). There are two fronto-central components the N2a (novelty detection) and the N2b (executive control); a posterior N2c (stimulus classification); as well as the N2pc, which is a posterior-contralateral component (attention related).

The larger N2 amplitude is typically elicited when a response is inhibited compared with when a response is executed (Maguire et al., 2009). The N2 varies in amplitude depending on the neuronal activity required for response inhibition (Jodo & Kayama, 1992). Although, it has been suggested that there is no evidence of a significant No-Go N2 in auditory stimuli in a Go/No-Go task (Falkenstein et al., 1995; Simson et al., 1977), there are several studies that support the hypothesis that the visual No-Go reflects a frontal inhibition mechanism (Ritter et al., 1982; Kok, 1986; Jodo & Kayama, 1992; Kopp et al., 1996; Falkenstein et al., 1999; Geczy et al., 1999).

Both the Go/No-Go and the Stop-signal tasks require that the participant responds to the Go stimuli and withholds a response when a No-Go or Stop-signal is presented. It has been shown that both of these paradigms share an underlying mechanism, as they both elicit larger amplitude N2 in the No-Go/Stop-signal condition (Van Boxel et al., 2001).

In a classic Go/No-Go paradigm, a negative potential (N2) is elicited at a latency of 200-300 ms, predominantly in frontal areas, and its amplitude increases specifically during No-Go trials (Simson et al., 1977; Pfefferbaum et al., 1985; Gemba & Sasaki, 1989). The N2 generated in a No-Go condition is attenuated and delayed in participants with high false alarm rates, compared to those with low false alarm rates (Falkenstein et al., 1999).

When the upper limit of the reaction time required to make a response to a Go stimulus was directly manipulated, it was discovered that the amplitude of the N2 component was significantly larger to No-Go stimuli then Go stimuli, particularly when faster responses to the Go stimuli were required (Jodo & Kayama, 1992). The amplitude of the N2 component to the No-Go stimuli increases when a mental load for withholding the Go response is high, indicating that the activity of the brain required for response inhibition is also high (Simson et al., 1977; Pfefferbaum et al., 1985; Gemba & Sasaki, 1989). Further, when a No-Go trial follows a Go cue the amplitude of the N2 increases, which may be related to an increase in efforts to activate the response inhibition system and to interrupt any preparations being made for response execution (Geczy et al., 1999). Indicating that when task demands are high, the amplitude of the N2 to the No-Go stimuli increases.

One study divided the participants into two groups the ‘Good’ group (low error rates in the No-Go trials) and the ‘Poor’ group (high error rates), and they identified a larger N2 amplitude coupled with an earlier latency of the No-Go N2 for the ‘Good’ compared to the ‘Poor’ group, supporting the concept that the No-Go N2 reflects inhibition (Falkenstein et al, 1999).

Further evidence supporting the theory that the N2 elicited during a Go/No-Go task is indicative of an inhibitory neuronal process, comes from a study comparing typically developing children and children with AD/HD. The typically developing children produced a large N2 wave over the right Inferior Fusiform Gyrus when response inhibition was required. However, the amplitude of the N2 was markedly reduced in the children with AD/HD (Pliszka et al., 2000).

The latency of the N2 may determine the success or failure of inhibitory control (Roche et al., 2005). Using a visual Go/No-Go task (in which the letter X and Y were presented sequentially in the center of the screen) participants were asked to respond every time a letter was presented, except when two identical stimuli followed each other (e.g. an X followed an X). A larger amplitude and later latency for the No-Go N2 compared to the Go N2 was identified, as well as a shorter latency for the N2 during successful No-Go responses compared with unsuccessful responses. The authors suggested that the No-Go N2 onset is the most valid index of active inhibitory processes (Roche et al., 2005).

A comparison between covert and overt responses in a Go/No-Go paradigm has also been discussed. In a visual Go/No-Go paradigm with two response modes, participants were required to respond manually in one condition and mentally count in the other (Bruin & Wijers, 2002). No difference in No-Go N2 was found between response conditions, with both conditions eliciting larger N2 amplitude to the No-go than Go trials.

However, the authors did identify smaller amplitude P3 in the covert (counting) condition, which they interpreted as a reflection of a smaller level of inhibition needed to withhold a response compared with the overt (manual) condition (Bruin & Wijers, 2002). This pattern of activation was also found in another study (Smith et al., 2008) comparing overt and covert responses in a Go/No-Go paradigm. Again, the covert condition elicited smaller amplitude No-Go P3 and no differences between response conditions for the No-Go N2. The authors concluded that the No-Go N2 effect that has been observed does not reflect motor inhibition, but that it may reflect a need to recognize that no response is needed, or management of the conflict between executing and withholding a response (Smith et al., 2008). Other authors have also concluded that the N2 observed in Go/No-Go tasks reflects response conflict and conflict monitoring, and that association with inhibition is limited (Donkers & Van Boxel, 2004; Nieuwenhuis et al., 2003; Smith et al., 2010).

The source of the N2 activity elicited during a Go/No-Go task is lateralized to the right hemisphere. The Anterior Cingulate Cortex (ACC) was part of the neural source for the No-Go N2 (Bokura et al., 2001; Nieuwenhuis et al., 2003), which is consistent with clinical studies on the involvement of the ACC in response inhibition (Malloy et al., 1993). The ACC participates in motor control by facilitating the execution of appropriate responses and suppressing the execution of inappropriate responses (Paus et al., 1993). Further, electrophysiological studies have also provided evidence that the ACC is involved in the suppression of irrelevant information (West & Alain, 1999; Liotti et al., 2000), as well as having a general role in monitoring the executive behaviors that require inhibitory control (Bokura et al., 2001) and conflict processing (Botvinick et al., 2001).

In summary, the N2 ERP component has been hypothesized to reflect inhibition, and many paradigms have been used to further understand the processes indicated by the N2 component (in the 200-400 ms window). Taken together, the studies conducted suggest that the processes related to the N2 component are indeed reflective of successful inhibition, but that the N2 specifically reflect conflict processes that are modality specific and are independent of motor processing (Pires et al., 2014).

2.2.3 *Attention, Memory and the P300*

Neuroinhibition is suggested as a predominant theoretical mechanism for the P300 component, which is elicited when stimulus detection engages with memory operations. The P300 is composed of several parts: information processing as well as attention and memory mechanisms (Polich, 2007). These separate mechanisms elicit two P300 subcomponents, the P3(a) and the P3(b). The P3(a) is elicited by attention mechanisms that are activated during task processing. The P3(b) is activated by attention mechanisms that are related to memory processing. The activation of the P3(a) and P3(b) waves indicates that inhibitory mechanisms are engaged with incoming stimuli in order to facilitate memory processing (Polich, 2007).

One model concerning the P300 is the Context-Updating Theory. The P300 component indexes brain activities that underlie the revision of mental representations elicited by incoming stimuli (Donchin, 1981). Attention mechanisms compare the present stimulus with the representations of the previous stimulus in working memory. If no stimulus attribute change is detected then the current mental model of the stimulus context is maintained and only sensory evoked potentials are recorded (N1/P2/N2). However, if a new stimulus is detected, the attention processes update the stimulus representation that is affiliated with the P300 (Polich, 2007). During a working memory or recognition task, the stimulus representations are maintained in memory from previous exposure, these representations can elicit P300 components to the reoccurrence of that stimulus that are larger than those elicited by stimuli that have not previously been encountered (Dolye & Rugg, 1992; Guo et al., 2006; McEvoy et al., 2001). Further, this model proposes that context is refurbished by updating operations that are sensitive to previous stimulus presentations. The intervening non-target events engage attention mechanisms to modify the current neural representation (Donchin et al., 1986). The Context-Updating Theory reflects the moderately strong initial target stimulus processing that is related to the P3(a), which diminishes as the repeated target stimuli occur, to produce the P3(b) (Kok, 2001).

During a two-stimulus oddball task, the process of discriminating the target from the standard stimulus produces a robust P300, which increases in amplitude as the target's global and local sequence probability decreases (Duncan-Johnson & Donchin, 1977; Johnson & Donchin, 1982; Squires et al., 1976). These target stimulus probability effects lead to the proposition that the P300 originates from tasks that engage with working memory (Donchin et al., 1986). The amplitude and latency of the P300 are sensitive to the amount of attention resources that are engaged during task performance. The overall arousal level that is required during the task determines the amount of processing capacity that is available for attention allocation (Kahneman, 1973). The more taxing a task is, the smaller the P300 amplitude and the longer the latency, whereas undemanding tasks elicit larger amplitude P300 with a relatively short latency (Polich, 2007).

In a memory recall task, distinct word stimuli that were subsequently recalled elicited larger P300 components during encoding than those that were not recalled. The P300 elicited was also affected by rehearsal, with larger amplitude P300 components produced following recall by participants who used rote rehearsal (Fabiani et al., 1986, 1990). Where as elaborative rehearsal strategies elicited P300 amplitudes that were unassociated with recall performance. Therefore, it has been proposed that tasks that alter stimulus attention and require memory processing affect P300 amplitude (Donchin, 1981). Further, additional attention processing affects P300 amplitude, with an increase in memory load reducing the size of the component, because the processing demands have increased (Kok, 2001; Wijers et al., 1989). Therefore, cognitive demands during task performance influence the P300.

The P300 latency elicited by a task is thought to index classification speed, which is proportional to the time required to detect and evaluate a target stimulus (Kutas et al., 1977; Magliero et al., 1984). A larger P300 and a longer response time are produced during semantic processing than spatial processing tasks. There are scalp differences in the latency of the P300, with a shorter latency over frontal areas and a longer P300 over parietal areas (Mertens & Polich, 1997a; Polich et al., 1997). The individual differences observed for P300 latency is correlated with mental function speed; shorter latencies indicative of superior cognitive performance (Emmerson et al., 1989; Johnson et al., 1985; Polich et al., 1983). In summary, P300 peak latency is proportional to stimulus evaluation timing, is sensitive to task processing demands, and varies with individual differences in cognitive capability (Polich, 2007).

If non-novel repeated stimuli are used as distracters in a three-stimulus oddball, where the participants do not respond to the infrequent distracter, a ‘no-go’ P300 is elicited (Kok, 1986; Pfefferbaum et al., 1985). The P300 elicited by this type of distracter has maximum amplitude over central/parietal areas. The ‘no-go’ P300 has been linked to response inhibition mechanisms (Polich, 2007). When the distracter stimulus is novel a frontal/central P300 can be elicited with a relatively short peak latency that habituates rapidly, this P300 is known as the novelty P300 and is interpreted as reflecting frontal lobe activity related to the hippocampus (Grunwald et al., 1998; Knight, 1996). Following repeated stimulus presentation the novelty P300 decreases in amplitude (Knight, 1984; Kok, 2001; Riggins & Polich, 2002; Rushby et al., 2005). The type of non-target distracter and the task demands determine the component amplitude. An easy discrimination task produced scalp topography similar to the ‘no-go’ P300, whereas a difficult discrimination task produced a P300 similar to the novelty P300 (Comerchero & Polich, 1998, 1999; Hagen et al., 2006). In subsequent studies it was proposed that the P3a, the novelty P300 and the ‘no-go’ P300 are variants of the same ERP that varies in scalp topography as a function of the attention and task demands.

The Inhibition Hypothesis is consistent with the functional descriptions of the P300. From an evolutionary perspective, low probability stimuli can be biologically important; it is adaptive to inhibit unrelated activity in order to promote processing efficiency, therefore yielding larger P300 amplitudes. In scenarios that utilize difficult and dual processing tasks, that also include high cognitive demands, limit attention resources to resist inhibitory control eliciting smaller P300 components. Further, arousal modulates the level of inhibition engaged; it manages the availability of attention resources for task performance, affecting P300 measures. Attention demanding stimuli elicit a P3(a) when the contents of working memory change, this in turn initiates neural activity towards the areas associated with P3(b) production and memory storage (Polich, 2007).

In summary, the P300 components may result from neural inhibition generated when cognitive mechanisms are engaged by stimulus and task demands. The process of stimulus evaluation engages focal attention (P3(a)), which in turn facilitates context maintenance (P3(b)) which is associated with memory operations (Hartikainen & Knight, 2003; Kok, 2001: Polich, 2003).

2.2.4 *Semantic processing and the N400*

Language is a uniquely human behaviour; is a central part of our everyday life; and it is a defining feature of who we are. Words and sentences that are uttered can assume diverse meanings, and the meaning of these utterances depends on a number of factors including: the context, the speaker, the listener, or the world knowledge relevant to the produced utterance. Organisation of meanings, and the process of understanding and producing language require the subservience of many different cognitive functions. The task of unraveling how, where and when the brain interprets language is important, in order to understand the processes behind the extraction of meaning from linguistic content.

A language-related ERP component is the N400. The N400 is a negative going waveform that is largest over centro-parietal areas of the scalp (Kutas & Hillyard, 1983). Typically, in adults the N400 reaches its maximum amplitude between 380-440 ms after stimulus onset. During language processing, the N400 is elicited when words, sentences, or discourses are presented as written text (Kutas & Hillyard, 1980), as connected speech (Holcomb & Neville, 1990, 1991), and with sign language (Kutas et al., 1987). If the words are presented visually, the N400 is elicited around 200 ms after stimulus onset and lasts for around 300 ms. When words are presented in the auditory domain, the N400 may be elicited as early as 100 ms after stimulus onset and lasts for around 400 ms (Swaab et al., 2012).

The N400 is an ERP component that is classically associated with semantic integration and semantic violations. Typically, in ERP N400 studies participants are presented with language stimuli, and the N400 effect is measured to the stimuli that have directly manipulated semantics. The use of ERPs in language research allows for the ERPs elicited to any and all the words in a given sentence to be measured without interrupting the participant with a behavioural task (Swabb et al., 2012). Often tasks have been included in ERP language research, whereby the participant is asked to respond following the language stimulus. In these tasks participants are often asked to make a ‘true’ or ‘false’ judgment about the content of the statement presented, However, it has been argued that ERP language studies do not require a task, as ERP N400 effects can be observed without the inclusion of a potentially interfering behavioural task (van Berkum, 2004).

In a seminal study (1980) Kutas and Hillyard first reported the existence of the N400. Initially Kutas set out to establish whether the P300 would also be sensitive to a language based “oddball” paradigm. Participants were asked to read sentences in three conditions, such as: “It was my first day at work” (congruent) / “He spread the warm bread with socks” (anomalous) / “She put on her high heeled SHOES” (physically deviant). ERPs were compared to the final words in the three conditions. In the congruent condition, the last word was semantically appropriate given the context, and produced no N400. In the anomalous condition, the final word was semantically incongruent to the context of the sentence, which elicited the N400. The physically deviant condition, where the sentence was semantically congruent but the final word was physically deviant from the rest of the sentence, elicited a P650 but no N400. Demonstrating that the N400 is sensitive to semantic violations.

Since the discovery of the N400, studies addressing word, sentence and discourse comprehension have been conducted. The early studies established that the N400 is modality independent, with the N400 effects being observed independently of whether the words are written, spoken or signed (Bentin et al, 1985; Holcomb & Neville, 1990; Kutas & Hillyard, 1980; Kutas et al., 1987; McCallum et al., 1984). Studies have also shown that the N400 is not only sensitive to semantic violations, but is also sensitive to cloze probability. For example, “She was stung by a wasp” is a semantically appropriate sentence but the inclusion of the word “wasp” in place of the more commonly expectant completion “bee” elicits larger amplitude N400 (Kutas & Hillyard, 1984; Kutas et al., 1984).

The N400 is also sensitive to lexical properties of words. A smaller N400 is elicited to real words (e.g., flower) compared to psuedowords,(e.g. flewer), and no N400 is elicited to random letter strings (e.g. werfle). Additionally, high-frequency words show smaller amplitude N400 effects than low-frequency words (Barber et al., 2004), but this effect is modulated by the context in such a way that words appearing later in a sentence no longer show lexical frequency effects (Van Petten & Kutas, 1991). Further, words with a small orthographic neighborhood show a reduced N400 effect relative to words with a large orthographic neighborhood (Holcomb et al., 2002; Grainger & Holcomb, 2009).

In studies addressing semantic priming, it has been shown that the elicited N400 is larger during trials were the target word is semantically unrelated to the preceding context word compared to when the target and prime are semantically related (i.e. table – nurse vs doctor - nurse) (Bentin et al., 1985; Brown & Hagoort, 1993; Chwilla et al., 1998, 2000; Holcomb, 1993). This N400 priming effect has been found in a array of tasks, including semantic judgment, lexical decision as well as no-task situations (participants just asked to listen to or read pairs of words for comprehension (Swaab et al., 2012). Lexical repetition results in a reduced N400 in semantic classification tasks (Hamberger & Friedman, 1992; Rugg et al., 1988). The observed reductions in the amplitude of the N400 to semantically related and repeated words have been obtained in the visual modality, the auditory modality, as well during cross-modal presentation (Domalski et al., 1991; Holcomb et al., 2005; Joyce et al., 1999; Rugg et al., 1993). Occasionally, the onset of the N400 priming effect during auditory tasks is earlier (Holcomb & Neville, 1990), which is consistent with previous findings that the identification of words occurs before the whole speech signal is heard (Grosjean, 1980).

A large volume of ERP semantic priming studies have previously focused on the processing nature of the N400 effect (Bentin et al., 1985; Brown & Hagoort, 1993; Chwilla et al., 2000; Friederici, 1995; Holcomb, 1993; Holcomb & Neville, 1990; Kutas & Hillyard, 1989). Three different priming mechanisms (Neely, 1991) have been proposed: automatic spread of activation within a lexical semantic network; expectancy-induced priming; semantic matching.

The automatic spread of activation mechanism suggests that activation spreads from the semantic node associated with the prime to the semantic node associated with the target, which in turn reduces the processing time of the target when presented. This spread of activation is assumed to be automatic and robust to influence from participants strategies (Collins & Loftus, 1975; Neely, 1977). The expectancy-induced mechanism was proposed in response to different patterns of results being obtained as a function of the task. When participants are presented with a prime they use the meaning of that word to generate an expectancy set of possible target words (Becker, 1980, 1985; Posner & Snyder, 1975). This mechanism reflects controlled processing, is capacity consuming, relatively slow, and probably receptive to the participants unique strategy. Expectancy-induced processing is not required to elicit an N400. In a paradigm that used backward priming (Chwilla et al., 1998), the contribution of expectancy-induced priming was prevented. In this paradigm the facilitation does not occur from prime to target, instead the target facilitates the prime. Therefore, in this paradigm neither a forward spreading of activation nor expectancy-induced processing can explain the facilitated processing of the target. Semantic matching is similar to the integration process that occurs in the more common processing of sentences and discourse (Brown & Hagoort, 1993; Chwillia et al, 1998; de Groot, 1985), also It may be an automatic process as it does not require the participant be consciously aware of the prime (Bodner & Masson, 2003). The N400 effects can be observed under automatic processing conditions, but the evidence from semantic priming paradigms fails to suggest that the N400 is exclusive to automatic integration and not spread of activation in a semantic network (Swaab et al., 2012).

In summary, the N400 is modulated by semantic aspects of the input whereby the amplitude of the N400 is reduced in response to words that can be easily related to the overall context. Other factors such as, orthographic neighborhood, frequency, and emotion can also influence the N400 effect. The cognitive activity that elicits the N400 may be reflective of top-down automatic processing, however, the evidence is inconclusive and there is also reason to suggest that there is a spread of activation within the semantic network.

2.2.5 Working Memory and the NSW

Memory processing has been divided into three categories: sensory memory, working memory and long-term memory. It has been hypothesized that working memory is made up of three major components, which are able to work independently of one another: a verbal memory system, a visuospatial memory system, and a central executive that determines which information is made available for conscious processing (Baddeley, 1986). The data obtained from these various systems reflects the combination of three aspects of working memory: storage, maintenance and retrieval operations. The use of ERP methodology affords an experimenter the opportunity to disentangle these operations. ERPs provide the opportunity to make inferences about the timing and topographical distribution of these working memory processes.

A number of ERP studies have examined the processes underlying retention of information in working memory (Barrett & Rugg, 1989, 1990; Barrett, Rugg, & Perrett, 1988; Lang, Starr, Lang, Lindinger, & Deecke, 1992; Runchkin et al., 1994; Runchkin, Johnson, Canoune, & Ritter, 1990; Ruchkin, Johnson, Grafman, Canoune, & Ritter, 1992; Rugg, 1984a, 1984b). These studies used variations of the delayed match-to-sample paradigm, whereby the participant is presented with an initial stimulus that must be committed to memory for a delayed comparison with a second stimulus. Following the second stimulus the participant must decide whether the two stimuli matched or mismatched. Successful performance on this task requires that the participant engage in a sustained retention-rehearsal strategy during the interval between the first and second stimulus; this interval typically ranges between 1.5 and 5 seconds.

During the interval, ERP slow wave amplitudes and topographies have varied as a function of the type of stimuli and information load. It has been shown that negative slow waves were largest over the left hemisphere during phonological memory processing (Barrett & Rugg, 1990; Rugg, 1984a, 1984b) and they were largest over the right hemisphere during visual memory processing (Barrett & Rugg, 1989; Barrett et al., 1988). When phonological load (in the visual modality) was manipulated two slow waves were found in the retention interval whose amplitudes increased with load: a parietal positive slow wave that may be associated with storage, and a left anterior negativity that may be associated with rehearsal of phonological stimuli (Runchkin et al., 1990).

The Negative Slow Wave (NSW) is an ERP component that has been observed across many studies of working memory. The NSW is a broadly distributed sustained negative wave that persists during the maintenance period of a memory task (Ruchkin et al, 1990). The NSW has been found to be maximal over parietotemporal sites for visuospatial stimuli and maximal over frontal sites for verbal stimuli. During a task testing visuospatial and verbal stimuli, the amplitude of the NSW increased as a function of memory load (Runchkin et al, 1992). There was a large negativity during the retention period of both the visuospatial and phonological memory tasks, where by the amplitude of the NSW increased as the number of items to-be-remembered increased. Therefore, the amplitude of the NSW may be an index of the memory load engaged during a working memory task. During the retention phase of a working memory task, when large amplitude NSW has been observed, there was a stronger probability of successfully recalling the information at test. This is a good indication that this activity is important for performance on the task, larger NSW greater successful retention, rehearsal and implementation of the information during the task.

3. A Developmental Study of Semantic Priming and Working Memory in Bilingual and Monolingual Infants

3.1 Abstract

The extent to which domain general processes contribute to language development is a central question in developmental science. Between 13 and 20 months of age, children often exhibit a rapid growth in vocabulary size. One hypothesis accounting for this rapid change is an improvement in memory abilities (Gershkoff-Stowe, 2002). For inexperienced word learners, the process of acquiring new words is susceptible to interference from lexical competitors. In contrast, more experienced word learners' show more resilience to interference as a function of stronger memory retrieval processes. Previous research suggests that bilinguals have improved working memory abilities compared to monolinguals (Craik & Bialystok, 2006). If so, bilingual infants may show less interference to lexical competitors even with smaller vocabularies.

The present study tests the hypothesis that semantic priming is enhanced in 14-to-22-month-old bilingual infants compared to monolingual infants as a function of improved working memory abilities. Event-related potentials (ERPs) were used to investigate the role of working memory in a semantic priming paradigm designed to elicit an ERP component linked to semantic integration called the N400. The N400 is larger when a stimulus is incongruent with the preceding context (Kutas & Hillyard, 1980), and has been demonstrated in young infants (Friedrich & Friederici, 2004, 2005). Building on a previous study by Mills and Sheehan (2006), 14-to-22-month-old Welsh/English bilingual and monolingual English infants heard a word and 500 ms after the onset of the word they saw a picture; the word either named the picture (match) or named another picture (mismatch). A larger N400 was expected in trials where there was a mismatch between the word-picture pair. The 500 ms delay between the onset of the word and the picture introduces a working memory component to the paradigm, as the infant must retain the word in memory to complete the task.

The results of the present study show that during the initial processing of the phonology of the word, the bilingual infants were better adept at holding the word in working memory than the monolingual infants. Following the presentation of the picture, the monolingual and bilingual infants responded similarly to the visual stimulus. During the 450 – 650 ms time window when the ERPs were time-locked to the visual stimulus, there were no group differences on how the match and mismatch conditions were processed, despite their being a condition effect. Overall, there does not seem to be semantic priming

differences between monolingual and bilingual infants, but the bilingual infants elicited ERPs to the word that suggest a better adept working memory system. This finding is consistent with the hypothesis that bilingualism is associated with increased working memory capacity even in very young children.

3.2 Introduction

Over the past two decades researchers have set out to determine whether bilingualism leads to changes in language and cognitive development (Bialystok, 2009; Grosjean, 1989). Differences have been shown throughout the lifespan, with significant cognitive differences being shown in childhood and older adulthood (Craik & Bialystok, 2006). More recently researchers have started to question whether the differences seen in childhood can be extended to development during infancy (Poulin-Dubois, Blaye, Coutya, Bialystok, 2011).

A bilingual advantage on tasks requiring executive control has been found in non-verbal infants as young as 6-months-old (Kovács & Mehler, 2009; Ibanez-Lillo et al., 2010; Singh et al., 2014). On a task similar to the A-Not-B, 7-month-old infants were given an auditory cue during the training phase that signaled the location of a visual reward. During the test phase, a novel auditory cue was presented that signaled the reward would appear in the opposite location. It was only the bilingual infants who were successful at redirecting their attention to the location for the visual reward. The monolingual infants persisted with attending to the previous location even though no reward was presented (Kovács & Mehler, 2009). A study using a similar paradigm to the one employed by Kovács and Mehler (2009) was conducted with 8-month-old infants. In contrast to the results found in the study with the 7-month-olds, this study found that both monolingual and bilingual infants were equally able to attend to the correct location for the visual reward during the test phase. The authors did note that the bilingual infants appeared to inhibit their attention to the incorrect location earlier than the monolingual infants (Ibanez-Lillo et al., 2010). Another study using a visual habituation task found that bilingual 6-month-old infants had better proficiency in stimulus encoding as well as better recognition memory for the familiar stimuli compared to the monolingual infants. It was concluded that there is a generalized cognitive advantage in bilingual infants, which is not specific to language, is early to emerge and is wide-ranging (Singh et al., 2014). It would therefore appear that even during early infancy executive control is influenced by exposure to more than one language, and that these developments are present before children become verbal.

Bilingual infants' experience with language is divided between two languages, and the result of this is less experience with words of these languages compared to a monolingual infant. This linguistic divide may affect the development of their lexical-semantic system; the infant must construct two different phonological-lexical systems in parallel as well as learning two words for objects and concepts. Nevertheless, It has been demonstrated that lexical development in bilingual infants occurs at the same rate as it does in monolingual infants (Pearson, Fernandez & Oller, 1993; Pearson & Fernandez, 1994; Oller, Eilers, Urbano & Cobo-Lewis, 1997; Petitto, Katerelos, Levy, Gauna, Tétreault & Ferraro, 2001), and the wide range of vocabulary sizes observed in normally developing monolingual 8-to-30-month old infants is also observed in bilingual infants in this age range (Pearson et al., 1993). Further, the vocabulary growth spurt seen in monolingual infants also occurs in the same percentage of bilingual infants (Pearson & Fernandez, 1994). Bilingual infants as a group differ (in how their lexicon develops) from one another in much the same way that monolingual infants do, but bilingual infants differ from one another in terms of one language relative to the other. There is independence within each language within each individual child, for example the learning strategies employed by a child may differ in one language relative to the other. As the pattern of growth in two languages in bilinguals corresponds to the growth of one language in monolinguals, it has been proposed that norms for lexical development in bilinguals should be made with reference to performance in both languages together (Pearson et al., 1993). The development of a bilingual infants lexicon is strongly correlated with the amount of language exposure in the two languages the child receives (Pearson, Fernandez, Lewedeg & Oller, 1997; David & Wei, 2008). Further, bilingual infants are able to distinguish between two languages at an early age (Bosch & Sebastiàn-Gallés, 1997; 2001) and there is not a delay in the development of native phonetic representations as a result of exposure to two languages (Burns, Yoshida, Hill, Werker, 2007). Although a bilingual infant may have smaller vocabularies in each of their languages than a comparable monolingual, their total combined vocabulary is equivalent to that of a monolingual (Bialystok, 2009; Hoff, Core, Place, Rumiche, Senor, & Parra, 2012; Poulin-Dubois, Bialystok, Blaye, Polonia, & Yott, 2013).

The semantic links between lexical items has already started to develop in infants as young as 21-months-old (Arias-Trejo & Plunkett, 2009). The development of the semantic system and word-word associations in infants (18-and-21-month olds) was assessed using an adaption of the inter-modal preferential looking task. Infants were presented with word pairs that directed their attention towards a target picture. A prime and a target word were presented in quick succession followed by a picture pair (target and distracter). The prime-target word pairs were either semantically related or unrelated, and the targets were either named or unnamed. There was a lexical priming effect for the 21-month olds but not the 18-month olds, and when the prime word was unrelated to the target there were interference effects for the 21-month olds. The 18-month olds responded correctly to the target names regardless of the priming condition, however when the target was unnamed there was no demonstration of a target object preference. This suggests that at 18-months old the infant is unable to activate a mental representation based on the prime word. They rely on the target word to determine their preference. The 21-month old infants, on the other hand, were highly influenced by the prime word. There was a lack of preference for the target object when the preceding prime word was unrelated. This would suggest that the unrelated prime is interfering with the processing of the target word and results in poor identification of the target object. As this interference only occurred when the prime was unrelated to the target indicated that the 21-month olds had started to selectively develop semantic associations (Arias-Trejo & Plunkett, 2009).

In addition to behavioural tasks such as the A-Not-B, habituation and preferential looking, infant studies have also incorporated electrophysiological methodology. The use of Event Related Potentials (ERPs) allows for the collection of physiological data as well as behavioral data, which benefits from high temporal resolution and is a covert and continuous measure of cognitive processing. It is therefore possible to observe the cognitive processes occurring between the onset of a stimulus and the response elicited. ERPs are therefore a suitable methodology for investigating the semantic relatedness and incongruity in infants and young children, for whom the use of behavioural tasks is often inappropriate (Torkildsen, Syversen, Simonsen, Moen & Lindgren, 2007). The N400 component, which is a negative going peak, is a sensitive index of semantic processing, and it reflects the neural mechanisms involved in semantic integration both in adults and infants (Kutas & Hillyard, 1980; Friedrich & Friederici, 2004).

In adults the N400 component is sensitive not only to semantic incongruity but also semantic relatedness between stimulus items. An ERP study using a unimodal auditory paradigm with semantically related and unrelated words addressed whether 24-month-old infants were able to index the semantic relatedness between word pairs. It was discovered that when the target word was preceded by a semantically unrelated word, a broadly distributed N400-like effect was elicited. Where as when the target was preceded by a semantically related word an early (200-400 ms) negative effect was elicited, indicating there was facilitation of lexical-phonological processing. The N400 in 24-month-old infants appears to be functionally equivalent to the N400 in adults (Torkildsen et al., 2007).

By 2-years of age the process of word recognition comprises a cascaded processing of phono-semantically related words (Mani, Durrant, & Floccia, 2012). A picture-priming paradigm was used, whereby 2-year-old toddlers were presented with phono-semantically related prime-target pairs (the label for the prime was phonologically related to the semantic associate of the target label). The results demonstrated that 2-year-old toddlers were faster at recognizing a word when it was preceded by a phono-semantically related prime relative to an unrelated prime. From these results it can be concluded that the process of word recognition by the age of 2-years old involves a cascaded processing of phono-semantically related words (Mani et al., 2012).

An ERP study investigated whether the mechanisms involved in lexical priming and semantic integration is developed in 14-month old infants. The infants were required to look at coloured pictures of known objects whilst being presented with words that were either congruous or incongruous to the picture. The study revealed that at 14-months old there is an early negativity for the congruous words and a later N400-like negativity for the incongruous words. The results of this study revealed that at 14-months old the processes involved in lexical priming and semantic integration are already present (Friedrich & Friederici, 2005). Lexical priming refers to the process of activating a representation of the word in the lexicon. As an early negativity in response to the congruous word has been elicited, there is an indication that the 14-month old infant is creating a lexical representation based on the picture presented; hence lexical priming is present at this age. Further the N400-like negativity elicited in response to the incongruous words, relative to the congruous, indicated that the mechanisms involved in semantic processing are present at 14-months old and they are subsequently affect by semantic priming (Friedrich & Friederici, 2005), therefore semantic integration has taken place. In this situation lexical priming has taken place as activation of representations in the lexicon have been engaged in order to determine whether the picture presented is congruous or incongruous to the word presented, hence semantic integration of the information presented has been processed in order to facilitate semantic priming.

By 14-months-old infants have become fast word learners. An ERP study exploring the brain activity related to the fast learning of object-word mapping in 14-month-old infants revealed both a word form priming effect as well as a semantic priming effect. Infants were presented with four repetitions of eight object-word pairs; by the forth repetition infants elicited a fronto-lateral negativity (200-500 ms) indicating a word form priming effect, as well as a parietal N400 effect, which indicated a semantic priming effect. The results of this study suggest that by 14-months-old infants are able to learn object-word mappings after four presentations. Further, when infants took part in a test phase at least one day later, the N400 elicited was able to differentiate between trained congruous and incongruous pairings, suggesting that knowledge about the object-word pairings had been stored in memory (Friedrich & Friederici, 2008).

Not only are infants fast word learners, there is also evidence to suggest that they are also able to implicitly name visually fixated objects whose names are known (Mani & Plunkett, 2010). A picture-based phonological priming task was conducted with 18-month-old infants. The study examined infants' recognition of named targets in primed (e.g., dog-dog) and unrelated trials (e.g., dog-boat). The prime image was never named. The results revealed that infants were better at recognizing the target object in the prime condition compared to the unrelated condition. As the prime was never explicitly named, these findings would suggest that infants as young as 18-months-old are able to implicitly name a visually fixated object and this subsequently generated name is able to prime infants' responses on a paired visual-object spoken-word-recognition task (Mani & Plunkett, 2010).

There are only a few studies in the literature concerning the neural representations of word recognition and word familiarity in bilingual infants and toddlers (Conboy & Mills, 2006; Vihman, Thierry, Lum, Keren-Portnoy, Martin, 2007; Kuipers & Thierry, 2012, 2013). The results of these studies have demonstrated that the word familiarity effect occurs earlier in age in monolingual infants than bilinguals infants (Vihman, Thierry, Lum, Keren-Portnoy & Martin, 2007); in bilinguals the familiarity effect is more pronounced for the dominant language than the non-dominant language and the neural representations of words in the two languages are not identical in the bilingual brain (Conboy & Mills, 2006); bilingual children allocate more attention to unexpected linguistic information in their dominant language (Kuipers & Thiery, 2013).

As the studies assessing lexical development have shown, there is often a rapid growth in vocabulary size between 13-and-20-months of age. Although comprehension appears to develop in a linear manor from birth, production has been shown to develop rapidly towards the end of the second year (Fenson et al, 1994). One hypothesis accounting for this rapid change is an improvement in memory abilities. Memory development is thought to aid this process by helping the infant become resilient to interference from lexical competitors when acquiring new words (Gershkoff-Stowe, 2002).

The working memory (WM) system is relied upon to perform a broad range of cognitive tasks; information is temporarily stored in mind so that it can then be manipulated or acted on (Baddeley & Hitch, 1974; Cowan, 2001). The covert nature of this temporary storage / retention period, makes it difficult to measure behaviourally as it is typically the overt outcome of the retention period that is measured. ERPs are useful for measuring covert cognitive processes. The high temporal resolution of ERPs allows for segregation of activity during the retention period of a memory task. Further, it also provides information about the timing of the brain processes recruited during working memory activation. An ERP component that has been linked to the retention/maintenance period during working memory tasks is a broadly distributed negative slow wave (NSW) (Ruchkin et al., 1990). Larger NSW amplitude observed during the retention period is related to a greater possibility of successful retrieval of the attended information (Rosler et al., 1997). Further, the NSW persist throughout the retention period until the test stimuli are presented (Klaver et al., 1999; Vogel & Machizawa, 2004), and the amplitude of the activity is diminished during the retention period when participants subsequently make an incorrect response during the test phase. This suggests that the NSW reflects retention processes necessary for correct performance on WM tasks (Vogel & Machizawa, 2004).

An ERP study (Mills, Conboy & Paton, 2005) investigated the role of working memory and vocabulary size on semantic processing, in adults and children aged 13, 20, and 36-months old. Two cross-modal paradigms were used that were designed to elicit the N400 component, one paradigm incorporated a working memory component and the other did not. In the first experiment, participants viewed a picture then 500 ms later they heard a word while the picture remained on the screen. The word either named the object represented in the picture (match) or named a different object (mismatch). A significant N400 effect to the mismatched words was observed at all ages, and there were no developmental differences or changes in the N400 for high compared to low comprehenders in each age group. The results of the first experiment showed that the neural mechanisms underpinning the N400 response are similar to adults even in early word learners (Mills et al., 2005). In the second experiment the word was presented first followed by a picture that either matched or mismatched the preceding word 500 ms later (Larson, Lewis, Horton, Addy, & Mills, 2005). The delay between the offset of the word and the onset of the picture introduced a working memory component. The 36-month-olds showed similar latency and distribution of the N400 as the adults. The 20-month-olds also showed an N400 effect but it differed in latency and distribution compared to the adults. As a group the 13-month-olds did not show a significant N400 effect when the delay was introduced. When the 13-month-olds were divided into low and high comprehenders, the 13-month-olds who had a receptive vocabulary over 100 words showed a significant N400 response. Where as the 13-month-olds who had a receptive vocabulary under 100 words did not show an N400 effect (Mills et al, 2005). These findings highlight the importance of domain-general processes in children's' semantic processing (Mills & Sheehan, 2007).

Working Memory is an executive function that is affected positively by bilingualism (Bialystok, 2009). However, much like the data reported regarding adult bilinguals, previous research regarding the affects of bilingualism on the development of working memory has yielded different results. A longitudinal study addressing bilingualism and working memory performance in 6-to-8-year-olds over a 3 year period found that monolingual and bilingual children, who were matched on age, sex and socioeconomic status, did not differ on the working memory tasks after verbal ability was considered (Engel de Abreu, 2011). Whereas the monolingual group performed significantly better than the bilingual group on language measures over the 3-year period. The author concluded that the process of managing several languages has a subsequent impact on a child's language abilities but it does not affect the development of the working memory system. On the other hand, a study with 5-year-olds that manipulated the Simon task to include a working memory element found a bilingual advantage (Morales, Calvo & wBialystok, 2013). The results revealed that bilinguals were faster than monolinguals when responding to all conditions, as well as responding more accurately to the incongruent trials. These results would suggest that there is an advantage for bilingual children on tasks that require working memory, especially when the task involves an additional cognitive demand (Morales, et al., 2013).

The current study takes into account the bilingualism advantage hypothesis and working memory and applies them to a semantic priming study. The semantic priming paradigm used in this study is a modified replication of the second experiment in the Mills and colleagues (2005) cross-modal study. Whereby a word-picture semantic priming paradigm incorporating a working memory delay was used. The purpose of this study was to establish whether exposure to multiple languages in infants aged 14-to-22-months would enhance semantic priming abilities as a function of working memory abilities. It was hypothesized that bilingual infants may show less interference in response to the working memory delay imposed between the onset of the word and the onset of the picture. In the previous study (Mills et al., 2005) the working memory component affected semantic processing in 13-month-olds who had smaller receptive vocabularies. Here it is hypothesized that the bilingual infants, irrespective of their vocabulary size, will manage the working memory element of the task more efficiently than the monolingual infants. Group differences are predicted to be more salient in the younger infant group (14-to-17-

months old) resulting in an N400 semantic priming effect for the bilinguals but not the monolinguals.

3.3 Method

3.3.1 Participants

The data for this current study came from fifty-two typically developing infants, who were recruited from areas local to Bangor University. In exchange for their participation parents/guardians were reimbursed £15 towards travel expenses and the infants were given a small gift. Following parental report all participants were free from any auditory or visual impairment, and there was no known history of any neurological conditions. All parents/guardians provided voluntary informed consent prior to the start of the study. Ethical approval was granted from the ethics committee prior to the start of the research.

Participants were categorised as either monolingual or bilingual based on the amount of exposure to English and Welsh that was reported by their parents/guardians. All participants in the bilingual group had significant exposure to both English and Welsh on a regular basis (≥ 20% exposure to their non-dominant language), with their parents being native speakers of one or both of the languages. Typically, the infants categorised as bilingual were being raised in bilingually balanced home, where they were exposed to both languages on a daily basis (English: M = 46.77, SD = 28.54; Welsh: M = 46.88, SD = 28.71).

The infants in the current study were aged between 14-and- 22-months old (+/- 2 weeks) and were categorised into two groups based on their age at test. The first group ranged in age from 14-to-17-months old (M = 15.09, SD = 1.32) and the second ranged in age from 18-to-22-months old (M = 19.83, SD = 1.15). These two age groups were separated according to their language exposure, therefore resulting in four participant groups: 14-to-17-month old monolingual (N = 13, 9 males), 14-to-17-month old bilingual (N = 13, 8 males), 18-to-22-month old monolingual (N = 13, 8 males) and 18-to-22-month old bilinguals (N = 13, 4 males). There was no difference in age between the 14-to-17-month old groups, $F(1,25) = .144$ $p = .708$, or the 18-to-22-month old groups, $F(1,25) = .175$ $p = .679$. Also, there were no gender differences between the 14-to-17-month old groups, $F(1,25) = .158$ $p = .695$, or the 18-to-22-month old groups, $F(1,25) = 2.526$ $p = .125$.

All parents and guardians were asked to report their highest level of education and their occupation, however only a subsample (N = 41) of these parents/guardians provided this information. The information collected was then scored using a modified version of

The Barratt Simplified Measure of Social Status (Barratt, 2006) to assess whether any group effects that may be seen could be attributed to Socio-economic status (SES) differences. Neither the 14-to-17-month old groups, $F(1,18) = 1.535$ $p = .232$, nor the 18-to-22-month old groups, $F(1,17) = .244$ $p = .628$, differed in SES, indicating that if any group differences were to be seen it would be unlikely that they could be attributed to differences in SES.

3.3.2 Vocabulary Measures

Data regarding infants' vocabulary development was collected via parental report on The Welsh English Bilingual Communicative Development Inventory (CDI). Parents were required to denote whether their child understood (U) and produced (UP) words from a collection of categories typically understood by infants in this age range. The group scores on the CDI are displayed in Table 1.

Analysis of the CDI data revealed that for both the 14-to-17-month old group, $F(1,25) = .187$ $p = .669$, and the 18-to-22-month old group, $F(1,25) = .134$ $p = .717$, there was no difference between the monolingual and bilingual infants on the amount of English they understood. Similarly there was also no difference in the number of English words produced between the monolingual and bilingual infants in both the 14-to-17-month old group, $F(1,25) = .491$ $p = .490$, and the 18-to-22-month old group, $F(1,25) = .108$ $p = .746$. As expected, there was a significant difference between the monolingual and bilingual infants in both the 14-to-17-month old group, $F(1,25) = 16.53$ $p = .000$, and the 18-to-22-month old group, $F(1,25) = 27.56$ $p = .000$ on the amount of Welsh that they understood.

Table 1. Comparison of vocabulary development reported on the CDI (Mean and Standard Deviation)

	Total E U Mean (SD)	Total E P Mean (SD)	Total W U Mean (SD)	Total WP Mean (SD)	Total WE U Mean (SD)	Total WE P Mean (SD)
Mono 14 – 17 – months	88.69 (81.76)	12.38 (19.05)	2.15 (4.52)	.000 (.000)	108.38 (96.89)	17.00 (21.99)
Bilingual 14-17 - months	75.54 (73.05)	7.92 (12.80)	61.38 (52.33)	5.23 (8.65)	159.77 (124.58)	18.00 (22.48)
Mono 18-22- months	148.00 (73.49)	52.62 (57.17)	.231 (.599)	.077 (.277)	177.23 (85.00)	67.15 (67.95)
Bilingual 18-22- months	138.15 (63.11)	46.31 (39.13)	127.54 (87.44)	40.69 (50.25)	303.69 (118.29)	107.62 (88.91)

**E=English, W = Welsh, U=Understands, P = Produced*

This was also true for the number of Welsh words produced by the monolingual and bilingual infants in both the 14-to-17-month old group, $F(1,25) = 4.75$ $p = .039$, and the 18-to-22-month old group $F(1,25) = 8.49$ $p = .008$.When total combined vocabulary (English and Welsh) was considered there was not a significant difference between the monolingual and bilingual infants in the 14-to-17-month old group on the number of words that they understood, $F(1,25) = 1.38$ $p = .252$, or produced, $F(1,25) = .013$ $p = .910$. However, there was a significant difference between the monolingual and bilingual infants in the 18-to-22-month old group on the number of words that they understood, $F(1,25) = 9.798$ $p = .005$, but there was no significant difference on the number of words that they produced, $F(1,25) = 1.70$ $p = .205$.

In addition to the CDI data, parents/guardians were also asked to rate on a 5-point Likert scale (Don't Know to Understands) how confident they were that their child understood the words included in the experiment.

3.3.3 Stimuli

The words selected as the stimuli for the current study were chosen based on the frequency with which infants between 14-and-22-months understand them. The words selected are 50 of the most frequently understood nouns (excluding proper nouns) based on the norms collected by the MacArthur Bates CDI (details regarding the norms can be found at http://www.sci.sdsu.edu/lexical/results.php). The words chosen for the stimuli included nouns such as ball, dog, cat, and banana (see Appendix for full Stimuli list).

In total there were 2 blocks of 100 trials (50 match, 50 mismatch). The match and mismatch trials were presented in a pseudo-random order; this was to ensure that the same audio/visual stimuli did not occur on simultaneous trials as well as ensuing that any closely related words did not appear sequentially (i.e. cat following dog). For the mismatch trials, the target words were paired with an unrelated word from the study i.e. the participant would hear “toothbrush” and then see an image of a door. The two blocks had audio from separate speakers, whose voices were accent free. All visual stimuli were photographs representing the words, which were presented on a grey background (see Figure 1 for an example of the visual stimuli). Each visual stimulus was presented as both a match and a mismatch, and each block had a separate set of images (total of 100 images).

3.3.4 Procedure

All the data was collected in the Bangor Brain and Cognitive Development Lab at Bangor University. The process of placing the head-cap and electrodes on the participant took place in the labs' playroom, where an experimenter entertained the infant whilst a second experimenter discreetly put the head-cap on and attached the electrodes.

During data collection participants sat on their parent/guardians' lap in a sound attenuated room, 120cm away from the TV screen. Participants were not required to respond overtly to the stimuli. Figure 1 depicts the organization of a trial. Each trial consisted of the presentation of an audio stimulus (i.e. "dog") followed, 500 ms after the onset of the audio stimulus, by a visual stimulus (i.e. dog). The visual stimulus remained on the screen for 1000 ms. During the study the experimenter coded when a participant was not attending to the stimuli on the screen (unattended trials were removed from the data analysis), as well as rewarding the participant when they were attending with an animated attention grabber.

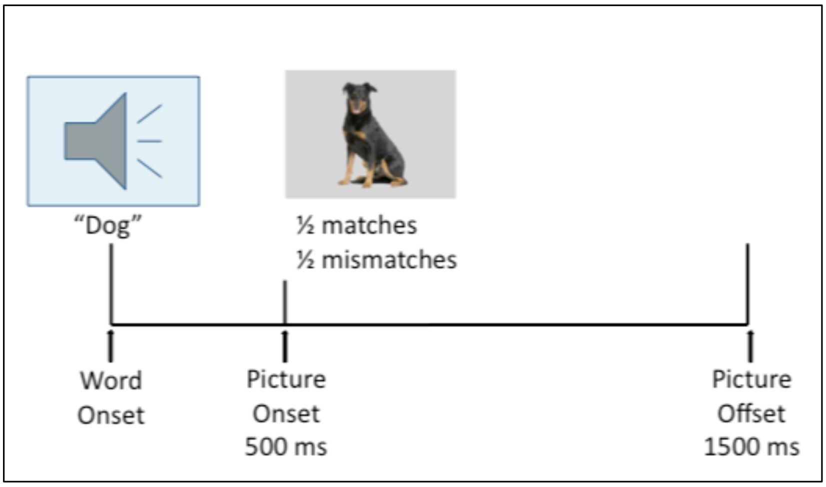


Figure 1. Depicts the organization of each trial within the experiment. Each trial consisted of the participant being presented with an auditory stimulus i.e. "Dog". Then 500 ms following the onset of the auditory stimulus the participant is presented with a visual stimulus i.e a picture of a dog (match condition) or a picture of a flower (mismatch condition). Matched and mismatched trials occurred in a pseudo-random sequence, with half the trials resulting in a match and half the trials resulting in a mismatch.

3.3.5 EEG Recording

The EEG was recorded continuously (BioSemi Version 6.05, 2007) from 32 pin-type Ag-AgCl active electrodes positioned according to the standard 10/20 layout affixed to a head-cap (BioSemi head-cap). Additional electrodes were placed over the left and right mastoid sites, as well as under the left eye and the right outer canthus. EEG recordings were amplified by a factor of 20,000, with a sampling rate of 2048 Hz. The EEG was recorded reference free and without filters during data acquisition. All offsets (conceptually related to impedance) were kept below 25µv.

3.3.6 ERP Data Analysis

Data analysis was conducted offline using the ERPLAB Toolbox (for more details see http://erpinfo.org/erplab), which is integrated with the EEGLAB Toolbox (Delorme & Makeig, 2004). The EEGLAB toolbox was operated using MATLAB (version 7.9.0 R2009b). A 200 ms pre-stimulus baseline correction was applied to all EEG data and was filtered offline with a bandpass of 0.1 Hz to 30 Hz. EEG was referenced offline to the average of the left and right mastoids. Data were segmented into epochs of 200 ms before to 1500 ms after the onset of the stimuli (match/mismatch trials). Artifact rejection thresholds to detect blinks, horizontal eye movement, drift, and muscle artifact, were determined for each participant separately through visual inspection of the raw EEG (as recommended by Luck, 2005). Any epochs or channels containing eye or movement artifact were excluded from the analyses. Individual ERP's were created for each participant by averaging across trials for each electrode and condition. Group averages were obtained by averaging across participants within each group.

The electrode sites analysed were chosen following visual inspection of topographic maps and after taking into consideration previous research, these are highlighted in Figure 2. All time windows were selected following a 10 ms window analysis to determine the onset and offset of each component. Three separate time windows were selected for analysis of the N400 component, these were: 200 – 400 ms, 450 – 650 ms and 650 - 850 ms time-locked to the picture; and 200-500 ms, 500-800 ms and 800 -1500 ms time-locked to the word. The N400 elicited by the match/mismatch trials was analysed at electrode sites: AF3, AF4, F3, Fz, F4, FC5, FC1, FC2, FC6, C3, Cz, C4, CP5, CP1, CP2, and CP6 for the ERPs time-locked to the picture; and at electrode sites: AF3, AF4, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, C3, Cz, C4 time-locked to the word.

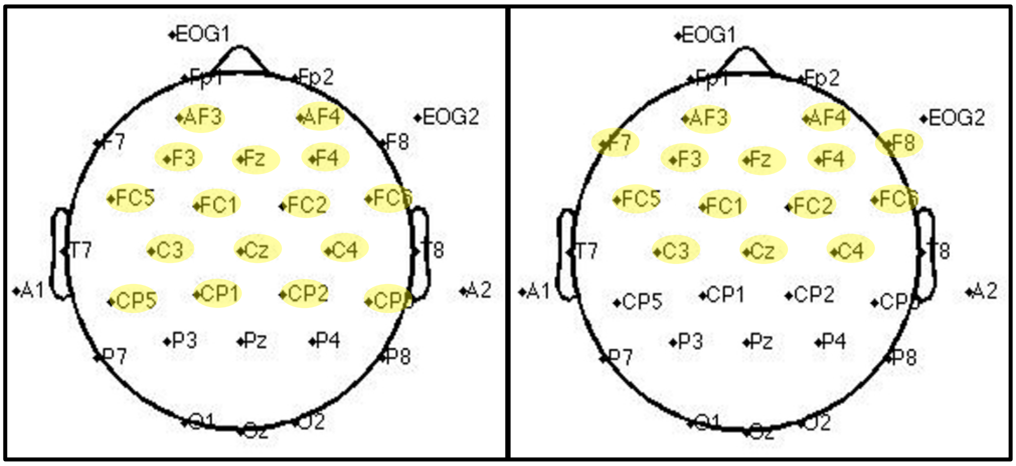


Figure 2. Head Maps displaying electrode sites chosen for analysis of the N400 when the ERPs were time-locked to the picture (left) and the word (right).

3.4 Results

3.4.1 Socioeconomic Status, Language Exposure and Receptive Vocabulary

In this section, the relationship between socioeconomic status (SES), language exposure and receptive vocabulary (comprehension and production) will be analysed. For the monolingual groups, only receptive vocabulary in English will be discussed. For the bilingual group, receptive vocabulary in English, Welsh and combined will be discussed. A series of linear regression analysis was conducted and α ≤ .05 will be discussed in terms of a significant effect.

When all infants were considered a significant regression equation was found, $F(1, 48) = 7.609$, $p=.008$, with an $R^2=.137$, predicting infants' English comprehension based on their total exposure to English. Whereby infants' average English comprehension increased .161 for every percentage of time exposed to English. However, infants English production, $F(1, 48) = 2.064$, $p=.157$, with an $R^2=.041$; total receptive comprehension, $F(1, 48) = .816$, $p = .371$, with an $R^2=.017$; and total receptive production, $F(1, 48) = .566$, $p = .455$, with an $R^2=.012$, produced non-significant regression equations based on total exposure to English. Exposure by mum to English did not predict English comprehension, $F(1, 48) = 2.840$, $p = .098$, with an $R^2=.056$; English production, $F(1, 48) = 1.244$, $p = .270$, with an $R^2=.025$; or total receptive production, $F(1, 48) = 1.065$, $p = .307$, with an $R^2=.022$; however, exposure to English by the mum did significantly predict total receptive comprehension, $F(1, 48) = 4.314$, $p = .043$), with an $R^2=.082$, whereby the infants' average total Welsh/English comprehension decreased -.086 for every percentage of time exposed to English by their mum. Exposure by dad to English was a significant predictor of infants' English comprehension, $F(1, 48) = 8.083$, $p = .007$), with an $R^2=.144$, whereby infants' average English comprehension increased .206 for every percentage of time exposed to English by their dad. However, English exposure by the dad did not significantly predict English production, $F(1, 48) = 1.647$, $p = .206$, with an R^2=.033; total receptive comprehension, $F(1, 48) = .126$, $p = .725$, with an R^2=.003; nor total receptive production, $F(1, 48) = .079$, $p = .780$), with an R^2=.002. SES was not a predictor of English comprehension, $F(1, 35) = .950$, $p = .337$, with an R^2=.026; English production, $F(1, 35) = .085$, p =.772, with an R^2=.002; total receptive comprehension, $F(1, 35) = .191$, $p = .665$, with an R^2=.005; nor total receptive production, $F(1, 35) = .530$, $p = .472$, with an R^2=.015.

When only the bilingual infants' were considered English comprehension was significantly predicted by total exposure to English, $F(1, 24) = 8.134$, p=.009, with an R^2= .253. Whereby infants' average English comprehension increased .194 for every percentage of time exposed to English. Total exposure to English did not significantly predict Welsh comprehension, $F(1, 24) = 1.338$, p=.259, with an R^2=.053; total receptive comprehension, $F(1, 24) = .554$, $p = .464$, with an R^2=.023; English production, $F(1, 24) = 1.537$, p=.227, with an R^2=.060; Welsh production, $F(1, 24) = 3.174$, p= .087, with an R^2=.117; nor total receptive production, $F(1, 24) = .144$, $p = .708$, with an R^2=.006. Exposure to English by the mum only significantly predicted Welsh comprehension, $F(1, 24) = 5.696$, $p = .025$, with an R^2=.192, whereby infants' average Welsh comprehension decreased -.196 for every percentage of time exposed to English by their mum. Exposure to English by the dad only significantly predicted English comprehension, $F(1, 24) = 6.135$, $p = .021$, with an R^2=.204, whereby infants' English comprehension increased .268 for every percentage of time exposed to English by their dad. Exposure to Welsh by the mum only significantly predicted Welsh comprehension, $F(1, 24) = 7.683$, $p = .011$, with an R^2=.243, whereby infants' average Welsh comprehension increased .234 for every percentage of time exposed to Welsh by their mum. Exposure to Welsh by the dad only significantly predicted English comprehension, $F(1, 24) = 6.998$, $p = .014$, with an R^2=.226, whereby infants' average English comprehension decreased -.284 for every percentage of time exposed to Welsh by their dad. SES was not a predictor of English comprehension, $F(1, 14) = .054$, $p = .820$, with an R^2=.004; English production, $F(1, 14) = 2.787$, p =.117, with an R^2=.116; Welsh comprehension, $F(1, 14) = 2.903$, $p = .111$, with an R^2=.172; Welsh production, $F(1, 14) = 2.794$, p =.117, with an R^2=.166; total receptive comprehension, $F(1, 14) = 1.318$, $p = .270$, with an R^2=.086; nor total receptive production, $F(1, 14) = 3.466$, $p = .084$, with an R^2= .198.

3.4.2 ERP Results

Analysis of the ERPs time-locked to the Picture and the Word are reported separately, and interactions with group are analysed using repeated measures ANOVAs (group x condition x electrode site). For all statistical analyses, when the assumption of sphericity is violated, the Greenhouse-Geisser correction is reported (Greenhouse & Geisser, 1959). When $\alpha \leq .05$ the results will be discussed in terms of a significant effect; when $\alpha = .05 - .095$ results will be discussed in terms of a trending towards a significant effect.

3.4.2.1 ERPs time-locked to the Picture

In this section ERPs time-locked to the picture will be discussed. As mentioned in the method section, the onset of the picture occurs 500 ms following the initial onset of the auditory word. There are three time-windows that will be discussed, 200 -400 ms, 450 – 650 ms and 650 – 850 ms, and data were analysed at 16 electrode sites (AF3, F3, FC5, C3, CP5, CP1, FC1, Fz, Cz, FC2, CP2, CP6, C4, FC6, F4, AF4).

14-to-17-month old groups

Analysis of the ERPs elicited in the three different time windows found no main effect of match-mismatch condition [200-400 ms: $F(1,24) = .646$ $p=.429$ $\eta^2 =.026$; 450-650 ms: $F(1,24) = .063$ $p=.804$ $\eta^2 =.003$; 650-850 ms: $F(1,24) = .133$ $p=.718$ $\eta^2 =.006$]. There was a main effect of group across all three time-windows [200-400 ms: $F(1,24) = 6.965$ $p=.014$ $\eta^2 =.225$; 450-650 ms: $F(1,24) = 4.717$ $p=.040$ $\eta^2 = .164$; 650-850 ms: $F(1,24) = 5.056$ $p=.034$ $\eta^2 =.174$], however, this main effect is only representative of an overall shift in ERP amplitude for the monolinguals compared to the bilinguals (see Table 2 for descriptive statistics), and does not represent an interaction between match-mismatch condition and language group [200-400 ms: $F(1,24) = .738$ $p =.399$ $\eta^2 =.030$; 450-650 ms: $F(1,24) = .053$ $p=.820$ $\eta^2 =.002$; 650-850 ms: $F(1,24)=.634$ $p =.434$ $\eta^2 =.026$].

18-to-22-month old groups

Analysis of the three time-windows revealed that there was no main effect of match-mismatch condition [200-400 ms: $F(1,24) = 1.022$ $p =.322$ $\eta^2 =.041$; 450-650 ms: $F(1,24) = .142$ $p=.710$ $\eta^2 =.006$; 650-850 ms: $F(1,24)=.057$ $p =.813$ $\eta^2 =.002$]; no main effect of language group [200-400 ms: $F(1,24) = .007$ $p =.933$ $\eta^2 =.000$; 450-650 ms: $F(1,24) = .886$ $p=.356$ $\eta^2 =.036$; 650-850 ms: $F(1,24)=.597$ $p =.447$ $\eta^2 =.024$]; and no interaction between match-mismatch condition and language group [200-400 ms: $F(1,24) = .106$ $p =.748$

η^2=.004; 450-650 ms: $F(1,24) = 1.290$ p=.267 η^2 =.051; 650-850 ms: $F(1,24)$= 2.326 p =.140 η^2 =.088], indicating that both the monolingual and bilingual groups elicited comparable ERPs across both match-mismatch conditions during all three time-windows.

Table 2. Descriptive statistics for the ERP amplitude over the three time-windows for the 14-to-17-month old and 18-to-22-month old groups (Means and Standard Error are displayed)

	Condition	200-400 ms Mean (SE)	450-650 ms Mean (SE)	650-850 ms Mean (SE)
Monolingual 14 – 17 –months	Match Condition	-14.877 (2.25)	-30.762 (3.13)	-16.928 (2.45)
	Mismatch Condition	-12.624 (2.16)	-31.736 (3.53)	-17.795 (2.79)
Bilingual 14-17-months	Match Condition	-6.313 (2.25)	-21.963 (3.13)	-11.509 (2.45)
	Mismatch Condition	-6.388 (2.16)	-22.004 (3.53)	-9.173 (2.79)
Monolingual 18-to-22-months	Match Condition	-13.888 (2.88)	-28.020 (3.66)	-11.086 (3.75)
	Mismatch Condition	-12.860 (2.71)	-30.365 (3.43)	-12.893 (3.22)
Bilingual 18-to-22-months	Match Condition	-14.075 (2.88)	-25.294 (3.66)	-9.570 (3.75)
	Mismatch Condition	-12.073 (2.71)	-24.118 (3.43)	-7.093 (3.22)

Age as a factor

When Age was analysed in a repeated measures ANOVA as a between-subjects variable (Age x Group x Condition x Electrode Site), there was no main effect of age group in any of the three time-windows, [200 - 400 ms, $F(12,29)$=.628 p = .851 η^2 =.603; 450 - 650 ms, $F(12,29)$ = .835 p =.669 η^2 =.669; 650 - 850 ms, F(12,29)=1.106 p=.446 η^2 =.728]. Additionally, there were no interactions between age group and language group, [200 -

400 ms, $F(9,12) = .689$ $p = .707$ $\eta^2 = .341$; 450 - 650 ms, $F(9,12)=1.256$ $p=.349$ $\eta^2 = .485$; 650 - 850 ms, $F(9,12)=.641$ $p=.744$ $\eta^2 = .325$], or age group and match-mismatch condition, [200 - 400 ms, $F(12,29) = .255$ $p = .999$ $\eta^2 = .381$; 450 - 650 ms, $F(12,29)=.521$ $p=.926$ $\eta^2 = .557$; 650 - 850 ms, $F(12,29)=.734$ $p=.761$ $\eta^2 = .639$] in any of the three time-windows. As age is not a significant factor across the three time-windows, the two age groups were collapsed to produce one monolingual group (N=26) and one bilingual group (N=26). The mean ages [monolingual ($M = 17.46$, $SE = .506$); bilingual ($M = 17.46$, $SE = .557$)] of these two language groups did not differ, $F(1,51) = .000$ $p = .996$.

Distribution effects time-locked to the picture

Analysis of the distribution of ERPs time-locked to the picture revealed that over the three time-windows, a difference in amplitude was elicited over frontal/frontal-central electrode sites compared to central/central-parietal electrode sites (200-400 ms, $F(1,50)=52.571$ $p=.000$ $\eta^2 = .513$; 450-650 ms, $F(1,50)=134.031$ $p=.000$ $\eta^2 = .728$; 650-850 ms, $F(1,50)=98.84$ $p=.000$ $\eta^2 = .664$). This amplitude difference was indicative of a larger amplitude effect over frontal/frontal-central sites [200-400 ms, ($M = -14.451$, $SE = 1.354$); 450-650 ms, ($M=-34.581$, $SE=1.869$); 650-850 ms, ($M=-17.539$, $SE=1.677$)] compared to central/central-parietal sites [200-400 ms, ($M=-7.723$, $SE=1.128$); 450-650 ms ($M=-16.154$, $SE=1.575$); 650-850 ms ($M=-3.702$, $SE=1.419$)]. Visual inspection of the distribution across the scalp revealed individual variability, however this visual inspection also revealed a consistent distribution across participants at electrode site Fz. This has resulted in a focal distribution at electrode site Fz (Figure 3). Therefore, further analysis was conducted at electrode site Fz.

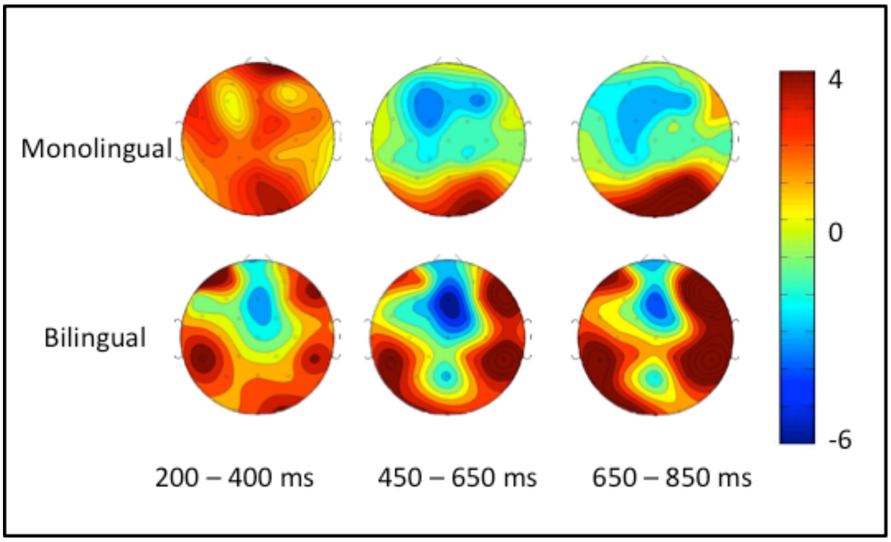


Figure 3. Scalp distribution maps of the difference wave for condition (mismatch-match) are displayed for the monolingual (N=26) and bilingual (N=26) groups, across the three time-windows (200-400 ms, 450-650 ms, 650-850 ms). These scalp distribution maps illustrate the focal distribution at electrode site Fz, when ERPs are time-locked to the picture.

Time-window 200 – 400 ms

Analysis conducted at electrode site Fz revealed there was an interaction between language group and match-mismatch condition that was trending towards significance, $F(1,50) = 3.41$ $p=.071$ $\eta^2 = .064$. However, there was no main effect of match-mismatch condition, $F(1,50) = .129$ $p=.721$ $\eta^2 = .003$, and no main effect of language group, $F(1,50) = .594$ $p=.444$ $\eta^2 = .012$. Moreover, analysis of the peak latency, at 16 electrode sites, revealed no differences between the monolingual and bilingual groups, $F(1,50) = .108$ $p = .744$ $\eta^2 = .002$, and there was no significant difference between the peak latency of the match and mismatch conditions in the 200 - 400 ms time window, $F(1,50) = .159$ $p=.692$ $\eta^2 = .003$.

Time-window 450 – 650 ms

Analysis conducted at electrode site Fz, found a main effect of group that was trending towards significance, $F(1,50) = 2.963$ $p = .091$ $\eta^2 = 0.56$. Further, it did reveal a main effect of match-mismatch condition, $F(1,50) = 5.83$ $p = .020$ $\eta^2 = .104$, whereby the mismatch condition (*M*=-38.46, *SE* = 2.45) elicited larger amplitude ERPs than the match condition (*M*=-34.11, *SE*=2.28) (Figure 4). Analysis of the match-mismatch condition for the monolingual and bilingual groups separately, at Fz, revealed a main effect of match-mismatch condition that is approaching significance for the bilingual group, $F(1,25) = 4.063$ $p =.055$ $\eta^2 = .140$, but no main effect of match-mismatch condition for the monolingual group, $F(1,25) = 1.763$ $p =.196$ $\eta^2 = .066$ (Figure 5). Although there was an overall match-mismatch condition effect, there was no interaction between match-mismatch condition and language group, $F(1,25) = .878$ $p =.353$ $\eta^2 = .017$.

Analysis of the peak latency in the 450-650 ms time window revealed no difference between the monolingual and bilingual groups, $F(1,50) = 2.035$ $p=.160$ $\eta^2 = .039$, and no difference between the match and mismatch conditions, $F(1,50) = .405$ $p=.527$ $\eta^2 = .008$. However, there was a significant interaction between language group and match/mismatch condition, $F(1,50) = 6.545$ $p = .014$ $\eta^2 = .116$, where by the monolingual group (*M* = 512.74, *SE* = 5.41) had a later peak latency for the mismatch condition than the bilingual group (*M* = 4.93.7, *SE* = 5.41).

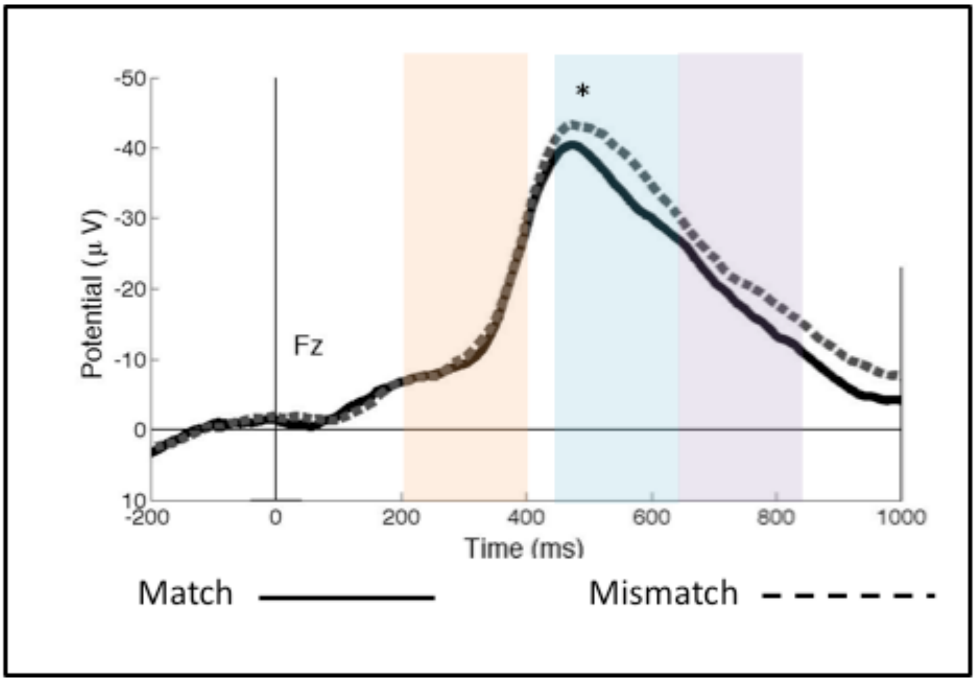


Figure 4. ERPs time-locked to the picture are presented to illustrate the main effect of condition in the 450 – 650 ms time-window, $F(1,51) = 5.839$ $p = .019$ $\eta^2 = .103$. ERPs are collapsed across age and group, and are therefore representative of the full participant sample.

Time-window 650 – 850 ms

As analysis conducted at electrode site Fz had uncovered main effects of group and condition in the previous time-windows, analysis was also conducted at Fz in the 650 – 850 ms time-window. However, this analysis only found a main effect of language group, $F(1,50) = 3.45$ $p = .069$ $\eta^2 = 0.65$, and a main effect of match-mismatch condition that were trending towards significance, $F(1,50) = 3.26$ $p=.077$ $\eta^2 = .061$. There was no interaction between language group and match-mismatch condition, $F(1,50) = .055$ $p = .815$ $\eta^2 =.001$, suggesting that there were no significant differences between the two language groups in this time-window. Additionally, analysis of the peak latency, at 16 electrode sites, revealed no differences between the monolingual and bilingual groups, $F(1,50) = 1.546$ $p=.220$ $\eta^2 = .030$, and there was no significant difference between the peak latency of the match and mismatch conditions in the 650-850 ms time window, $F(1,50) = 2.326$ $p=.134$ $\eta^2 = .044$.

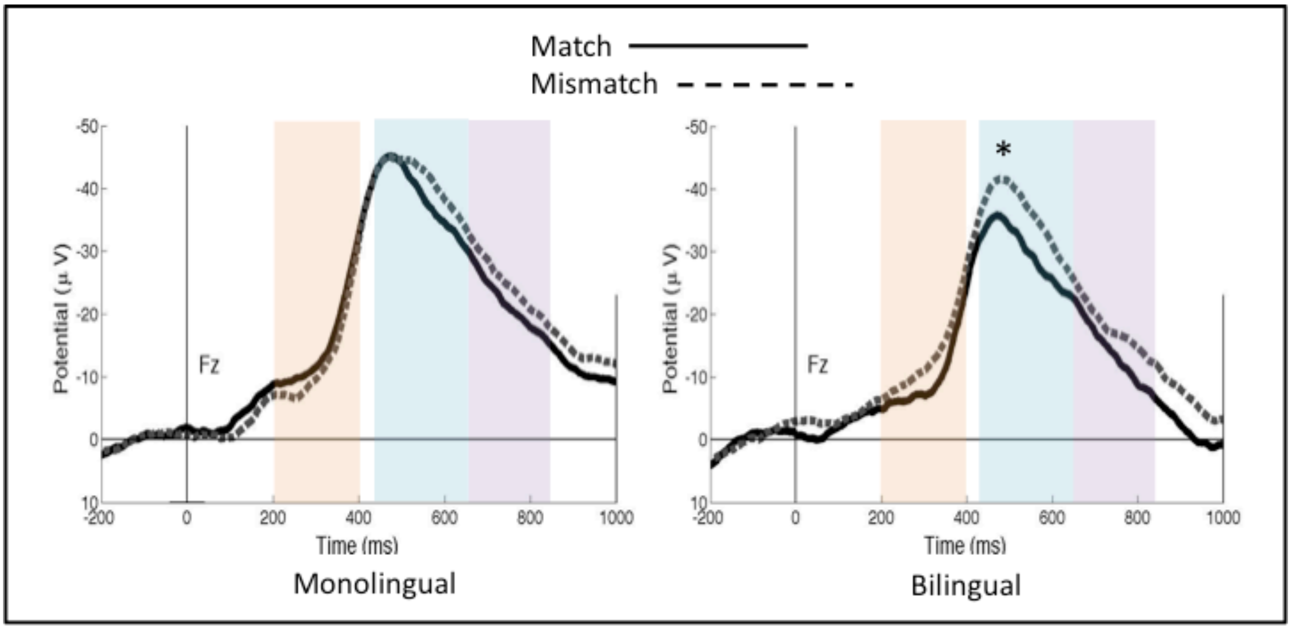


Figure 5. ERPs time-locked to the picture for the monolingual (Left) and bilingual (Right) participants are presented. ERPs are collapsed across age group. Illustrated is the approaching significant main effect of match-mismatch condition in the 450 – 650 ms time-window for the bilingual group, $F(1,25) = 4.063$ $p = .055$ $\eta^2 = .140$.

3.4.2.2 ERPs time-locked to the Word

In this section ERPs time-locked to the word will be discussed. As mentioned in the method section, the initial onset of the word occurs 500 ms prior to the onset of the picture. In the following analysis match-mismatch condition has been removed as a factor, as the initial processing of the word should not be influenced by condition. Here the 200 - 500 ms time-window is discussed and 14 electrode sites were analysed (F7, FC5, AF3, F3, FC1, C3, Fz, Cz, AF4, F4, FC2, C4, F8, FC6). When α ≤ .05 the results will be discussed in terms of a significant effect; when α = .05 - .095 results will be discussed in terms of a trending towards significant effect.

In the previous section it was established that when the two age groups are collapsed, there is an approaching significant interaction between language group and match-mismatch condition in the 200-400 ms time-window, which is not present in the 450 – 650 ms or 650 – 850 ms time-windows. A possible interpretation of these results is that during the early processing of the word and picture, the two groups are performing differently. When analyses of ERPs time locked to the word were conducted, similar patterns of results were found.

In the early time-window (200 - 500 ms), when the match and mismatch conditions were combined, there was a main effect of language group for the 14-to-17-month olds, $F(1,24) = 7.34$ $p = .012$ $\eta^2 = .234$, but not for the 18-to-22-month-month old group, $F(1,24) = 3.20$ $p = .086$ $\eta^2 = .118$. After collapsing the language groups by age, creating one monolingual (N=26) and one bilingual (N=26) group, there is a main effect of language group, $F(1,50) = 9.818$ $p = .003$ $\eta^2 = .164$. The bilingual group (M= -3.27, SE=1.28) elicited a larger NSW than the monolingual group (M=2.41, SE=1.28). This NSW elicited by the bilingual group suggests that in the early stages of processing the bilingual group are better adept at storing words in working memory than their monolingual peers (Figure 5). Analysis of the peak latency revealed no difference between language group, $F(1,50) = 2.656$ p=.109 $\eta^2 = .050$.

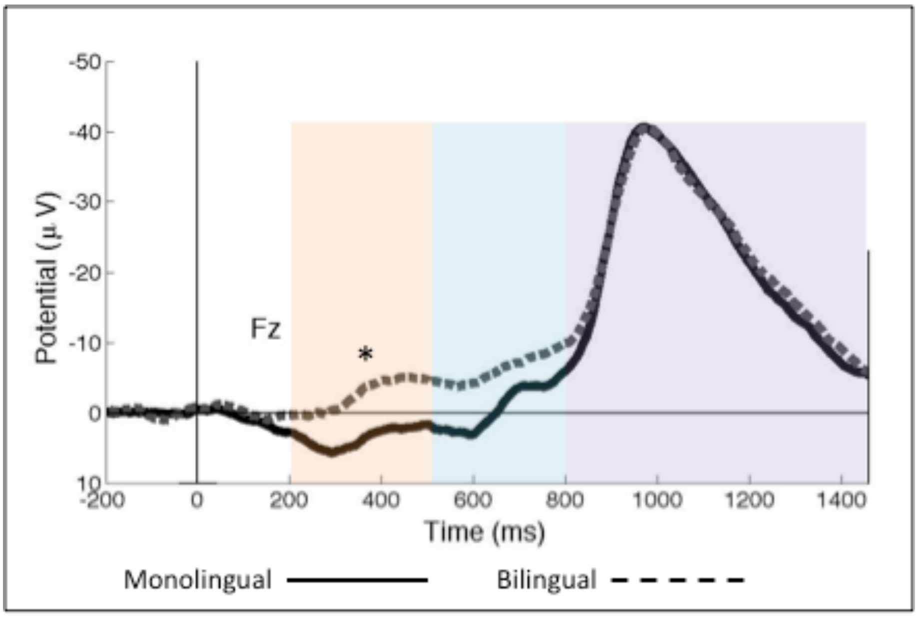


Figure 5. ERPs time-locked to the word at Fz, are presented for the match and mismatch conditions combined. A larger amplitude NSW is elicted in the 200-500 ms time-window for the bilingual group compared to the monolingual group, F(1,50) = 9.82 p = .003 η^2 = .164.

Analysis of the distribution over the frontal/frontal-central and central/central-parietal regions In the 200-500 ms time window, found a main effect of language group, $F(1,50) = 9.818$ $p = .003$ $\eta^2 = .164$, which is illustrated in Figure 6. In this early time-window the monolingual group have a positively deflected distribution (frontal/frontal-central: M=3.609, SE=1.259; central/central-parietal: M=1.209, SE=1.372), where as the bilinguals have a negatively deflected distribution (frontal/frontal-central: M = -2.389, SE = 1.239; central/central-parietal: M=-4.158, SE=1.372). There is no interaction between language group and region, $F(1,50) = .552$ $p = .461$ $\eta^2 = .011$. These distribution effects support the results previously found in this study, where by the monolingual and bilingual groups appear to be processing the word differently between 200 and 500 ms, where by the bilingual infants elicit an NSW that is not elicited by the monolingual infants.

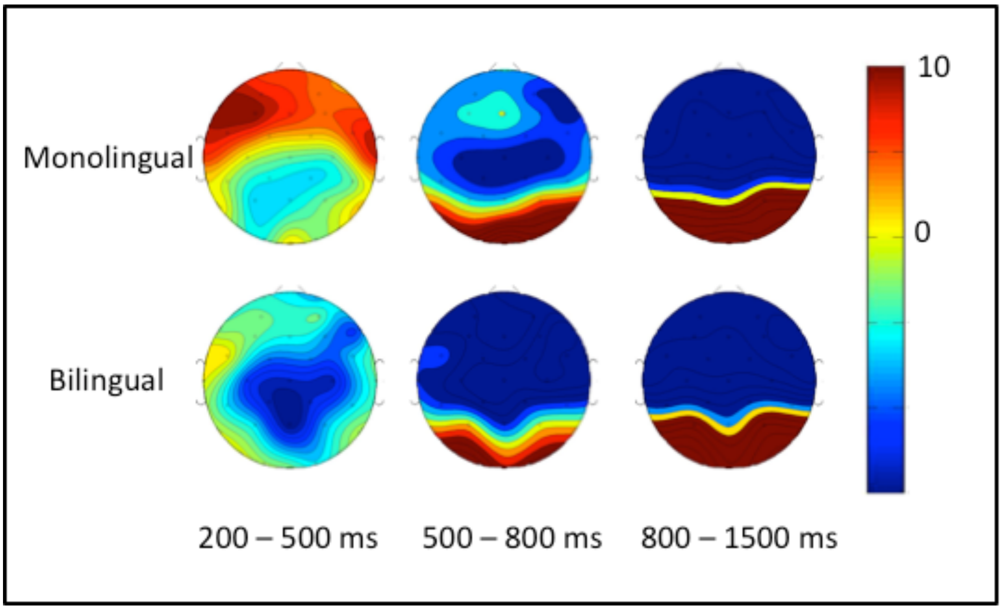


Figure 6. Scalp distribution maps of the ERPs time-locked to the word, over three time windows (200-500 ms, 500-800 ms, 800-1500 ms). Displayed are the words from the match and mismatch conditions combined. The scalp distribution maps for the time window 200-500 ms illustrate the group difference found, $F(1,50) = 9.818$ $p = .003$ $\eta^2 = .164$.

3.4.2.3 Correlations between the ERPs and the CDI

In the following section, analysis of whether the participants' receptive vocabulary (comprehension and production) predicts the ERP effects elicited during the task will be discussed. The vocabulary scores obtained from the parental report on the CDI will be correlated with the ERPs at electrode site Fz to establish whether the effects seen in the 200 – 500 ms (time-locked to the word) and the 450 – 650 ms (time-locked to the picture) time windows are related to any demographic factors or receptive vocabulary in English and Welsh.

For the monolingual group, SES had a high positive correlation with the mismatch condition at Fz in the 450-650 ms time window, $r = .559$ $p = .004$, suggesting that higher SES predicts a larger amplitude waveform in the 450-650 ms time window for the mismatch condition. There were no correlations between exposure to English by the mother and condition at electrode Fz in any of the time windows. Also, there were no correlations between exposure to English by the father and condition at electrode Fz in any of the time windows. Further, comprehension in English had no correlations with condition at electrode site Fz in any of the time windows. Neither comprehension nor production of English correlated with condition in any of the time windows, when the ERPs were time-locked to the picture. Production in English had a medium negative correlation in time window 200-500 ms, when the ERPs at electrode site Fz are time locked to the word, $r = -.461$ $p = .018$. Therefore, production in English affects how the initial phonology of the word is processed, as the higher the production in English the more negative the amplitude of the NSW in response to the word. The more negative the NSW in response to the word, the more adept the child is at holding the phonology of the word in working memory.

For the bilingual group, SES had a high positive correlation with the match condition in the 450-650 ms time window, r = .563 p = .023, as well as a medium positive correlation with the mismatch condition that was trending towards significance, r = .442 p = .086. This suggests that higher SES predicts larger amplitude waveform in the 450-650 ms time window for both the match and mismatch conditions. There was no correlation between the ERPs time locked to the word and SES. Exposure to English by the mother had a medium negative correlation with mismatch in the 450-650 ms time window that was trending towards significance, r = -.386 p = .052. Also, exposure to Welsh by the mother had a medium positive correlation with the mismatch condition in the 450-650 ms time window, r = .461 p = .018. The amount of exposure to English and Welsh by the mother did not correlate with the ERPs in the 200-500 ms time window when the ERPs were time-locked to the word. Both exposure to English and Welsh by the father did not correlate with the ERPs in any of the time windows. Further, receptive vocabulary in English and Welsh did not correlate with the ERPs at electrode site Fz, in any of the time windows, for any of the conditions.

3.5 Discussion

The current study aimed to build upon the results found by Mills and colleagues (2005) in respect of domain-general processes and their effect on semantic priming in bilingual infants. The results of the current study demonstrated no differences between monolingual and bilingual infants in their semantic priming ability, despite the working memory component, as indexed by the N400 elicited. There were early processing differences between the two language groups in the 200-500 ms time window in response to the word. These differences between the monolingual and bilingual infants may reflect differences in their working memory abilities, as shown by the presence of the NSW for the bilingual but not the monolingual infants in response to the word.

The latency differences seen in the 450-650 ms time-window time-locked to the picture, suggest that the bilingual infants had faster memory processing speed. More specifically the bilingual infants had faster retention processing of the word, which elicited a faster response when the picture was presented. This is an interesting finding as it demonstrates that early exposure to a second language can positively affect memory processing at an early age, even when the infant is a relatively early word learner. Further evidence for this being an indication of working memory processing rather than a simple semantic priming effect comes from the non-significant correlations between the CDI data and the ERPs elicited. There were no differences between the two groups when receptive vocabulary was considered. This would suggest that the latency differences elicited are due to working memory retention and subsequent retrieval processes in response to the picture presented 500 ms post word onset.

The results obtained previously (Mills et al., 2005) found that the working memory component only affected semantic priming in 13-month-old infants who had low receptive vocabulary (under 100 words). The 20-and 36-month old infants as well as the 13-month-old infants with high receptive vocabulary (over 100 words) elicited an N400 effect in response to the mismatched trials; by 36-months the N400 elicited reflected the N400 elicited by adult participants. These results suggested that domain-general processes and receptive vocabulary contribute to an infant's response on semantic priming tasks. In the current study, there were no differences between the monolingual and bilingual groups in their receptive vocabulary. Differences were seen in the initial processing of the word 200-500 ms, but following the onset of the picture (500 ms after the onset of the word), the monolingual and bilingual infants ERP waveforms over-lapped indicating no differences in response to the picture.

The initial processing differences in response to the word (200-500 ms) were indexed by a NSW that was present for the bilingual infants but not for the monolingual infants. This NSW could indicate that the bilingual infants were holding the word in mind; therefore demonstrating enhanced working memory abilities. Previous memory research with adults has found a consistent pattern of NSW on tasks that required the participant retain information in working memory in order to complete a task (Klaver et al., 1999; Rosler et al., 1997; Ruchkin et al., 1990; Vogel & Machizawa, 2004). Furthermore, the NSW elicited during these tasks has been predictive of the recall and recognition displayed during the test phase; where by participants who have demonstrated greater recall have elicited larger NSW during the retention period. Indicating that the NSW elicited reflects the processing and retention of the stimulus to be attended (Rosler et al., 1997).

Conversely, it could be argued that the difference in NSW between the bilingual infants and monolingual infants is reflective of increased demands on memory load. Previous studies with both visual-spatial and phonological stimuli have reported larger NSW for stimuli that place greater demands on the working memory system. The NSW increased as a function of increasing demands on memory load (Ruchkin et al., 1992), However, as there was only one type of phonological stimulus presented during the current task, it is probable that the NSW elicited reflects word processing and retention in working memory rather than increased memory load. An ERP study addressing the initial encoding and recognition memory of congruent and incongruent words, revealed that the processes that determine whether a word will be recognized in the near future have taken place within 250 - 450 ms of the word being presented (Neville, Kutas, Chesney & Schmidt, 1986). Therefore, it would appear that the presence of a NSW in the 200-500 ms time-window is reflective of retention processes.

Enhanced memory processes are also suggested in prior research with infants, which has shown bilingual infants as young as 6-months-old are more likely to generalize than monolingual 6-month-old infants (Brito & Barr, 2012; 2014). During a deferred imitation task, infants were shown a puppet (e.g. grey mouse) and the experimenter performed three target actions (pull off mitten, shake mitten to ring the bell, replace mitten) three times in succession. After a 30-minute delay, the infant was shown a novel puppet, which either differed in one (e.g. colour) or two features (e.g. colour and shape) and was encouraged to play with the puppet. The results showed that when the puppet differed on one feature both the monolingual and bilingual infants were able to generalize. Where as when the puppet differed on two features, the bilingual infants were more likely to generalize the actions to the novel puppet (Brito & Barr, 2014). The findings of this study demonstrate that there are early developmental differences in the process of memory generalization between monolingual and bilingual infants. Early exposure to environmental factors, such as an additional language, can shape memory development in early infancy.

The results of the current study along with previous literature would suggest that the bilingual infants demonstrated enhanced retention processes during the initial 500 ms of the word being presented compared to the monolingual infants. However, this enhanced NSW did not result in an enhanced N400 effect. A significant main effect of condition was elicited for the incongruous versus the congruous stimuli when the full sample was considered, however, neither the monolingual nor bilingual group elicited an N400 effect that was significant; although, the N400 effect elicited by the bilingual group was approaching significance (p = .055). These results are in contrast to the results found by Mills and colleagues (2005), who established that a working memory component within a semantic priming task did not affect the processing of the congruous/incongruous stimuli, as demonstrated by the N400 elicited by the monolingual infant sample (excluding 13-month-old low comprehenders).

A criticism of the current study may be directed at the decision to include a 500 ms interval between the onset of the word and the onset of the picture, as a way of testing working memory ability. It may be argued that a 500 ms interval may not be sufficiently long enough to activate working memory processing. Once the word is presented, the infant will activate representations of the word in his or her lexicon, this lexical priming will activate working memory as the infant holds the word in mind while the representation of the word is activated. The 500 ms delay between the onset of the word and the picture is a delay that will require that the word remain in working memory following lexical priming, so that semantic integration can occur once the picture has been presented, therefore resulting in semantic priming. Also, the group differences found in the early time-window indicate that memory processes have been activated. An option for future studies would be include three different delays between the onset of the word and the picture, such as 500 ms, 750 ms, and 1000 ms. By including different inter stimulus interval lengths it would be possible to assess working memory capacity in infancy, and whether a longer delay produces greater differences between monolingual and bilingual groups. Also, in addition to the ERP study it would be beneficial to assess working memory directly by including a behavioral working memory task appropriate for the age range. It would then be possible to correlate the working memory task with the ERP study in order to establish whether the results found are due to working memory ability and capacity.

A possible explanation for the lack of an N400 group by condition interaction for the monolingual and bilingual groups could be due to vocabulary size. Within the sample 29% of the infants comprehended under 100 words in total across both languages. When the monolingual group was considered separately 38% of the sample understood fewer than 100 words, in total across both languages. Also, within the bilingual group 19% of the sample were low comprehenders and understood fewer than 100 words in total. When English comprehension was considered separately, there were also a high proportion of the monolingual (46%) and bilingual (50%) infants who understood fewer than 100 words. The inclusion of these infants may have affected the N400 effect, as the results from Mills and colleagues (2005), demonstrated that the N400 effect was not elicited by those infants who had low comprehension.

In addition to the infant study, a pilot study with adult participants has been conducted. Figure 7 illustrates the ERPs time-locked to the picture, for monolingual (N = 12) and bilingual (N = 8) participants for the match and mismatch conditions. From visual inspection of the ERPs it appears that the adult bilingual participants have elicited larger amplitude N400 ERPs in response to the match and mismatched conditions. Also, visual inspection of the difference wave topographies (match – mismatch), support the ERP data, in that it appears the bilingual group have a more negative broadly distributed effect, where as the monolingual group have a less negative effect over posterior regions. These pilot data demonstrate that a study as simple as a match-mismatch study that incorporates a working memory element is able to elicit potential group differences in working memory and semantic priming between monolingual and bilingual adults.

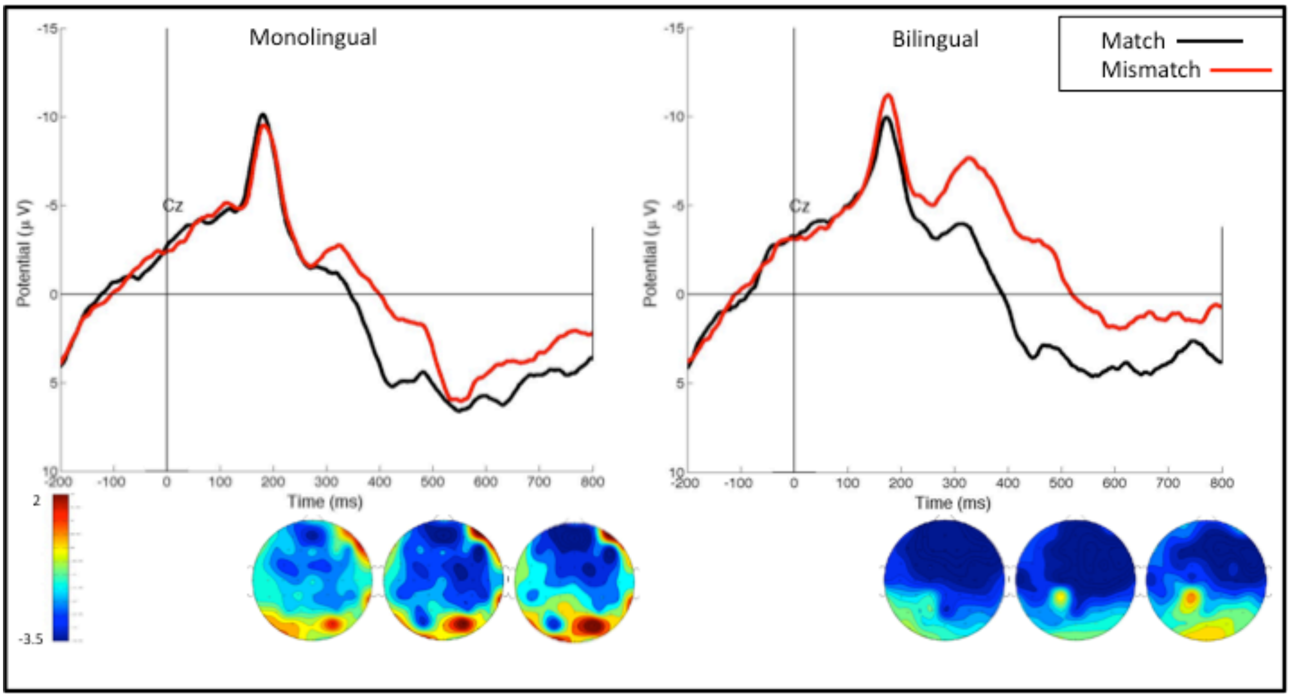


Figure 7. Illustrates the adult ERPs in repose to the match-mismatch paradigm. ERPs are time-locked to the picture. The topographic maps are difference waves (match-mismatch) and the time-windows: 200-400, 450-650, and 650-850 ms are shown. Monolingual data is presented to the left, and bilingual data is presented to the right. These pilot data (*N*=20) show that group differences between monolingual and bilingual data may be elicited in response to semantic priming working memory paradigm.

In addition to prior research in the field of bilingualism and executive functioning, the current study provided data that supports the stance that exposure to a second language affects the development of other cognitive processes, such as working memory. It also highlighted the significance of other factors such as vocabulary size and their affect on domain-general processes. The field of infant bilingualism is an exciting one, and more research needs to be conducted regarding the effect experiences such as language exposure have on the development of other cognitive processes. Further, research with younger infants will provide more information concerning when these cognitive processes, effected by experiences such as language acquisition, begin to emerge. As it would appear that experiences that occur from birth can affect executive functions early in infancy.

4. An advantage in suppression of irrelevant information for late but not early bilinguals in an ERP Go/No-Go task

4.1 Abstract

A recent controversy in the study of cognition is whether bilingualism is advantageous in the development of executive function. The bilingualism advantage hypothesis proposes that cognitive control over two competing languages leads to a bilingual advantage in executive function. An fMRI study suggested that bilingualism affects neural systems involved in suppression of irrelevant information but not response inhibition (Luk et al., 2010). The bilingual advantage hypothesis has been critised (Paap & Greenberg, 2013; Hilchey & Klein, 2011), as the tasks used to analyse the theory have been limited. We tested the hypothesis using a novel event-related potential (ERP) Go/No-Go spatial attention paradigm in monolinguals, early and late bilinguals. ERPs were collected during a Go/No-Go task, where participants (N=57) were required to respond when a brown gopher was detected (go) and withhold responses to other stimuli (no-go). Simultaneously, irrelevant distracter stimuli appeared three, six and nine degrees away from fixation. As predicted by the bilingual advantage hypothesis there were no group differences in ERP latencies or amplitude related to response inhibition (N2 to no-go stimuli) or target detection (P3 to target), The irrelevant stimuli elicited a positivity at 100 ms (P1) that decreased in amplitude with distance from fixation. Further, there was a group difference in attenuation of ERPs to the irrelevant stimuli. The late bilinguals showed a smaller P1 to the irrelevant stimuli than did the monolinguals or early bilinguals, suggesting suppression of attention to the irrelevant stimuli. The results support the bilingualism advantage hypothesis with respect to suppression and inhibition. However, more effortful cognitive control rather than automatic processing may be necessary to maintain the cognitive advantage.

4.2 Introduction

A recent controversy in the study of cognition is whether bilingualism is advantageous in the development of executive functions. There is research that has concluded that bilingualism does indeed aid the execution of executive functions (Bialystok, 2011). Conversely, there are also studies that have questioned the bilingualism advantage (Paap & Greenberg, 2013). The aim of the present study is to address this debated topic and establish whether there is indeed a bilingual advantage in the implementation of executive functions.

The study of bilingualisms' effect on executive functions developed from the idea that both languages known by a bilingual are active in all linguistic contexts (Jared & Kroll, 2001; Marian & Spivey, 2003; Martin, Dering, Thomas, & Thierry, 2009). This dual activation requires constant monitoring and control, which is driven by the executive control system. The executive control system inhibits attention of competing languages, as well as switching from one language to another, therefore allowing the target language to be performed successfully (Green, 1998). This inhibition of and switching between multiple languages is argued to have implications for other cognitive domains (Bialystok & Craik, 2010). Primarily executive functions such as attention, inhibition, suppression and working memory are affected positively by bilingualism (Bialystok, 2011).

Studies that have reported a bilingual advantage in the execution of executive function have used tasks such as the Dimensional Change Card Sort (DCCS) Task (Bialystok & Martin, 2004), the Simon Task (Bialystok et al., 2005), the Flanker task (Eriksen & Eriksen, 1974) embedded in the Attentional Network Test (Carlson & Meltzoff, 2008; Costa et al., 2009; Costa, Hernández, & Sebastian-Gallés, 2008) and the Spatial Stroop Task (Bialystok et al., 2006). To successfully complete these tasks the participant must be able to inhibit their response and suppress their attention to irrelevant information. Typically on theses tasks bilingual individuals out perform their monolingual peers, demonstrating that there may be non-linguistic benefits associated with speaking multiple languages (Bialystok, 2011). These cognitive benefits are seen across the lifespan, with differences found both in children as well as older adults (Bialystok, Craik, Klein and Viswanathan, 2004).

However, a number of researchers have doubted the cognitive benefits of bilingualism (Paap & Greenberg, 2013; Hilchey & Klein, 2011). A review by Hilchey & Klein (2011) surmised that the bilingual advantage is infrequent and in some cases absent.

A criticism of previous bilingual research is directed at the type of tasks typically employed. A high proportion of bilingualism research only utilizes one task (e.g. Simon/Flanker/Stroop) therefore providing one measure, which means there is little convergent validity. It is argued that this is not an adequate method, as it has been shown that the Simon Task, the Flanker Task and the Stroop do not correlate with one another. The lack of a correlation between these tasks paired with the inconsistency of their results places doubt on their use when assessing executive functions (Paap & Greenberg, 2013). Further, it has been argued that tasks such as the DCCS and Stroop retain linguistic properties that may engage language-specific inhibitory mechanisms leading to improved accuracy in bilinguals (Hilchey & Klein, 2011).

Another criticism is that there is a lack of consistency across studies with regards to the methodology and design of the tasks used (Hilchey and Klein, 2011). In a review of 13 studies Hilchey and Klein (2011) demonstrated that there are discrepancies across studies with regards to the methodology used. It is noted that although the studies may have used the Simon and Flanker tasks, few are identical in design. The discrepancies include differing numbers of trials, differing numbers of participants, differences in participant demographics, differences in experimental design including task difficulty. These differences may account for significant disparities among the data that has previously been reported.

The present study will address the question of bilingualism and executive function with the use of Event Related Potentials (ERPs) and a non-linguistic go/no-go task. ERPs provide a researcher with a multidimensional measure of cognitive processing, which allows for the subcomponents of cognition to be separated and observed. A typical reaction time experiment can be extremely useful in providing a researcher with response times to a given stimulus. This method however, does not allow the researcher the ability to observe the cognitive processes that are occurring between the onset of the stimulus and a participants' response. ERPs allow for the collection of physiological data as well as behavioral data, which benefits from high temporal resolution and is a covert and continuous measure of cognitive processing. An EEG is when the signal from an electrode placed on the scalp is amplified, and the voltage over time is plotted. This allows any changes in voltage to be analyzed. Within the EEG data there are neural responses associated with sensory, cognitive and motor events. An event related potential (ERP) is when these responses are extracted from the EEG by averaging the data (Luck, 2005). When averaging the data, it is possible to time lock to specific stimulus events, which in turn allows the analysis of the voltage change created by that given stimulus event. This creates waveforms with positive and negative going peaks known as components. By measuring these components, it is possible to analyze amplitude and latency effects related to these specific sensory, cognitive and motor events (Luck, 2005).

The design of the current study includes distracter stimuli that are irrelevant to the task. The purpose of these irrelevant trials is to establish whether there are differences between monolinguals and bilinguals in their ability to suppress attention. Suppression refers to the conscious act of controlling impulses such as thoughts and irrelevant information. In relation to the current task, suppression tasks place when the participant are controlling their attention to distracting stimuli that are not relevant to the task. Suppression is a conscious and active process. Bilingualism research has demonstrated that when a task requires the suppression of irrelevant stimuli, bilingual individuals are more effective at suppressing their attention to that stimulus (Bialystok, Craik & Ryan, 2006). For example, the Flanker Task typically contains irrelevant distracters whose aim is to divert the participant's attention away from fixating on the correct stimulus for response. In this situation bilingual individuals responded quicker than their monolingual peers, which the researchers concluded was due to better monitoring processes, the bilinguals were better able to monitor which stimuli to respond to (Costa et al., 2009; Costa, Hernández, & Sebastian-Gallés, 2008).

The distracter stimuli in the current study are predicted to elicit an early positive component that is produced in parietal regions around 100ms, named the P100 (P1). The P1 is indicative of early detection of sensory information e.g. visual information about a stimulus (Luck, 2005). The P1 has been elicited in studies investigating visual attention (Eimer, 1999; Eimer, 2000). These studies have found that when a participant is attending to a stimulus the amplitude of the P1 is larger than when they are not attending to the stimulus. When an individual is presented with a complex visual array their attention mechanism needs to allocate attention to the correct stimulus regardless of any competing stimuli that might appear simultaneously with the target. In this situation the attention mechanism must engage with suppression processes in order to suppress attention to the irrelevant non-target stimuli. In these scenarios it has been found that there is greater activation indicating that suppression is induced by the competing stimuli (Ungerleider, 2000; Pessoa, Kastner, Underleider, 2003). In the context of the present study, participants will have to suppress attention to irrelevant distracter stimuli presented in their peripheral vision. Successful suppression of these distracter stimuli should result in smaller amplitude P1, as the participants should not be attending to these stimuli.

In the present study a go/no-go ERP paradigm was used. To successfully complete a go/no-go task the participant needs to withhold responses to non-target stimuli, which requires inhibitory control (Reiss et al, 2001). Inhibition is the process of restraining from actions; these actions can be both physical and cognitive. Successful completion of Go/No-Go tasks require the participant engage with response inhibition, which is a form of inhibitory control whereby the participant must actively restrain from responding to a No-Go stimulus. Go/No-Go ERP studies typically elicit a negative potential at a latency of 200-300 ms (N2), which predominantly has a distribution over frontal areas (Jodo & Kayama, 1992; Simson et al, 1977; Pfefferbaum et al, 1985; Gemba & Sasaki, 1989). The amplitude of the N2 component varies depending on the neuronal activity required for response inhibition (Jodo & Kayama, 1992). Typically there is a greater increase in the amplitude of the N2 to no-go stimuli than go stimuli (Simonson et al, 1977; Pfefferbaum et al, 1985; Gemba & Sasaki, 1989) particularly when faster responses to go stimuli are required (Jodo & Kayama, 1992). There are several studies that support the theory that the N2 elicited in visual no-go tasks reflects a frontal inhibitory mechanism (Ritter et al, 1982; Kok, 1986; Jodo & Kayama, 1992; Kopp et al., 1996; Falkenstein et al., 1999; Geczy et al., 1999). The anterior N2 produced during a go/no-go task is associated with response selection processes and cognitive control (Kok, 1986; Van Boxtel et al., 2001; Nieuwenhuis et al, 2003; Donkers & Van Boxtel, 2004; Falkenstein, 2006; Gajewski et al, 2008; Folstein & Van Petten, 2008). In a situation where a go response must be withheld, the mental load for withholding that response is high; this task demand increases the amplitude of the N2 (Simson et al, 1977; Pfefferbaum et al, 1985; Gemba & Sasaki, 1989). This increase in amplitude occurs because the activity of the brain required for response inhibition is also high. Therefore, the N2 component reflects the activity of a response inhibition system of the brain (Jodo & Kayama, 1992). In a recent ERP study comparing bilinguals, musicians and controls on a go/no-go task, it was found that the bilingual group elicited a larger N2 effect than the other two groups. The authors propose this indicates that bilinguals are more sensitive in detecting existing response competition or that they are better at allocating resources to resolve conflict than controls (Moreno et al., 2014).

A second component elicited during a go/no-go task is the P300 (Bokura et al., 2001). The P300 is a positive going component that is typically elicited around 300-600ms and has a distribution over central and parietal areas (Polich, 2007). The P300 waveform is created when cognitive mechanisms, such as attention, are enhanced by stimulus detection and task demands relative to the contents of working memory (Polich, 2007; Knight, 1997; Soltani & Knight, 2000). During a go/no-go task the P300 is elicited when the participants detection of a stimulus engages memory operations. Attention processes update the present stimuli representations in working memory, as comparisons between the incoming stimuli and previous stimuli stored in working memory are made (Donchin, 1981). If there is no change in stimulus attributes then the current mental representation is maintained, but if a new stimulus is detected then attention processes update the stimulus representations in working memory (Polich, 2007; Kok, 2001). The recent study by Moreno et al (2014) found that the P3 elicited during a go/no-go task was comparable between the bilingual and control groups. A protracted late positivity for the bilingual group was also observed, which they interpret as an indication that bilinguals have a more robust supervisory mechanism that ensures the desired response outcome was achieved (Moreno et al., 2014).

The P300 has two subcomponents, the P3(a) and the P3(b). The P3(a) is elicited when a stimulus is detected, which engages attention mechanisms, where as the P3(b) is elicited when these attention mechanisms facilitate memory processes (Polich, 2007). In effect focal attention (P3a) facilitates the memory processing associated with context maintenance (P3b) (Hartikain & Knight, 2003; Kok, 2001; Polich, 2003). In the context of the present study, when the participant sees a stimulus their early attention processes will engage with their working memory to establish whether the stimulus is a target. If the stimulus is not a target, the working memory representations will be updated so that the attention mechanisms know to withhold a response to the non-target stimulus that has been presented. Therefore, producing both the P3a (attention processes) and P3b (memory updating) components. The P3a component is considered to be an inhibitory mechanism in the context of a go/no-go paradigm as it has larger amplitude during no-go than go conditions (Eimer, 1993; Kopp et al, 1996).

Both the N2 and P3 components elicited during go/no-go tasks are linked to different levels of inhibitory control (Bokura et al., 2001). Therefore a go/no-go paradigm used in conjunction with ERPs will help untangle the controversies surrounding bilingualism and executive control. To perform the task successfully participants will need to monitor the task and update the memory processes (P3b), they will need to engage in response inhibition (N2) as well as engaging in early attention processes (P3a), which will lead to successful inhibition of irrelevant task stimuli.

The current task will require efficient control of attention regulation systems, namely response inhibition and suppression of irrelevant information. Regulation of the attention network requires cognitive control of response inhibition, which is engaged when an inappropriate response to a task must be either overridden or inhibited. Suppression of irrelevant information is engaged by cognitive control when attention needs to be focused on relevant cues required by the task, and distracting stimuli and/or irrelevant cues must be ignored.

The majority of previous bilingualism research has used bilinguals who have been exposed to both languages simultaneously in early childhood. The results of these studies have established that early and highly proficient bilingualism impacts the functioning and neural basis of general executive functions (Bialystok & Martin, 2004; Costa et al, 2009; Abutalebi et al, 2012). Typically, early bilinguals control both their L1 and L2 from birth, and use both on a daily basis. This leads to early highly proficient bilinguals benefiting from the language control mechanism they have developed from birth (Martin et al, 2013). Conclusions drawn from bilingualism research generally lead to the idea that more experience in bilingualism is correlated with greater advantages in general cognitive control (Abutalebi, 2008; Abutalebi et al, 2012). Conversely, there is research that has suggested that late bilinguals may train their executive control to a greater degree than early bilinguals. The late bilinguals need to engage their executive control network to control interference from their other language as well as using it to support their less automatic L2. Therefore, they may display a larger cognitive benefit as a result (Hernandez et al., 2005; Abutalebi & Green, 2007; Wodniecka et al., 2011). In the present study the bilingual group will be split, so that early bilingual versus late bilingual comparisons can be made, as it is important to establish which aspects of bilingual experience are crucial for the emergence of advantages in executive functioning.

The present study will differentially examine response inhibition and suppression of irrelevant information in relation to the bilingualism advantage hypothesis. Previous literature proposes that in relation to response inhibition the performance of monolingual and bilingual participants does not differ (Bialystok et al., 2010; Costa el al., 2008). However when a task involves suppression of irrelevant information or interference, bilingual participants typically outperform their monolingual peers i.e. faster reaction times on incongruent trials (Costa et al., 2008). Taking into account these previous studies it is hypothesised that the monolingual and bilingual participants will respond appropriately to the go stimuli and will inhibit their responses to the no-go stimuli. Therefore, it is predicted that there will not be differences in the reaction times or accuracy of the responses to the go/no-go trials. Further, it is predicted that there will be no difference between groups in the amplitude or latency of the N2/P3 components elicited by the go/no-go task.

On the other hand, when participants are required to suppress their attention to irrelevant stimuli, it is hypothesised that there will be differences between the monolingual and bilingual groups. These differences will be seen in the participants' covert responses to distracting stimuli, which will elicit the P1 component. It is predicted that the amplitude of the P1 component, elicited by the irrelevant stimuli, will be larger in the monolinguals than the bilingual groups. The literature on bilingualism has produced varying results in regard to the differences between early and late acquisition of a second language and cognitive control. In respect to the current study it is hypothesised that the early bilingual group will demonstrate greater control of their attention network, than the late bilingual group. Therefore, it is predicted that the early bilingual group will be able to suppress their attention to the distracting stimuli more successfully than the late bilingual group, resulting in a smaller amplitude P1 for the early than the late bilingual group.

4.3 Method

4.3.1 Participants

Fifty-seven university students were recruited from the psychology department at Bangor University, Wales, and took part in exchange for course credit. All participants were right handed (assessed using a modified version of the Waterloo Handedness Questionnaire (Steenhuis & Bryden (1989)). Participants reported that they were free from any auditory or visual impairment, and had no known history of any neurological conditions (Thomas & Gathercole, 2007). Participants provided voluntary informed consent prior to the start of the study. Ethical approval was granted from the ethics committee prior to the start of the research.

Participants were categorised as either monolingual, early bilingual or late bilingual based on their responses to a detailed Language Background Questionnaire (Thomas & Gathercole, 2007). Monolinguals stated that English was their only language, and that they did not speak any other language fluently. To differentiate between early and late bilinguals, participants were asked to report at what age they began using their languages. Early bilinguals were classified as individuals who began using both their languages by the age of 5 (M = 3.40, SD = 1.05), and late bilinguals those who began using both their languages after the age of 5 (M = 8.56, SD = 3.60). The age of 5 was chosen as an appropriate age to differentiate between the two bilingual groups, as this is the age at which children typically begin full time education, and therefore children's linguistic input and exposure changes (Gathercole, 2007).

An additional participant was run but was excluded due to a technical error during EEG recording. Participants were aged between 18 and 35 years (M = 21.8, SD = 4.16). There were 18 monolinguals (10 males; M = 20.84, SD = 2.93), 19 early bilinguals (7 males; M = 21.45, SD = 3.69), and 18 late bilinguals (3 males; M = 23.22, SD = 5.41). The three language groups did not differ in age, $F(2,56)= 2.739$ $p= .074$, or gender $F(2,56) = 1.669$ $p = .198$.

All participants were fluent in English. The early and late bilinguals spoke a variety of languages: Welsh (early: 11 participants, late: 7 participants), Hindi (early: 3, late: 1), French (late: 3), German (late: 2), Gujarati (early: 1), Greek (early: 1, late: 1), Portuguese (late: 1), Chinese (early: 1), Bulgarian (early: 1), Russian (late: 1), Cantonese (early: 1), Mandarin (early: 1) and Romanian (late: 2). A proportion of the early (40%) and late (61%) bilinguals were born outside the UK. All monolinguals were born in the UK with the exception of one participant who was born outside the UK in another English-speaking country.

Both the monolinguals and the bilinguals were asked to indicate the percentage of time that they spend using each of their languages (Table 1). As expected the monolinguals stated that they used English 100% of the time in the community and home contexts. Both in the context of the family home, $t(36) = .727$, $p = .472$ and the community, $t(36) = .740$, $p = .464$, the two bilingual groups did not differ in the amount of English they speak. Further, there was no difference between the amount of L1 and L2 usage in either the early, $t(19) = .694$, $p = .496$, or late, $t(17) = .421$, $p = .679$ bilingual groups, indicating that both groups consisted of balanced bilinguals.

Table 1. Displays the means (Std. Dev) percentage of English usage reported

	Home Mean (SD)	Community Mean (SD)	L1 Usage Mean (SD)	L2 Usage Mean (SD)
Monolingual	100 (0)	100 (0)	100 (0)	
Early Bilingual	45.00 (34.98)	67.5 (25.78)	60.0 (32.85)	51.25 (29.77)
Late Bilingual	36.11 (40.42)	61.11 (27.42)	59.72 (32.24)	54.17 (27.45)

In addition both monolingual and bilingual participants were asked to report their language proficiency in English on a Likert scale ranging from 1 to 20 (20 being highly proficient). All three groups rated themselves as highly proficient in English: monolingual ($M = 20.00$, $SD = .000$), early bilingual ($M=19.30$, $SD = 1.129$) and late bilingual ($M=18.67$, $SD = 2.029$). However, there was a significant difference between the three groups English proficiency ratings, $F(2,54) = 4.720$, $p = .013$. Post Hoc analysis showed that the group difference lies between the monolingual and late bilingual groups ($p = .009$) but there was no significant difference between the two bilingual groups' ratings ($p = .310$) or the monolingual and early bilingual groups (p = .232).

Participants were asked to complete a modified version of The Barratt Simplified Measure of Social Status (Barratt, 2006) to assess whether any group effects that may be seen could be attributed to Socio-economic status (SES) differences. Only a sub-sample of 40 participants completed this measure. The three groups (monolinguals: $M =34.88$, $SD = 15.019$; early bilinguals: $M = 43.97$, $SD = 13.584$; late bilinguals $M = 44.00$, $SD = 15.513$) did not differ in SES, $F(2,37) = 1.644$, $p = .207$, indicating that if any group differences were to be seen it is unlikely that they could be attributed to differences in SES.

4.3.2 Stimuli

Participants viewed a green background depicting a field, the target and non-target stimuli appeared from a black hole in the centre of the screen that also acted as the fixation point (See Figure 1). The stimuli consisted of targets (brown gophers), non-targets (coloured gophers and cartoon characters), and distracters (cartoon bees) that were irrelevant to the task. The target stimuli (Go trials) were “Brown Gophers” presented on 36 trials per block (180 total trials). The non-target stimuli (No Go Trials) were different coloured Gophers (Green, Blue, Purple and Red) and cartoon characters which totaled 36 trials per block (18 coloured Gophers; 18 cartoon characters).

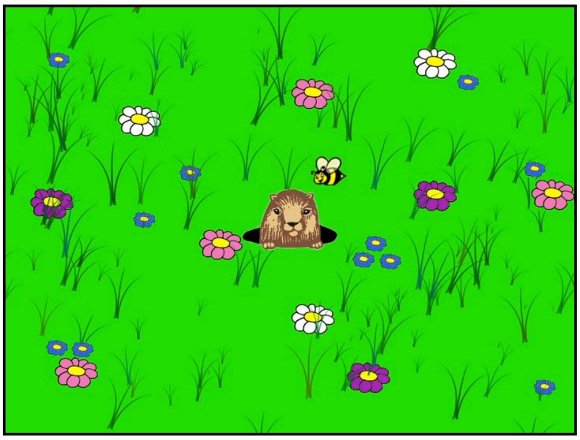


Figure 1. Example of a Go trial (brown gopher) with a distracter (bee) 3° from fixation.

Distracting stimuli in the form of cartoon bees appeared randomly for 100ms (ISI 400-600ms) at one of six locations (-9°, -6°, -3°, 3°, 6°, 9°) along the horizontal axis above the centre. There were a total of 50 bees per location per block (30 bee only trials; 20 bees during Go/No-Go trials) with a total of 250 bee trials per location during the experiment.

Participants received feedback from the task, when a correct response was made a “POW” graphic and sound was presented, following an incorrect response a “bzzt” sound was presented, and if the participant failed to respond to the target a “laughing” sound was presented.

4.3.3 Procedure

Participants sat in a sound attenuated room, 120cm away from the TV screen. Participants were instructed to respond using the response box whenever the target stimuli appeared on the screen (“Brown Gopher”) and to refrain from responding to non-target stimuli. Participants were not instructed or notified about the distracter stimuli (bees).

4.3.4 EEG Recording

The EEG was recorded continuously (BioSemi Version 6.05, 2007) from 64 pin-type Ag-AgCl active electrodes positioned according to the standard 10/20 layout affixed to a head-cap (BioSemi head-cap). Additional electrodes were placed over the left and right mastoid sites, as well as under the left eye and the right outer canthus. EEG recordings were amplified by a factor of 20,000, with a sampling rate of 2048 Hz. The EEG data were down sampled offline to a sampling rate of 512 Hz. The EEG was recorded reference free and without filters during data acquisition. All offsets (conceptually related to impedance) were kept below 25μv.

4.3.5 ERP Data Analysis

Data analysis was conducted offline using the ERPLAB Toolbox (for more details see http://erpinfo.org/erplab), which is integrated with the EEGLAB Toolbox (Delorme & Makeig, 2004). The EEGLAB toolbox was operated using MATLAB (version 7.9.0 R2009b). A 200 ms pre-stimulus baseline correction was applied to all EEG data and was filtered offline with a bandpass of 0.01 Hz to 30 Hz. EEG was referenced offline to the average of the left and right mastoids. Data were segmented into epochs of 200 ms before to 1500 ms after the onset of the stimuli (Go / No-Go trials and irrelevant distractors). Artifact rejection thresholds to detect blinks, horizontal eye movement, drift, and muscle artifact, were determined for each participant separately through visual inspection of the raw EEG (as recommended by Luck, 2005). Any epochs or channels containing eye or movement artifact were excluded from the analyses. On average 31.55% of the trials had to be removed from the EEG data due to a combination of blinks and drift (monolingual: 32.36%, early bilingual: 28.29%, late bilingual: 34.04%). A one-way Analysis of Variance (ANOVA) indicated that there were no differences between the three groups on the number of trials rejected, $F(2,54) = .847$, $p > .05$. Individual ERP's were created for each participant by averaging across trials for each electrode and condition. Group averages were obtained by averaging across participants within each group.

The electrode sites analysed were chosen following visual inspection of topographic maps and after taking into consideration previous research, these are highlighted in Figure 2. All time windows were selected following a 10 ms window analysis to determine the onset and offset of each component. For the N200 a time window of 250 – 400 ms was selected and electrode sites AF3, AFz, AF4, F5, F3, F1, Fz, F2, F4, and F6 were analysed. A time window of 450 – 550 ms was selected for analysis of the P300 (a) at

AF7, AF3, AFz, AF4, AF8, F3, F1, Fz, F2, and F4 electrode sites. For the P300(b) a time window of 300 – 550 ms was chosen and electrode sites CP3, CP1, CPz, CP2, CP4, P5, P3, P1, Pz, P2, P4, P6, PO3, POz and PO4 were analysed. Finally, for the P100 component a time window of 110 – 160 ms was selected and electrode sites P5, P3, P1, Pz, P2, P4, P6, PO3, POz, and PO4 were analysed. The N2 and the P3 components measured were time-locked to the Go / No-Go task, where as the P1 component measured was time-locked to the distracter stimuli (bees).

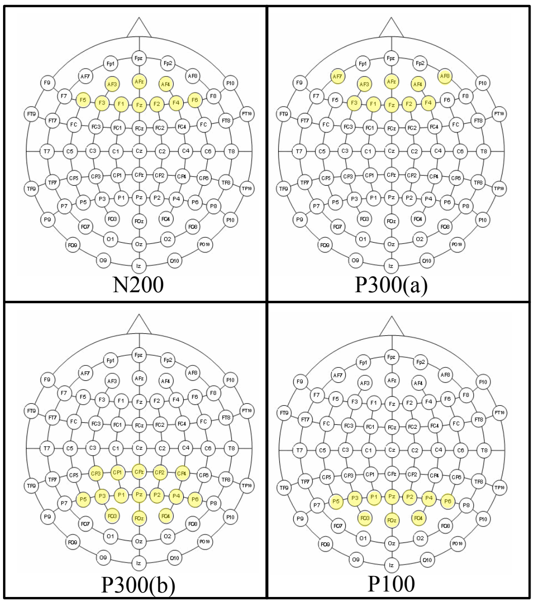


Figure 2. Head maps displaying electrode sites chosen for analysis for the N2, P3a, P3b and the P1.

4.4 Results

4.4.1 Behavioral Data

Behavioral measures were calculated as a combined average score of all 5 blocks. Group scores for mean reaction time on go stimuli (RTGo), mean reaction time in response to false alarm stimuli (RTFA), mean scores for correct hits on go stimuli, and mean scores for false alarm hits on no-go stimuli are displayed in Table 2. A d prime (d') score for accuracy (Z(hits)-Z(misses)) for all three groups was calculated, and there was no significant difference between groups, $F(2,54) = .718$, $p = .492$.

Table 2. Comparison of Behavioral Performance on Go/No-Go task (Mean and Std. Dev).

	RTGo Mean (SD)	RTFA Mean (SD)	Correct Hits % Mean (SD)	False Alarm % Mean (SD)
Monolingual	438.68 (42.62)	438.47 (97.28)	96.5 (3.6)	1.5 (1.4)
Early Bilingual	437.08 (30.53)	461.30 (193.45)	94.5 (4.5)	1.6 (1.1)
Late Bilingual	436.48 (42.18)	448.93 (137.06)	96.8 (3.02)	3.04 (4.4)

Differences in reaction time and accuracy across groups and conditions were assessed using a one-way ANOVA for group x condition (go vs no-go). There were no differences between the three groups on how they performed behaviorally on the Go / No-Go task. With reaction time on both go stimuli, $F(2,54) = .016$, $p = .984$, and false alarm stimuli, $F(2,45) = .095$, $p = .909$, producing non-significant differences between the three language groups. This was also true for accuracy on go stimuli, $F(2,54) = 2.024$ $p = .142$, and the number of false alarms produced by the three groups, $F(2,54) = 1.802$ $p = .175$.

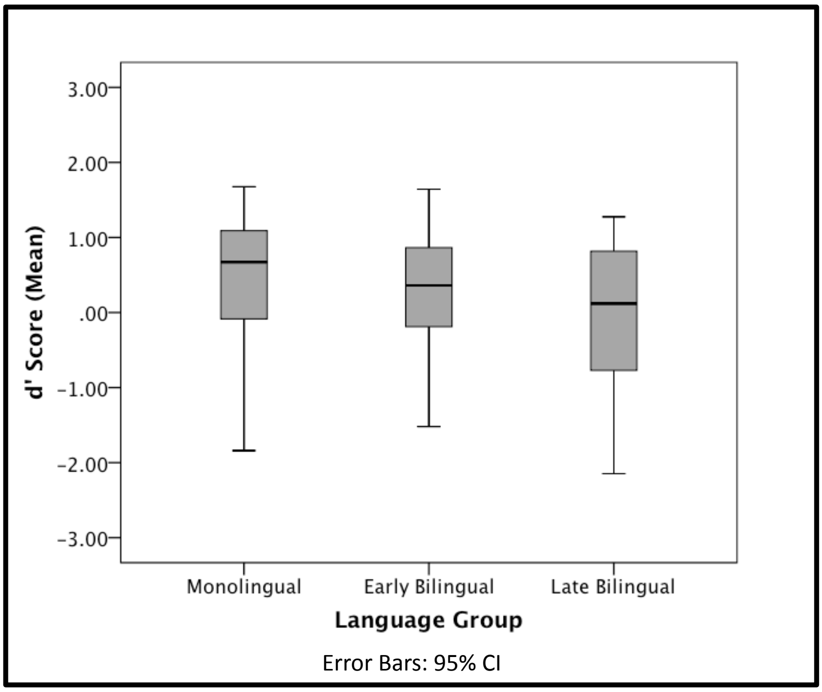


Figure 3. Calculated mean d prime (d') accuracy (Z(hits)-Z(misses)) score for all three groups. When d' scores were considered there was no significant difference between groups, F(2,54) = .718, p = .492.

4.4.2 ERP Results

Each cognitive process and their associated component (P1, N2, P3(a), and P3(b)) are reported separately, and interactions with group are analysed using repeated measures ANOVAs (group x condition x electrode site). For all statistical analyses, when the assumption of sphericity is violated, the Greenhouse-Geisser correction is reported (Greenhouse & Geisser, 1959). When $\alpha \leq .05$ the results will be discussed in terms of a significant effect; when $\alpha = .05 - .095$ results will be discussed in terms of a trending towards significant effect.

4.4.2.1 Suppression (P1)

The distracters at three degrees [*M* = 1.34, *SE* = .176] away from fixation produced a larger amplitude P1 than both the distracters at six degrees [*M* = .466, *SE* = .168] and nine degrees [*M* = -.073, *SE* = .170] away from fixation, resulting in a main effect of degree, $F(2,54) = 40.543$ $p = .000$ $\eta^2 = .429$. In contrast to the predictions there was no interaction between language group and degree, $F(4,54) = 1.38$ $p = .246$ $\eta^2 = .049$, however there was a main effect of language group, $F(2,54) = 4.06$ $p = .023$ $\eta^2 = .131$. The difference in P1 amplitude observed between the three language groups, is driven by the late bilingual group, who elicited smaller amplitude P1 than the other two groups. A repeated measures ANOVA between the monolingual and early bilingual groups did not produce a main effect of language group, $F(1,37) = .635$ $p = .431$ $\eta^2 = .017$. However, analysis between the monolingual and the late bilingual groups did reveal a main effect of language group, $F(1,33) = 4.38$ $p = .044$ $\eta^2 = .111$, as did analysis between the early and late bilingual groups, $F(1,36) = 7.104$ $p = .011$ $\eta^2 = .165$. Differences in mean amplitudes between groups for each condition are illustrated in Figure 4.

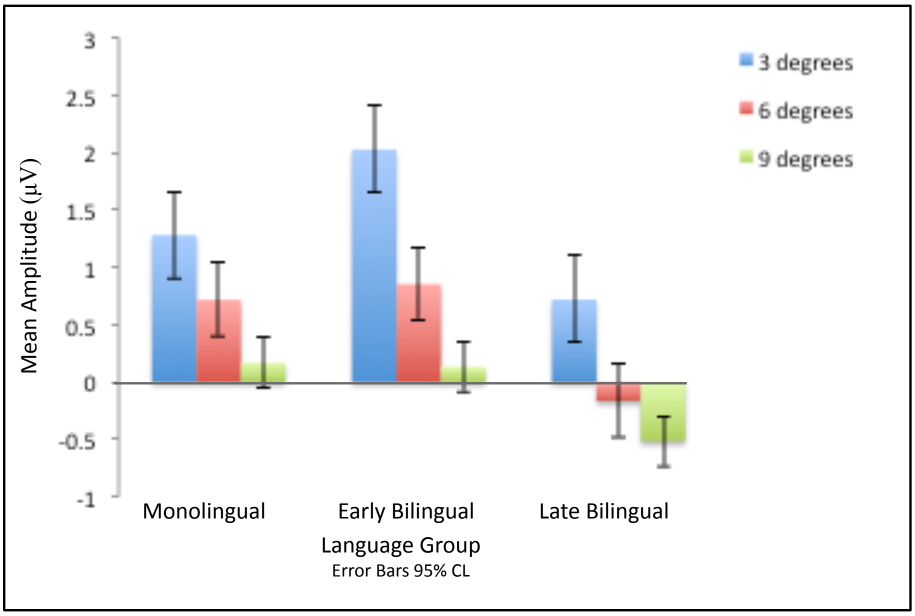


Figure 4. Bar chart showing the differences in mean amplitude across the three conditions between the three language groups.

The distracters nine degrees away from fixation elicited no significant difference in P1 amplitude between language groups, $F(2,54) = 1.656$ $p = .201$ $\eta^2 = .058$. However, the distracters at six degrees, $F(2,54) = 3.499$ $p = .037$ $\eta^2 = .115$, and three degrees, $F(2,54) = 4.657$ $p = .014$ $\eta^2 = .147$, away from fixation did elicit a significant difference in P1 amplitude between language groups. At six degrees away from fixation there was a significant difference in P1 amplitude between the monolingual and late bilingual groups, $F(1,35) = 4.966$ $p = .032$ $\eta^2 = .124$, as well as between the early and late bilingual groups, $F(1,36) = 5.703$ $p = .022$ $\eta^2 = .137$. The P1 amplitude at three degrees away from fixation elicited a difference between the early and late bilingual groups, $F(1,36) = 9.406$ $p = .004$ $\eta^2 = .207$. ERPs illustrating the difference between language groups for each condition are shown in Figure 5.

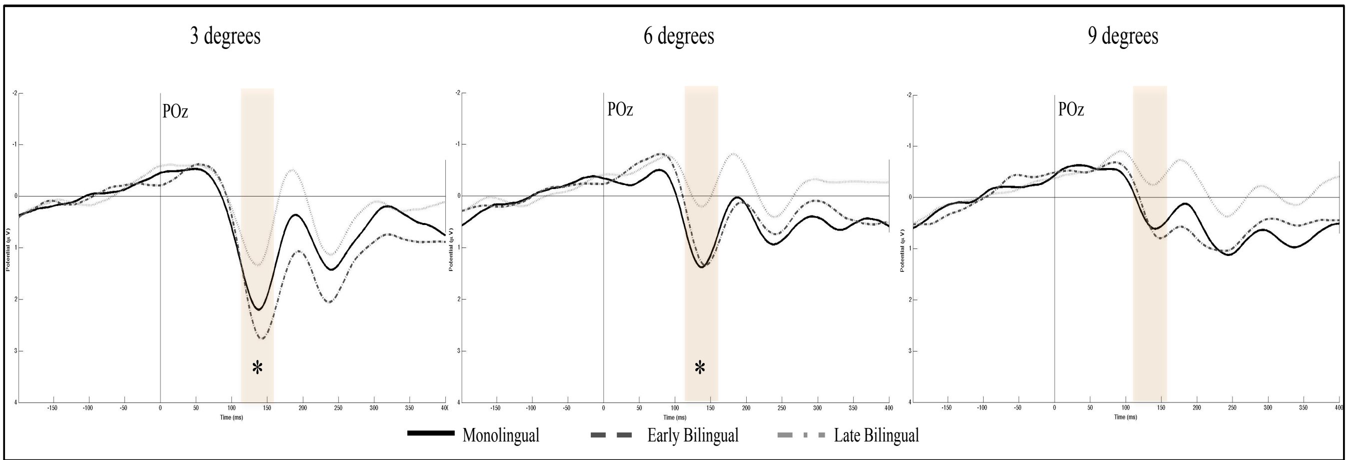


Figure 5. ERP waves for the P100 at electrode site POz for each condition (3,6 and nine degrees), showing the differences between the three language groups. Highlighted is the time window 110 – 160 ms.

Distribution of the P1 component at nine degrees, $F(2,54) = 1.513$ p = .229 $\eta^2 = .053$, away from fixation was similar for all three language groups. However, there was a difference in distribution between the three language groups when the distracters were three degrees, $F(2,54) = 4.441$ $p = .016$ $\eta^2 = .141$, and six degrees, $F(2,54) = 3.311$ p = .044 $\eta^2 = .109$, away from fixation (Figure 6). The distribution between language groups differed across hemispheres. There was a significant difference between language groups over the left hemisphere, $F(2,54) = 4.196$ p = .020 $\eta^2 = .135$, where as the difference was trending towards significance over the right hemisphere, $F(2,54) = 2.846$ p = .067 $\eta^2 = .095$. The distracting stimuli elicited a larger distribution over the right than the left hemisphere for the late bilingual group, which differed in comparison to the early bilinguals (Bonferroni post hoc p = .018), whose distribution of the P1 was bilateral. Further these distribution effects are supported by a main effect of both hemisphere $F(1,54) = 6.291$, $p = .015$ $\eta^2 = .104$, and language group, $F(2,54) = 3.77$ $p = .029$ $\eta^2 = .123$. Topographic maps illustrating the different distributions at three, six and nine degrees are shown in Figure 6.

The peak latency of the P1 component did differ across language groups, $F(2,54) = 5.925$ $p = .005$ $\eta^2 = .180$. Further analysis revealed that the P1 peak latency of the early bilingual group differed significantly from both the monolingual, $F(1,37) = 4.503$ $p = .041$ $\eta^2 = .109$, and late bilingual groups, $F(1,36) = 13.542$ $p = .001$ $\eta^2 = .273$. The peak latency of the P1 did not differ between the monolingual and late bilingual groups, $F(1,35) = 1.408$ $p = .243$ $\eta^2 = .039$. There was not a significant difference in degree for the peak latency of the P1 component, $F(2,54) = 1.343$ $p = .265$ $\eta^2 = .024$.

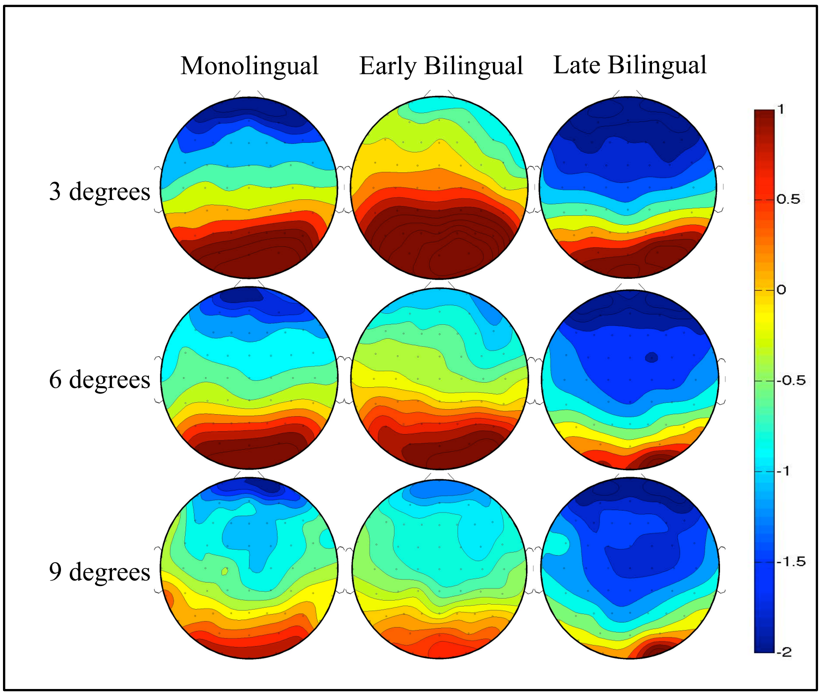


Figure 6. Topographic maps showing the distribution of the P100 for the three conditions during the 110 – 160 ms time window for the three language groups.

4.4.2.2 Response Inhibition (N2) and Inhibition (P3(a))

For the Go/No-Go task a significant main effect of response inhibition was elicited, $F(1,54) = 39.54$ $p = .000$ $\eta^2 = .423$, where the N2 component was larger in amplitude for the No-Go [$M = 1.86$, $SE = .706$] than Go [$M = 4.312$, $SE = .670$] trials, indicating that participants inhibited their response during the No-Go trials (Figure 7).

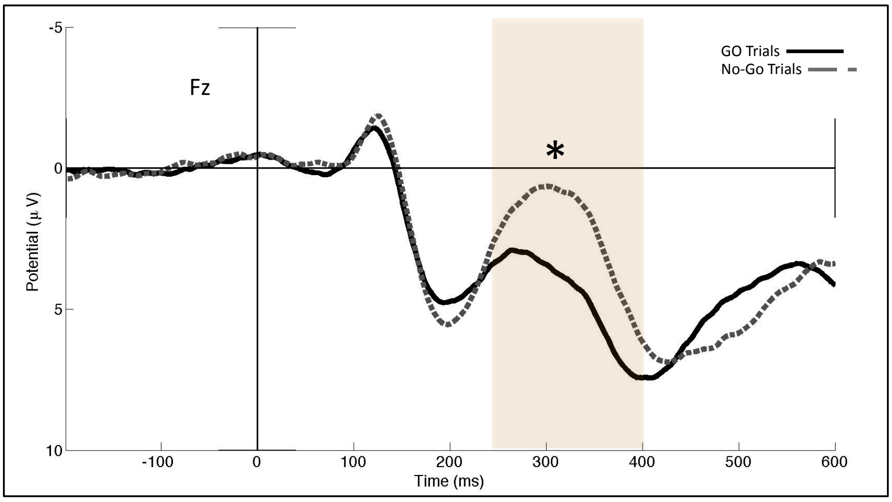


Figure 7. ERP waveforms displaying the go/no-go trials collapsed across groups. A significant condition effect at electrode site Fz for the go/no-go task in the early time window (250-400ms) is shown F(1,54) = 39.54 p = .000 η^2 = .423.

As predicted, when response inhibition was considered there were no differences between the three language groups, *F*(2,54) = 1.53 *p* = .226 η^2=.052, on the amplitude of the N2 component. Difference wave (No-Go condition minus Go condition) ERPs of interactions between group and condition are illustrated in Figure 8.

The peak latency of the N2 component did not differ across language groups, *F*(1,54) = 1.039 p = .361 η^2 = .037. However, there was a significant difference in peak latency between the Go and No-Go trials, *F*(2,54) = 395.25 p = .000 η^2 = .880, whereby the Go [*M* = 315.88, *SD = 4.45]* trials elicited an earlier peak latency than the No-Go [*M* = 389.54, *SD = 3.41]* trials.

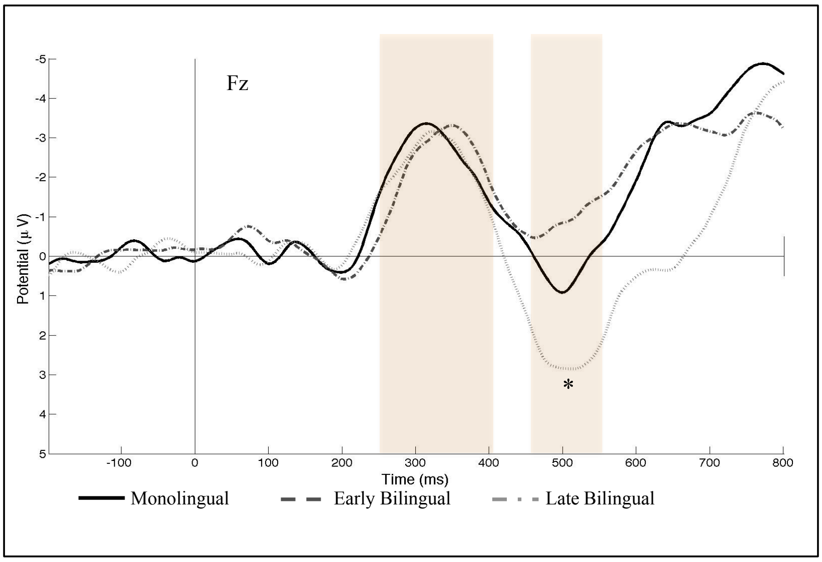


Figure 8. Difference wave (No-Go – Go) ERPs at electrode site Fz) for the Go / No-Go task. No significant difference between the two conditions was produced between groups

within the early time window (N2 250 - 400 ms) but a significant group difference can be seen in the late time window (P3(a) 450 - 550 ms),which is driven by the late bilingual group.

Analysis of the P3a revealed that there was an interaction between Go/No-Go condition and language group, $F(2,54) = 3.678$, $p = .032$ $\eta^2 = .120$. Further analysis showed that the late bilinguals displayed significantly smaller amplitude P3a for both the Go [$M = .947$, $SE = 1.147$] and No-Go [$M = 3.794$, $SE = .955$] trials, than the early bilinguals [*Go* (M = 5.434, $SE = 1.088$); No-Go ($M = 4.71$, $SE = .906$)] or the monolinguals [*Go* (M = 3.958, $SE = 1.116$); No-Go ($M = 4.417$, $SE = .929$)]. Difference wave (No-Go minus Go) ERPs of interactions between group and inhibition are illustrated in Figure 8.

The peak latency of the P3(a) component did not differ between language groups, $F(2,54) = .176$ $p = .839$ $\eta^2 = .006$. However, there was a significant difference in peak latency between the Go and No-Go trials, $F(2,54) = 1283.99$ $p = .000$ $\eta^2 = .960$, whereby the No-Go [$M = 346.63$, $SD = 4.21$] trials elicited a earlier peak latency than the Go [$M = 497.56$, $SD = 3.16$] trials.

4.4.2.3 P3(b)

The P3(b) was larger to the Go than No-Go trials, $F(1,54) = 115.512$ $p = .000$ $\eta^2 = .681$, with response to the Go trials [$M = 12.77$, $SE = .657$] yielding a larger P3(b) amplitude than the No-Go trials [$M = 8.25$, $SE = .548$]. In respect to Go/No-Go condition, there was no significant difference between the three language groups, $F(2,54) = .272$, $p = .763$ $\eta^2 = .010$.

Figure 9 illustrates the mean amplitudes and distributions of the P3(b) for the three language groups for the Go and No-Go trials. There was no difference in distribution of the P3(b). Analysis showed that there was no main effect of hemisphere, $F(1,54) = .140$ $p = .710$ $\eta^2 = .003$, and no interaction between language group and hemisphere, $F(2,54) = 2.46$ $p = .095$ $\eta^2 = .083$. Further, there was also no interaction between group, Go/No-Go trials, and hemisphere, $F(2,54) = .433$ $p = .651$ $\eta^2 = .016$. This validates that the distribution of the P3(b) is similar between groups as there is no significant difference in mean amplitude across the left and right hemispheres when group and condition are both considered.

The peak latency of the P3(b) component did not differ between language groups, $F(2,54) = .646$ $p = .528$ $\eta^2 = .023$. However, there was a significant difference in peak latency between the Go and No-Go trials, $F(2,54) = 227.54$ $p = .000$ $\eta^2 = .808$, whereby the Go [$M = 411.51$, $SD = 4.58$] trials elicited an earlier peak latency than the No-Go [$M = 454.43$, $SD = 3.93$] trials.

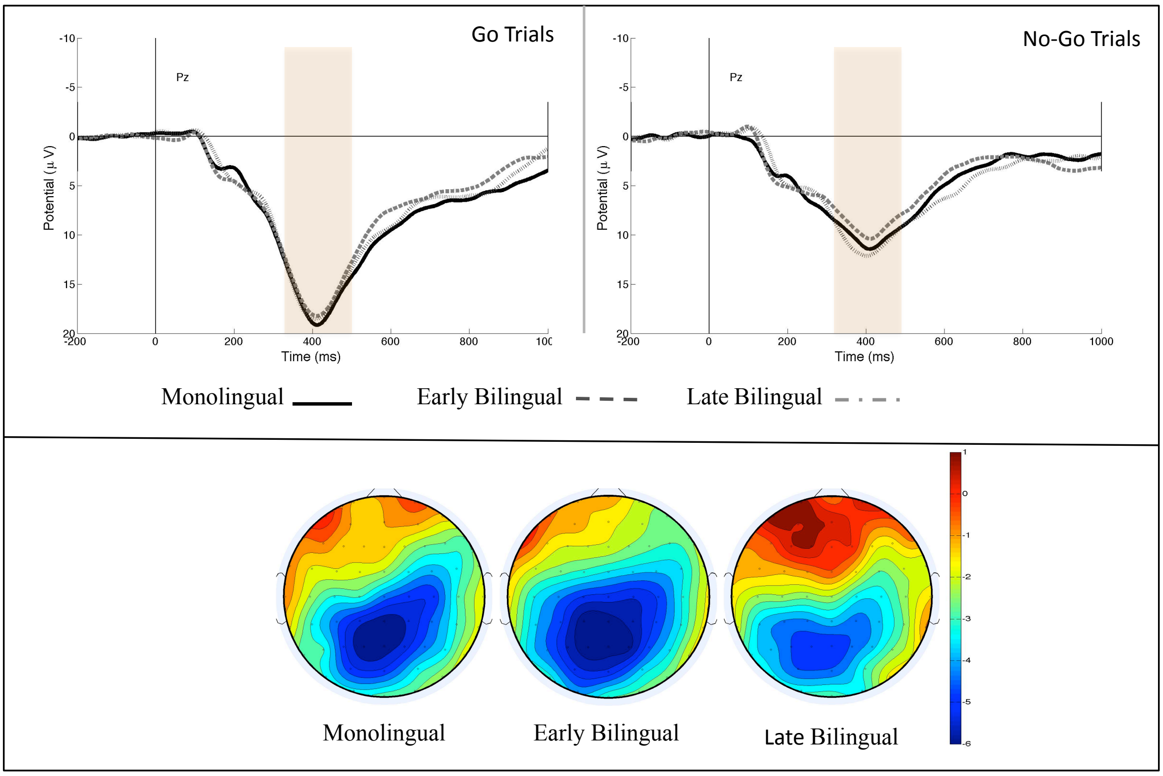


Figure 9. ERPs displaying the P3(b) component for the Go and No-Go trials during the 300 – 550ms time window are illustrated in the figures at the top. The topographic maps at the bottom are difference waves (No-Go – Go) showing distributions of the P3(b) for the three language groups during the 300 – 550 ms time window.

4.5 Discussion

Analysis of the irrelevant distracter trials indicated that the late bilingual group was better able to suppress attention to irrelevant task stimuli. The P1 amplitude elicited by the irrelevant trials was smaller for the late bilingual group than the monolingual and early bilingual groups across all three conditions. There were also differences in distribution, with the late bilinguals having a more focal distribution in the posterior P1 sites than the monolingual and early bilinguals. Across all participants the amplitude and latency of the N2 and P3(a) that was modulated by the go/no-go task was comparable, particularly to the no-go stimuli. Indicating that the three language groups were able to inhibit their response to the task successfully. The elicited P3(b) had comparable amplitude, latency and distribution across language groups, suggesting that memory representations were updated similarly.

As predicted the current study supported previous bilingualism research with regards to response inhibition, as the finding of the present study replicates previous research results (Luk et al., 2010). During a task such as the go/no-go task, participants are required to inhibit their response to non-target stimuli, in this context there does not appear to be any difference between the cognitive control system engaged by monolingual and bilingual individuals. A previous fMRI study used a flanker task to examine the effect bilingualism has on cognitive control. During the task participants were presented with no-go trials that required they inhibited their response to non-target stimuli efficiently. The results found no difference between monolingual and bilingual groups on their reaction times, further both groups activated the same brain regions when engaging with the no-go trials. These results suggested that bilingualism does not selectively affect the neural correlates involved in response inhibition (Luk et al., 2010).

As predicted there were differences between the monolingual and bilingual groups on their ability to suppress attention to irrelevant stimuli. The results of the present study support previous literature that has suggested that bilingualism results in a more effective ability to suppress attention (Luk et al., 2010). When participants were required to suppress attention to incongruent trials, the brain regions activated by the monolingual and bilingual individuals differed. Monolinguals activated brain regions including the left temporal pole and left superior parietal regions, where as the bilinguals activated a more extensive network including bilateral frontal, temporal and subcortical brain regions (Luk et al., 2010). It was concluded by this previous study that there is a bilingual specific cognitive network, which has been affected by the demands required when controlling multiple languages.

Previous bilingualism research has suggested that early proficient bilinguals develop more effective control of their executive functions than late bilinguals (Abutalebi, 2008; Abutalebi et al, 2012). The results of the present study contradict this hypothesis, as it was the late bilingual group who most efficiently performed aspects of the task that particularly involved control of attention. A possible explanation for the results in the present study could come from the population sample making up our late bilingual group. The majority of the participants in the late bilingual group were international students, whose first language was not English. Although the current study is not language based, this factor could be important to interpreting the present findings. When an individual learns a new language later in life they must prevent interference from their native language in order to speak the new language successfully. Therefore, the learner must control the interference from the unintended language in order to communicate in the desired language. The act of conversing in the new second language requires a large amount of effort and effective control of cognitive processes such as inhibition and suppression (Martin et al., 2013).

In a study assessing whether American Sign Language – English Interpretation students would show bilingual effects on cognitive control, Macnamara and Conway (2014) found that the students showed significant cognitive control and working memory gains after two years of high demand of managing ASL and English. It was interpreted that these behavioral gains were specific to needing to manage two languages but were not related to any preexisting cognitive abilities. Therefore, sufficient intensive bilingual management (such as being an international student or a student of ASL) is necessary to experience cognitive improvement (Macnamara & Conway, 2014). Although it is argued that all bilinguals must utilise their cognitive functions effectively in order to control their languages (Green, 1998), there have been studies that have suggested that the structure and function of the brain differs depending on whether an individual is an early or late bilingual (Klein, Mok, Chen & Watkins, 2014; Hull & Vaid, 2007).

Although the results of the current study would suggest that bilinguals are better than their monolingual peers at suppressing attention to irrelevant stimuli, it could be argued that the results relating to the irrelevant stimuli are a reflection of attention modulating processes. An alternative explanation for the difference in P1 amplitude between the monolingual and bilingual groups could be that the late bilingual group had selectively focused their attention on the go/no-go task, therefore they simply did not get distracted by the other stimuli. The late bilingual group had modulated their attention according to the task, therefore resulting in P1 amplitudes reflective of unattended stimuli. In order to establish a more conclusive conclusion, future research needs to directly manipulate attention in order to ascertain whether bilingualism indeed results in a better ability to suppress attention or whether bilingual individuals are simply better are focusing their attention on the task.

The results of the current study support the hypothesis that bilingualism does have a positive impact on executive functions. Some researchers have doubted this hypothesis (Paap & Greenberg, 2013; Hilchey & Klein, 2011) and have criticized the design and methodology of previous studies. However, through the use of a go/no-go study and ERPs, the present study supports the findings of previous bilingualism research. Bilingualism positively affects the cognitive development of attention mechanisms, and the processes involved in both selectively attending to a target stimulus and suppressing attention to irrelevant stimuli. Through controlling attention to one language versus another, bilinguals have more practice in exercising control over their attention processes. However, the results of this study with regards to attention have raised the question of whether bilingual individuals are better able to suppress irrelevant stimuli or are better at modulating their attention towards relevant task demanding stimuli.

Conclusions

The current study provides increasing support to the field of bilingualism and the positive effect it has on the development of other cognitive functions, such as attention. Further, the differences seen between monolingual and bilingual individuals are not dependent on the bilingual individual being an early learner of a second language. Late learners can also benefit from positive cognitive changes that are associated with bilingualism.

Following on from the results obtained in Chapter 4, the current Chapter aims to establish whether the group differences produced on the distracter trials are due to suppression of attention to irrelevant stimuli, or attention modulating processes. In order to answer this question, the study described below will directly manipulate attention by directing the participants' attention to 'to-be-attended' stimuli, which will allow analysis of attended versus unattended stimuli.

5. Lack of a bilingual advantage for modulation of attention and suppression during an ERP Go/No-Go attention task

5.1 Abstract

Attention is a flexible mechanism that is capable of both facilitating and inhibiting the processing of stimuli (Behrmann & Haimson, 1999). Attention acts by biasing the competition between rival representations at various stages in visual processing (Desimone & Duncan, 1995), which results in an advantage for attended over unattended stimuli (Luck, 2000). These attended stimuli elicit greater neural activity, are better perceived, remembered and are more likely to produce a response (Fockert, 2010). The bilingualism advantage hypothesis suggests that the exercise of cognitive control over two competing languages results in an advantage in executive function. In particular this hypothesis suggests that bilingualism leads to an advantage in the ability to suppress attention to irrelevant information (Luk et al., 2010). We directly manipulated attention in order to establish whether the results seen in Chapter 4 were due to an advantage in suppression or modulation of attention. A modification of the novel event-related potential (ERP) Go/No-Go spatial attention paradigm from Chapter 4 was used. ERPs were collected during a Go/No-Go task, where participants (N= 28) were required to respond when a brown gopher was detected (go) and withhold responses to other stimuli (no-go). Additionally, participants were instructed before each trial block to attend to either the left or right in order to monitor and respond to additional go trials, which were located three, six and nine degrees away from fixation (the same location as the irrelevant stimuli (bees)). In contrast to the results seen in Chapter 4, there were no differences between groups on suppression of irrelevant stimuli, and no differences in their ability to modulate attention to the attended and unattended conditions. The results do not support the bilingualism advantage hypothesis with respect to suppression, and demonstrate that the affect bilingualism has on cognition is complex.

5.2 Introduction

When perceiving auditory or somatosensory information, there arises occasions where the perception of one source of information competes with other sources, this is also true in the visual domain. Several attention mechanisms work alongside the visual system so that target objects can be processed efficiently. These attention mechanisms include, overt attention (gaze is shifted to an object in order for that object to be processed by the fovea), covert attention (processes objects at a potentially relevant spatial location before making an overt shift of gaze), feature-based attention (highlights objects containing relevant features in the environment), and object-based attention (allows processing to be determined by the shape of the attended object) (Luck & Kappenman, 2012).

Research using ERPs to address attention processes, have typically compared ERPs to an attended stimulus and the ERPs to a physically identical unattended stimulus. The Hillyard sustained attention paradigm (Van Voorhis & Hillyard, 1977) is a well-established and extensively used paradigm to study the allocation of attention to visual locations. Typically in this paradigm participants fixate at a central location. At the beginning of every block the participant is instructed to attend to either the left visual field (LVF) or the right visual field (RVF) for the duration of that block. Each block consists of a sequence of stimuli, which appear at a rapid rate and are equally likely to appear in the LVF and the RVF. The task requires that the participants monitor the attended location for deviant stimuli, when they detect a deviant stimulus they are required to press a button. Previous studies have used a variety of different items for the standard and deviant stimuli including, bars of different sizes, different categories of words, and faces with different expressions. There is one main constraint when determining the items to use as the stimuli, as the deviant-standard discrimination must be more difficult to discriminate than the difference between the two locations. This increases the probability that both the standards and the deviants fall within the same perceptual channel and that the task is difficult enough that is motivates participants to focus their attention wholly on the to-be-attended location.

In this visuospatial paradigm, it has been widely found that a larger amplitude P100 is elicited in response to the attended stimuli relative to the unattended. This indicates that the participant is directing more attention to the ‘to-be-attended’ stimulus rather than the ‘to-be-unattended’ stimulus (Luck, 2000). A similar P100 effect is also observed in the Posner cueing paradigm (Eimer, 1994a, 1994b; Hopfinger & Mangun, 1998; Luck et al, 1994; Mangun & Hillyard, 1991).

During spatial cuing studies, such as the Posner cueing paradigm, a cue directs attention to a particular location on each trial. A target is then presented at either the attended or unattended location. Participants are instructed to respond to the target no matter where it appears, whether it is in an attended or unattended location. This allows for behavioural measures of attention to be obtained. Studies have shown that responses are faster and more accurate at the cued location than the un-cued location (Posner et al., 1980). When the cue is presented in the 'to-be-attended' location (peripheral cue rather than central cue), attention is summoned automatically to the cued location. Even if the target is equally likely to appear at the cued or un-cued location, peripheral cues will orient attention to the cued location (Jonides, 1981). Resulting in faster more accurate responses on the attended relative to the unattended trials. It has also been found that larger sensory-evoked ERPs for targets on the cued than un-cued trials are elicited (Luck et al., 1994; Eimer, 1994; Mangun & Hillyard, 1991). This suggests the enhanced speed and accuracy responses found in the behavioural data are perhaps due to enhanced sensory processing (Luck, 2000).

Attention can be directed to a spatial location or the objects in those locations, depending on the conditions imposed during the study; attention can be directed to a location, objects or surfaces (Duncan, 1984; Egly et al., 1994; Vecera & Farah, 1994; He & Nakayama, 1992). Attention can be directed towards a given location in the visual field and the resulting processing that occurs will be biased towards information in that location (Posner, Davidson & Snyder, 1980). There are also certain circumstances where selection cannot be based solely on location, and there is evidence that attention can also be directed to certain objects, even if these objects occur in more than one spatial location in the visual field (Driver & Baylis, 1989). Further, Roelfsema et al (1998) found that the firing rates of neurons in V1 that corresponded to various segments of a curved line were enhanced relative to responses to a distractor line, even when the lines were spatially overlapping. The results suggested that it is the object that is modulating the firing rate rather than attention spreading across spatial locations occupied by the curve. Therefore, selection of attention is not always based on spatial information; it can be modulated by stimulus-driven and task-driven factors (Fockert, 2010). Relative to the current study, if a participant is instructed to monitor either the left or right visual field and in that visual field target stimuli are presented in any one of three locations (3, 6 or 9 degrees away from central fixation), the attention processes aiding the visual system are able to monitor the cued location for the target object and disregard any distracter stimuli that may also be presented in those locations. As it has been established that what captures the attention of an individual relies on both spatial and object representations interacting, which then results in the generation of a behavioural response (Behrmann & Haimson, 1999).

There are two models of attention an early selection model and a late selection model. The early selection model (Broadbent, 1958) proposes that stimuli are selected to be attended to at an early stage during processing. In this respect stimuli with similar basic features such as colour, pitch, or direction are selected and processed for meaning, any stimuli that are irrelevant are filtered out, and are therefore not selected. In essence the early selection model proposes that perception of the stimulus is not required prior to selecting whether it is relevant. The late selection model, on the other hand, argues that information is selected after processing for meaning has taken place (Deutsch & Deutsch, 1963). These models of late selection propose that all information is attended to until semantic encoding and analysis can be performed. In this situation the filter that decides whether stimuli will be attended to or not, acts as an attenuator - it intensifies the pertinent information and attenuates the intensity of the irrelevant stimuli. It has since been suggested that selection of attention is dependent upon perceptual load. In a situation that requires an individual perform a coherent cognitive function the individual must remain focused on the goal-relevant stimuli in the presence of potentially interfering distractors. However, even in a situation where an individual is instructed to ignore goal-irrelevant stimuli, the processing of to-be ignored stimuli is not prevented. The debate concerning early and late selection may be resolved if perceptual load of relevant information determines the processing of irrelevant information. It has been shown that distractor processing depends on the level and type of load involved in the processing of goal-relevant information. In a study that directly manipulated perceptual load (Lavie, 1995), interference from distractors was found only in conditions requiring low-load processing. In this study the distractor stimuli was clearly distinct from the target, and it was concluded by the authors that physical separation between the distractor and the target is not a sufficient condition for selective perception; overloading perception is also required. If an individual is engaged in high perceptual load this can eliminate distractor processing, however if there is high load on frontal cognitive control processes this can lead to an increase in distractor processing. This provides a load theory of attention that provides a resolution to the early and late selection debate and that is able to integrate attention research with executive function (Lavie, 1995; 2005). It has been shown through brain-imaging and neurophyiological data that attention is not located in a single brain area. The process of attention are mediated by an amplification of blood flow and electrical activity in cortical areas processing the attended computation (Posner & Dehaene, 1994). An fMRI study that addressed the attention processes of alerting, orienting and executive control, found that there are functional contrasts within a single task (ANT) that differentially activate three separable anatomical networks related to attention (Fan, McCandliss, Fossella, Flombaum & Posner, 2005).

The bilingual advantage hypothesis proposes that the cognitive control required to effectively switch between two languages leads to more efficient cognitive functions. Specifically this hypothesis supports the theory that there is a bilingual advantage when suppression of irrelevant information is needed (Luk et al., 2010). If the orienting network involved in processing attention during cueing studies is considered. The research to date is contradictory with regards to a bilingual advantage. In one study, the effect of bilingualism on target detection was explored (Colzato et al., 2008), using a visual cueing paradigm. The visual cue preceded the target at different Stimulus Onset Asynchronies (SOAs), and it was predicted that both the monolingual and bilingual groups would perform comparably on short SOAs (100 ms) but that the bilingual advantage would be seen on trials with a long SOA (700 ms), therefore showing a more pronounced Inhibition of Return (IOR) effect (Colzato et al., 2008). The results were interesting in that they showed a cueing facilitation effect only for the monolinguals when the SOA was short, and on trials where the SOA was long there were only IOR effects seen for the bilingual group.

The cueing facilitation effects found by Colzato et al (2008) contradict the results found by Costa et al (2008), who observed no bilingual impact on visual cueing effects. Where Colzato et al (2008) found cueing facilitation effects only for the monolingual group, Costa et al (2008) found identical cueing facilitation effects for both the monolingual and bilingual groups. However, it is hard to draw any concrete conclusions from these results as there are too many variables that differ and therefore it is hard to compare the results. A later study by Hernandez et al (2010) aimed to more closely replicate that of Colzato et al (2008), however the results of this study show a similar pattern of cueing effects for both the monolingual and bilingual groups. The authors conclude that this indicates that there is no bilingual effect on attention orienting processes that depend on the orienting network.

In a visual search paradigm, where task was manipulated by search type (feature or conjunction), it was found that the monolingual and bilingual participants performed similarly on the feature searches but the bilingual group were faster on the more difficult conjunction searches. It is proposed that these findings indicate that bilinguals have better control of visual attention (Friesen et al., 2014). The contradictory results of these attention studies demonstrate the complexity of the attention processes involved in visual processing, and how they're affected by bilingualism.

The present study is a modification of the study conducted in Chapter 4. In this current study the task is identical to the one presented in Chapter 4, apart from the addition of a secondary task that directly manipulates attention. With regards to the go/no-go task, it is predicted that a replication of the results found in Chapter 4 will be observed. That is, it is expected that there will be no difference between the monolingual and bilingual groups on the amplitude of the N200 or P300, which will indicate no difference between groups on response inhibition or memory updating in relation to the central go/no-go task.

In Chapter 4, the late bilingual group elicited smaller P100 amplitudes towards the distracter stimuli (compared to both the monolingual and early bilingual groups), which suggested a bilingual advantage in suppression of attention to irrelevant stimuli. There was no significant difference between the monolingual and early bilingual groups in the results seen in Chapter 4; therefore in the current study it was only the late bilingual and monolingual groups that were of interest. There are two possible explanations for the results seen in Chapter 4. Either the late bilingual group displayed more efficient suppression of attention, or they are more efficient at modulating attention (Fockert, 2010; Kastner, De Weerd, Desimone & Ungerleider, 1998). In the current study the main aim is to determine whether the attention results seen in Chapter 4 are a result of suppressed attention or modulation of attention.

The task of the current study will directly manipulate attention, by cuing attention to either the left or right visual field. In both the attended and unattended locations, target stimuli will appear in the same spatial locations as the distracter stimuli. It is predicted that if group differences produced are due to suppressed attention, then there will be no difference between groups on the attended trials, but the two groups will differ on the unattended trials (with the bilingual group having a smaller attenuation effect to the unattended stimuli, i.e. a smaller amplitude P100). On the other hand, if the group differences are due to modulation of attention then it is predicted that both the monolingual and bilingual groups will show an attenuation effect (i.e larger amplitude to the attended trials), however it is predicted that the difference between the attended and unattended trials will be greater in the late bilingual group.

5.3 Method

5.3.1 Participants

Twenty-eight university students were recruited from the psychology department at Bangor University, Wales, and took part in exchange for course credits. All participants were right handed (assessed using a modified version of the Waterloo Handedness Questionnaire (Steenhuis & Bryden (1989)). Participants reported that they were free from any auditory or visual impairment, and had no known history of any neurological conditions (Thomas & Gathercole, 2007). Participants provided voluntary informed consent prior to the start of the study. Ethical approval was granted from the ethics committee prior to the start of the research. Participants were categorised as either monolingual or bilingual based on their responses to a detailed Language Background Questionnaire (Thomas & Gathercole, 2007).

Participants placed in the bilingual group were exposed to their second language (L2) after the age of 5 (M = 7.14, SD = 3.04) and were therefore classed as late bilinguals (see previous chapter for reasoning). Participants were aged between 18 and 28 years (M = 22.21, SD = 2.46). There were 14 monolinguals (6 males) and 14 bilinguals (2 males) with no difference in age, $t(26) = -1.582$ $p = .126$, or gender, $t(26) = -1.700$ $p = .101$ between groups.

The bilingual group spoke a variety of languages: Vietnamese (2), German (2), French (1), Bulgarian (1), Cantonese (1), Sinhalese (1), Hungarian (1), Spanish (1), Dutch (1), Urdu (1), Iranian (1), and Punjabi (1). A proportion of the bilinguals (78.6%) were born outside the UK. All monolinguals were born in the UK with the exception of two participants who were born outside the UK in another English-speaking country.

Both the monolinguals and the bilinguals were asked to indicate the percentage of time that they spend using each of their languages. As expected the monolinguals stated that they used English 100% of the time in the community and home contexts. The bilingual group stated that they used English significantly more in the community (M =78.57, SD = 27.47) than they did in home (M = 48.21, SD = 38.56) contexts, $t(13)$ = 2.795, $p = .015$.

All participants were fluent in English with both monolinguals (M = 20.00, SD = .000) and bilinguals (M = 18.36, SD = 2.44) scoring highly when they were asked to report their language proficiency in English on a Likert scale ranging from 1 to 20 (20 being highly proficient). However, due to English being the majority of the bilinguals second language there was a significant difference between the two groups in English Proficiency, $t(26) = 2.552$ $p = .018$.

Participants were asked to complete a modified version of The Barratt Simplified Measure of Social Status (Barratt, 2006) to assess whether any group effects that may be seen could be attributed to Socio-economic status (SES) differences. The two groups did not differ in SES, $F(1,27) = .044$, $p = .836$ indicating that if any group differences were to be seen it is unlikely that they could be attributed to differences in SES.

To assess if there were any differences in IQ between the two groups, all participants were asked to complete the Raven's Progressive Matrices (Raven, Raven, & Court, 1996). There was no difference between the monolingual ($M = 49.43$, $SD = 6.11$) and bilingual ($M = 48.93$, $SD = 5.78$) groups on their performance, $F(1,27) = .049$, $p = .826$.

5.3.2 Stimuli

In addition to the stimuli presented in Chapter 4, the participants also viewed additional smaller target stimuli, which would appear infrequently in the same locations as the distracter stimuli from Chapter 4 (-3°, -6°, -9°, 3°, 6°, and 9° along the horizontal axis above the central fixation). These additional target stimuli were smaller brown gophers (see Figure 1). Each block had six of the smaller targets, three in the attended condition and three in the unattended condition. In total there were 36 smaller target stimuli presented, each for 400 - 600 ms.

Figure 1. Example of a Go trial (brown gopher) with an additional target stimulus (brown gopher) 6° from fixation. .

5.3.3 Procedure

Participants sat in a sound attenuated room, 120cm away from the TV screen. Participants were instructed to respond using the response box whenever the target stimuli appeared on the screen (“Brown Gopher”) in the central fixation location and to refrain from responding to non-target stimuli. In addition to these instructions, the participants were notified that before each block of trials the experiment would ask them to attend to either the left or right hand side of the screen, where additional smaller targets may appear. There were six blocks in total, with participants attending to the left for three blocks and to the right for the other three blocks. The order of left or right first was counterbalanced across participants. Participants were instructed to respond to these additional target stimuli in the same manner as the targets in the central position. Participants were not instructed or notified about the distracter stimuli (bees). Participants received feedback from the task in the same manner they did in Chapter 4.

5.3.4 EEG Recording

The EEG was recorded continuously (BioSemi Version 6.05, 2007) from 64 pin-type Ag-AgCl active electrodes positioned according to the standard 10/20 layout affixed to a head-cap (BioSemi head-cap). Additional electrodes were placed over the left and right mastoid sites, as well as under the left eye and the right outer canthus. EEG recordings were amplified by a factor of 20,000, with a sampling rate of 2048 Hz. The EEG data were down sampled offline to a sampling rate of 512 Hz. The EEG was recorded reference free and without filters during data acquisition. All offsets (conceptually related to impedance) were kept below 25μv.

5.3.5 ERP Data Analysis

Data analysis was conducted offline using the ERPLAB Toolbox (for more details see http://erpinfo.org/erplab), which is integrated with the EEGLAB Toolbox (Delorme & Makeig, 2004). The EEGLAB toolbox was operated using MATLAB (version 7.9.0 R2009b). A 200 ms pre-stimulus baseline correction was applied to all EEG data and was filtered offline with a bandpass of 0.01 Hz to 30 Hz. EEG was referenced offline to the average of the left and right mastoids. Data were segmented into epochs of 200 ms before to 1500 ms after the onset of the stimuli (Go / No-Go trials and irrelevant distractors). Artifact rejection thresholds to detect blinks, horizontal eye movement, drift, and muscle artifact, were determined for each participant separately through visual inspection of the raw EEG (as recommended by Luck, 2005). Any epochs or channels containing eye or movement artifact were excluded from the analyses. On average 21.88% of the trials had to be removed from the EEG data due to a combination of blinks and drift (monolingual: 21.89%, late bilingual: 21.87%). A one-way Analysis of Variance (ANOVA) indicated that there were no differences between the two groups on the number of trials rejected, $F(1,26) = .000$, $p = .995$. Individual ERP's were created for each participant by averaging across trials for each electrode and condition. Group averages were obtained by averaging across participants within each group.

The electrode sites analysed were chosen following visual inspection of topographic maps and after taking into consideration previous research, these are highlighted in Figure 2. All time windows were selected following a 10 ms window analysis to determine the onset and offset of each component. For the N200 a time window of 250 – 400 ms was selected and electrode sites AF3, AFz, AF4, F5, F3, F1, Fz, F2, F4, and F6 were analysed. A time window of 450 – 550 ms was selected for analysis of the P300 (a) at AF7, AF3, AFz, AF4, AF8, F3, F1, Fz, F2, and F4 electrode sites. For the P300(b) a time window of 300 – 600 ms was chosen and electrode sites CP3, CP1, CPz, CP2, CP4, P5, P3, P1, Pz, P2, P4, P6, PO3, POz and PO4 were analysed. A time-window of 125 – 155 ms was selected for the P100 component, where electrode sites P3, P1, Pz, P2, P4, PO3, POz, PO4 were analysed. The N2 and the P3 components measured were time-locked to the Go / No-Go task, where as the P1 component measured was time-locked to the distracter stimuli (bees).

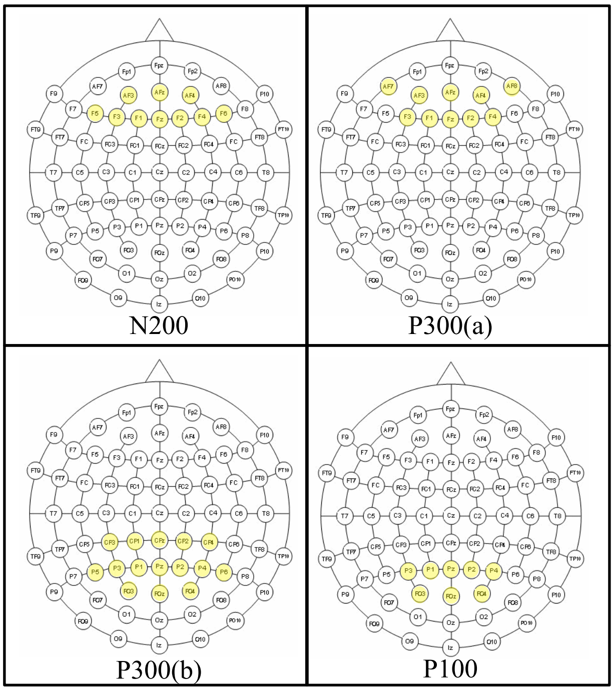


Figure 2. Head Maps displaying electrode sites chosen for analysis for the N2, P3(a), P3(b) and the P1.

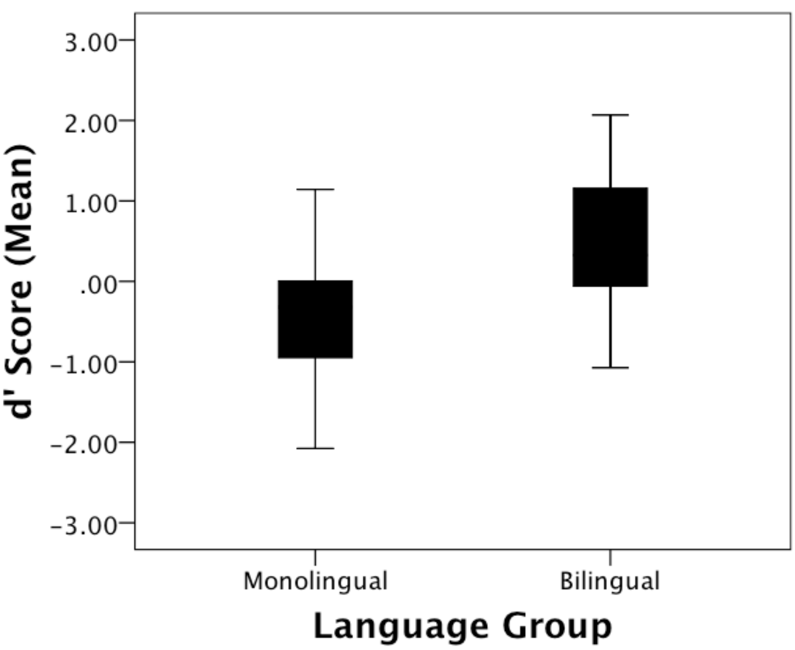
5.4 Results

5.4.1 Behavioral Data

Behavioral measures were calculated as a combined average score of all 6 blocks. Table 1 displays group scores for mean response time on go stimuli (RTGO), mean response time to false alarms (RTFA), mean scores for correct hits on go stimuli, and mean scores for false alarm hits. Differences in response time and accuracy across groups and conditions were assessed using a one-way ANOVA for group x condition (GO vs FA). There were no differences between the two groups on their response time to the go stimuli, $F(1,27) = 1.693$, $p = .205$, however there was a significant difference between the two language groups on their response time to the FA, $F(1,24) = 4.395$, $p = .047$, with the bilingual group producing slower responses. A d prime (d') score for accuracy (Z(hits)-Z(misses)) for both groups was calculated, and there was no significant difference between groups, $F(1,24) = .3.389$ p = .079

Table 1. Behavioral Performance on the Go/No-Go task (Mean and Std.Dev).

	RTGO Mean (SD)	RTFA Mean (SD)	Hits % Mean (SD)	FA % Mean (SD)
Monolingual	667.16 (66.19)	535.86 (63.51)	95.93 (2.03)	2.72 (1.1)
Bilingual	709.44 (101.96)	591.62 (69.50)	93.69 (3.19)	2.63 (.998)



Error bars: 95% CI

Figure 3. Calculated mean d prime (d') accuracy (Z(hits)-Z(misses)) score for both groups.

5.4.2 ERP Results

Each cognitive process and their associated component (P1, N2, P3(a), and P3(b)) are reported separately, and interactions with group are analysed using repeated measures ANOVAs (group x condition x electrode site). For all statistical analyses, when the assumption of sphericity is violated, the Greenhouse-Geisser correction is reported (Greenhouse & Geisser, 1959). When $\alpha \leq .05$ the results will be discussed in terms of a significant effect; when $\alpha = .05 - .095$ results will be discussed in terms of a trending towards significant effect.

5.4.2.1 Suppression of attention (P1)

The distracter stimuli produced a main effect of attention at three degrees, $F(1,26) = 11.218$ $p = .002$ $\eta^2 = .301$ with the attended [*M*=419, *SE* = .286] stimuli eliciting a larger amplitude P1 than the unattended [*M* = -.203, *SE* = .248] stimuli (Figure 4). There was no main effect of attention at either six, $F(1,26) = .014$ $p = .907$ $\eta^2 = .001$, or nine, $F(1,26) = .009$ $p = .923$ $\eta^2 = .000$, degrees.

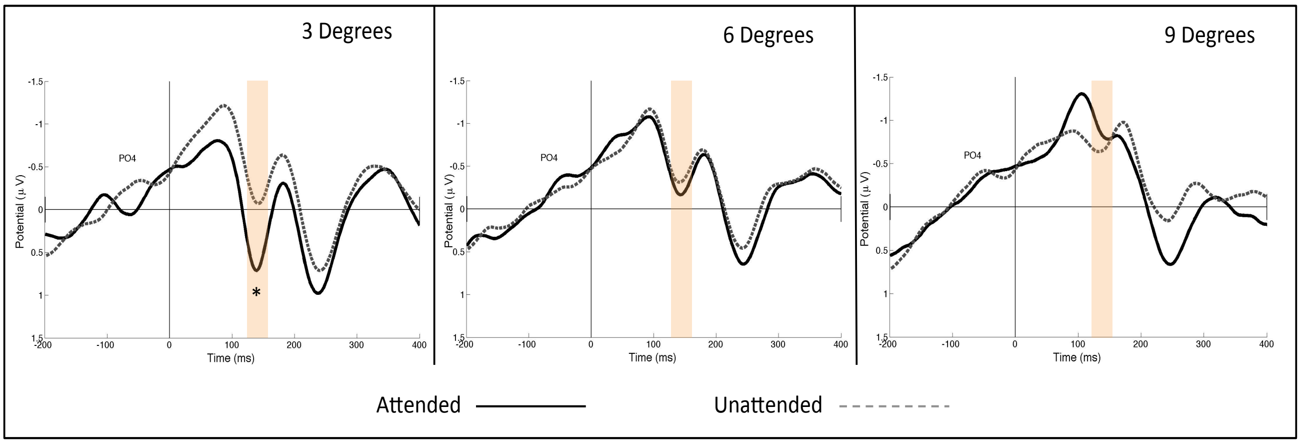


Figure 4. ERPs showing the main effect of attention elicited at three degrees are displayed to the left. ERPs showing attended versus unattended stimuli at six and nine degrees are displayed centrally and to the right respectively. All ERPs are collapsed across group.

For the attended distracter stimuli there was a main effect of degree, $F(2,26) = 10.822$ $p = .000$ $\eta^2 = .294$, with the stimuli presented at three degrees [*M*= .419, *SE* = .286] eliciting a larger amplitude P1 than the stimuli presented at both six [*M*= -.521, *SE* = .254] and nine [*M*= -.820, *SE* = .276] degrees. The unattended stimuli also produced a main effect of degree, $F(2,26) = 3.406$ $p = .045$ $\eta^2 = .116$, where the stimuli at three degrees [*M*=-.203, *SE* = .248] again elicited a larger amplitude P1 than the stimuli presented at both six [*M*=-

.552, *SE* = .165] and nine [*M*=-.843, *SE* = .251] degrees (Figure 5).

In contrast to our hypothesis there was no significant interaction between language group and attention, $F(1,26) = .135$ $p = .717$ $\eta^2 = .005$, nor language group and degree, $F(2,26) = .223$ $p = .791$ $\eta^2 = .009$. Both the attended, $F(1,26) = .612$ $p = .441$ $\eta^2 = .023$, and unattended, $F(1,26) = .463$ $p = .502$ $\eta^2 = .018$, stimuli elicited no significant difference between groups. Further, the stimuli presented at three, $F(1,26) = .088$ $p = .773$ $\eta^2 = .003$, six, $F(1,26) = .766$ $p = .389$ $\eta^2 = .029$, and nine, $F(1,26) = .823$ $p = .373$ $\eta^2 = .031$, degrees elicited a similar amplitude P1, resulting in non-significant differences between the monolingual and bilingual groups.

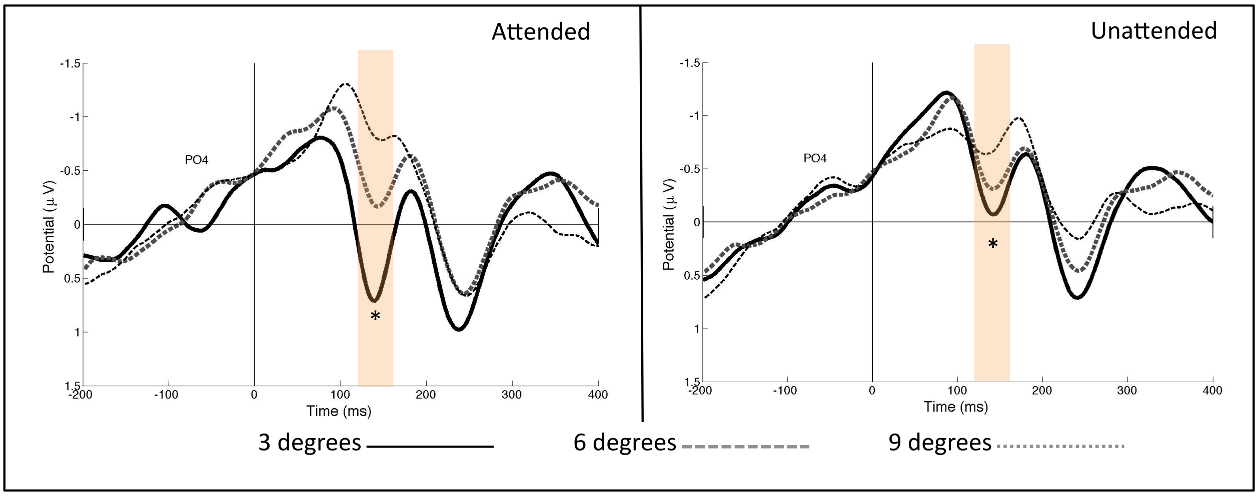


Figure 5. The ERPs displayed to the left show the main effect of degree found in the attended stimuli, and the ERPs displayed to the right show the main effect of degree found in the unattended stimuli. All ERPs are collapsed across group.

Although there was a significant main effect of attention at three degrees, there was no interaction with group, $F(1,26) = .054$ $p = .817$ $\eta^2 = .002$, nor was there a main effect of group for either the attended, $F(1,26) = .110$ $p = .743$ $\eta^2 = .004$, or unattended, $F(1,26) = .043$ $p = .837$ $\eta^2 = .002$, stimuli presented at three degrees. This was also true for the stimuli presented at six, $F(1,26) = .914$ $p = .348$ $\eta^2 = .034$, and nine degrees, $F(1,26) = .420$ $p = .522$ $\eta^2 = .016$ in the attended condition, as well as the stimuli presented at six, $F(1,26) = .101$ $p = .753$ $\eta^2 = .004$, and nine, $F(1,26) = 1.012$ $p = .324$ $\eta^2 = .037$, degrees in the unattended condition (Figure 6).

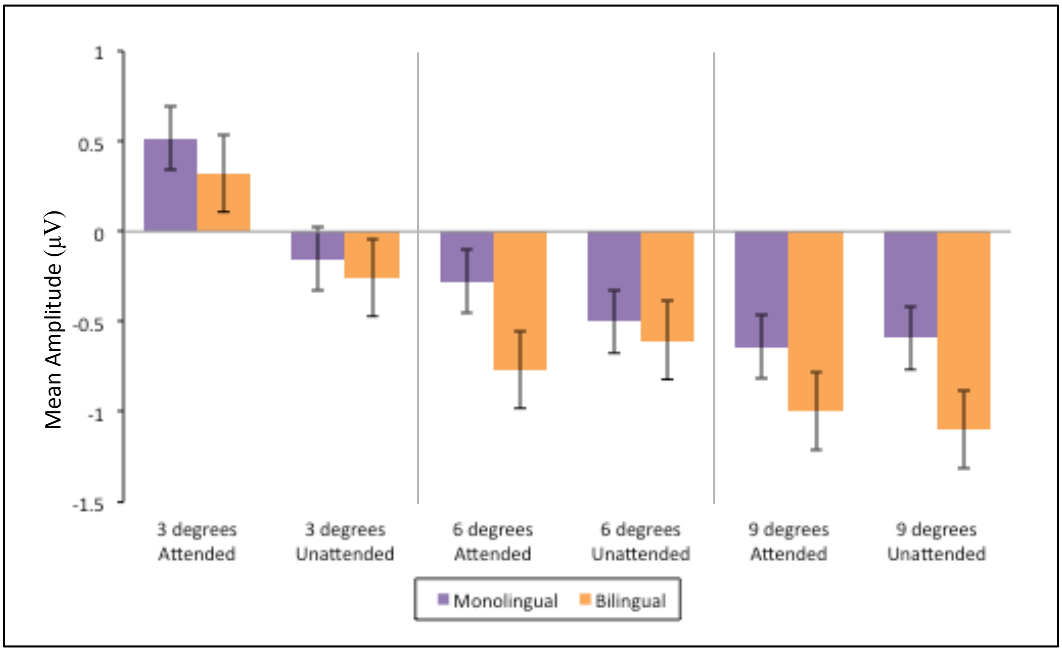


Figure 6. Bar chart illustrates the mean amplitudes of the P1 for the distracter stimuli, at three, six and nine degrees away from fixation, during the attended and unattended conditions for both the monolingual and bilingual groups. The standard error bars have a confidence level of 95%.

Analysis of the distribution of the P1 component was conducted using a Repeated Measures ANOVA (Group (2) x Attention (2) x Degree (3) x Hemisphere (2) x Electrode Site (3)). Both hemispheres showed similar activation of the P1 component for the distracter stimuli as no main effect of hemisphere was found, $F(1,26) = .009$ p = .925 η^2 =.000. There was also no interaction between attention and hemisphere, $F(1,26) = .120$ p = .731 η^2 =.005, or degree and hemisphere, $F(2,26) = 1.627$ p = .208 η^2 =.059, indicating that both manipulations activated a bilateral distribution. Further, there was no interaction between group and hemisphere, $F(1,26) = .207$ p = .653 η^2 =.008, indicating that both the monolingual and bilingual groups activated a comparable bilateral distribution of the P1 component in posterior regions.

Inspection of the distribution of the difference wave for the attended minus unattended trials time locked to the distracter stimuli (bees) at 3 degrees, revels a difference between the monolingual and bilingual participants (Figure 7). Visual inspection of the distribution reveals positivity over right posterior regions for the monolingual participants, where as the bilinguals have positivity distributed over anterior regions. Quadrant analysis of the distribution [electrode sites, Quad 1 (AF3, F7, F5, F3), Quad 2 (AF4, F4, F6, F8), Quad 3 (P7, P5, P3, PO3), and Quad 4 (P4, P6, P8, PO4)] revealed a significant interaction between quadrant, language group and attention condition, $F(3,26) = 3.404$ $p = .036$ $\eta^2 = .116$.

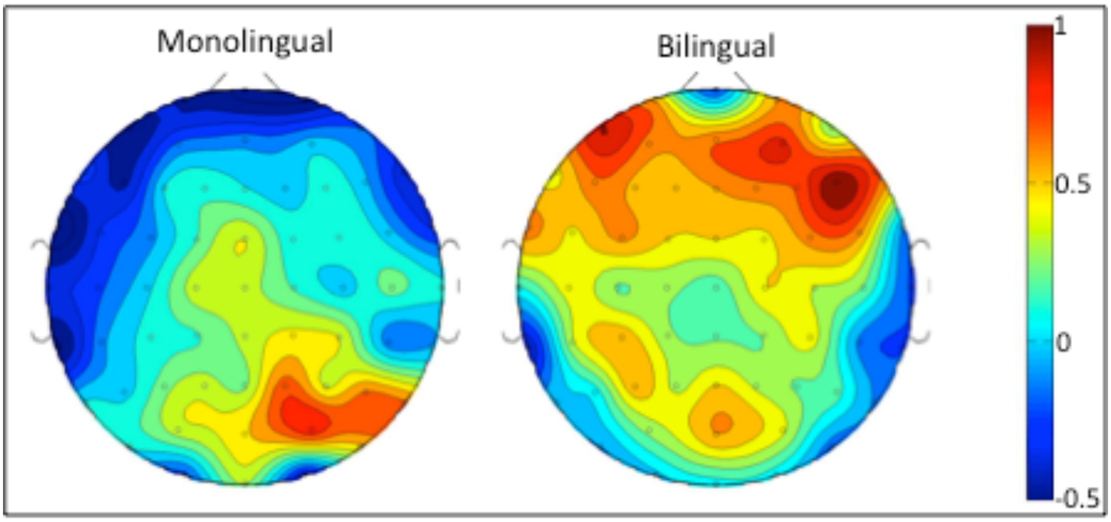


Figure 7. Illustartes the distribution of the difference wave (attended-unattended) for the distracter stimuli at 3 degrees, during the time-window 125 – 175 ms. Repeated measures ANOVA revealed a significant interaction between quadrant, language group and attention condition, $F(3,26) = 3.404$ $p = .036$ $\eta^2 = .116$.

There was no main effect of attention, $F(1,26) = 1.187$ $p = .286$ $\eta^2 = .044$, or degree, $F(2,26) = .711$ $p = .479$ $\eta^2 = .027$, when the peak latency of the P1 component was analysed. In addition, the peak latency of the P1 component did not differ across language groups, $F(1,26) = 2..059$ $p = .163$ $\eta^2 = .073$, and there was no interaction between group and attention, $F(1,26) = .443$ $p = .511$ $\eta^2 = .017$, or group and degree, $F(2,26) = 1.217$ $p = .301$ $\eta^2 = .045$. These results indicate that the P1 elicited by the distracting stimuli had a peak latency that was comparable across manipulations and between groups.

5.4.2.2 Response inhibition (N2) and inhibition (P3a)

A replication of the results seen in Chapter 4 was found for the central Go/No-Go trials. There was a main effect of condition $F(1,26) = 13.225$ $p = .001$ $\eta^2 = .337$, with pair-wise comparisons revealing that the N2 component was larger in amplitude for the No-Go [$M = -.900$, SE = ,724] than the Go [$M = .862$, $SE = .412$] trials indicating that participants inhibited their response to the No-Go trials (Figure 8).

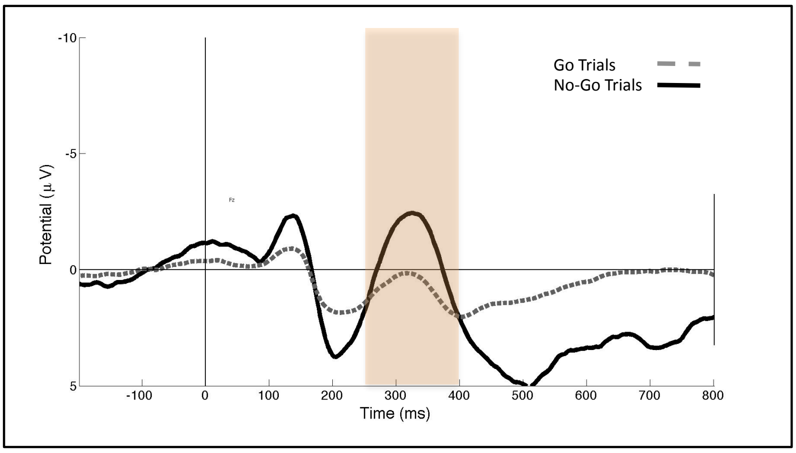


Figure 8. ERP waveforms at electrode site Fz, displaying the go/no-go trials collapsed across groups. A significant condition effect for the go/no-go task in the early time window (250-400ms) is shown F(1,26) = 13.225 p = .001 η^2 = .337.

Further, there was no difference between groups on the amplitude of the N2 component, F(1,26) = .028 p = .867 η = .001. Difference wave (No-Go condition minus Go condition) ERPs of interactions between group and condition are illustrated in Figure 9. Peak latency of the Go condition compared to the No-Go condition did not differ, F(1,26) = 1.626 p =.214 η^2 = .059. In addition, the peak latency of the N2 component did not differ across language groups, *F*(1,26) = .690 p = .414 η^2 = .026.

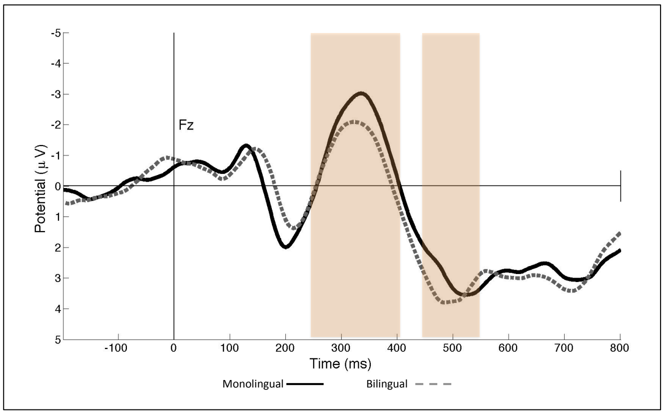


Figure 9. Difference wave (No-Go – Go) ERPs at electrode site Fz for the Go / No-Go task. No significant difference between the two conditions was produced between groups within the early time window (N2 250 - 400 ms) or the late time window (P3(a) 450 - 550 ms).

Analysis of the P3a revealed that there was a main effect of condition, *F*(1,26) = 12.537, *p* = .002 η^2 = .325, with additional analysis revealing that the No-Go [*M*=4.25 *SE* = .810] condition produced a larger amplitude P3(a) than the Go [*M* = 1.60, *SE* = .529] condition. The amplitude of the P3(a) did not differ between groups, *F*(1,26) = .139, *p* = .712 η^2 = .005. Difference wave (No-Go minus Go) ERPs of interactions between group and condition are illustrated in Figure 8. The peak latency of the P3(a) component did not differ between the Go and No-Go conditions, F(1,26) = .008 p= .928 η^2 = .000. Further, the peak latency of the P3(a) component did not differ between language groups, F(1,26) = .353 p = .558 η^2 = .013.

5.4.2.3 P3(b)

As was found in Chapter 4, the central task produced no main effect of condition between the Go and No-Go trials, F(1,26) = 1.666, p = .208 η^2 = .060 in the posterior region where the P3(b) was elicited. In respect to the Go/No-Go trials, there was no significant difference between the two language groups, F(1,26) = .855, p = .364 η^2 = .032. Figure 10 illustrates the mean amplitudes of the P3(b) for the two language groups for the Go and No-Go trials.

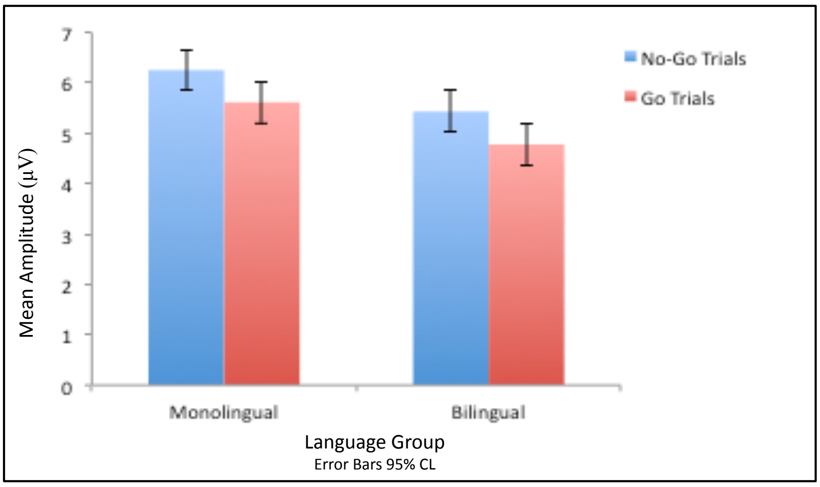


Figure 10. Mean amplitude of the P3(b) during the 300 – 600ms time window is illustrated in the bar chart, standard error bars have a confidence level of 95%.

A replication of the results found in Chapter 4, was also seen for the distribution of the P3(b). There were no differences in the distribution of the P3(b). Analysis showed that there was no main effect of hemisphere, F(1,26) = .873 p = .359 η^2 = .032, and no interaction between language group and hemisphere, F(1,26) = 0.35 p = .853 η^2 = .001. Further, there was also no interaction between group, condition and hemisphere, F(1,26) = .1.442 p = .241 η^2 = .053. This validates that the distribution of the P3(b) is similar between groups as there is no significant difference in mean amplitude across the left and right hemispheres when group and condition are both considered. The peak latency of the P3(b) component did not differ between the Go/No-Go trials, F(1,26) = .011 p = .917 η^2 = .000. Further, the peak latency of the P3(b) component did not differ between language groups, F(1,26) = .792 p = .382 η^2 = .030.

5.5 Discussion

Regarding the irrelevant distracter stimuli, the results failed to replicate those found in Chapter 4. Unlike the results found in Chapter 4, there were no significant group differences in the P1 amplitudes elicited for the distracters at three, six and nine degrees away from fixation. Further, in both the attended and unattended conditions the monolingual and bilingual groups elicited similar amplitude P1 waves. However, there were significant differences between the monolingual and bilingual groups when the distribution of the P1 (difference wave for the attended minus the unattended conditions) was considered. The current study did replicate the findings of Chapter 4 with regards to the go/no-go task. The amplitude and latency of the N2 and P3(a) that was modulated by the go/no-go task was comparable between groups. Also, the elicited P3(b) had comparable amplitude, latency and distribution across language groups.

The differences in distribution of the attended minus unattended difference wave for the monolingual and bilingual groups suggests a difference in how these groups have processed the stimuli in relation to the task. The lack of a significant difference in the amplitude and latency of the P1 elicited by the distracter stimuli in the attended and unattended conditions suggests that both groups generated a P1 at the posterior electrode sites analysed. However, in addition to the posterior P1, the bilingual group has also generated an anterior N1 in response to the distracter stimuli presented during the attended/unattended conditions. This anterior N1 and frontal distribution suggests the bilingual group engaged top-down processing during the task, a strategy that does not appear to have been employed by the monolingual group. By engaging with top-down processing strategies the bilingual group have formed perceptions starting with the larger concept of the task and have then worked towards the more detailed information. In the context of the task, the bilingual group has selectively attended to the 'to-be-attended' stimuli, in accordance with the task, and has subsequently modified their attention.

Although a main effect of attention was elicited (larger P1 amplitude to the attend condition), there was also a main effect of degree in both attention conditions. The presence of a main effect of degree in the unattended condition suggests that both groups attended, to a certain extent, to the 'to-be-unattended' stimuli. A possible explanation for this could be attributed to the task demands that required participants to divide their attention between the central fixation (in order to complete the central go/no-go task) and the 'to-be-attended' location, which may have lead to inaccurate recall of the 'to-be-attended' location (Close et al., 2014). When attention is endogenously divided between multiple locations, the performance on the task is limited by inaccurate recall of the attended locations. Attention places additional demands on the same cognitive processes that are involved in remembering the spatial information required to complete the task efficiently, even when the ‘to-be-attended’ location is the same as the location held in memory (Close et al., 2014). The link between bilingualism and performance on working memory tasks (Bialystok et al., 2014; Blom et al., 2014), would suggest that bilinguals should show less interference from additional task demands; and would therefore be able to hold the ‘to-be-attended’ location in working memory whilst also attending to the central fixation task. However, the bilingual and monolingual groups in our study have performed similarly (both behaviorally and the ERPs elicited by the task) on both the attended and unattended conditions with no detriment to the central Go/No-Go task. Suggesting a lack of a bilingual advantage with regards to suppression of irrelevant stimuli.

These results are however in agreement with those found in visual cueing studies conducted by Costa et al (2008) and Hernandez et al (2010), who found identical cueing facilitation effects for both monolingual and bilingual participants. Although, the current study was not a visual cueing paradigm per se, the attended versus unattended trials and the valid versus invalid trials are comparable. The combined results of these studies appear to demonstrate that both monolinguals and bilinguals are equally able to monitor and modulate attention process involved in visual processing, specifically in situations where attention is directed by a cue. The orienting attention network, engaged following the presentation of an attention-directing cue, is not enhanced by bilingualism (Hernandez et al., 2010).

Following a review of a wide range of the tasks that have assessed the effect bilingualism has on executive functions; Valian (2015) concluded that the data are mixed. In studies with children the effects have been weak or non-existent when the sample size has been large compared to studies with small sample sizes. When young adults have been tested the results have been inconsistent, and although the overall data are mixed the only benefit of bilingualism seems to be observed most consistently in older adults (Valian, 2014). These mixed results have lead to the suggestion that the effect bilingualism has on executive functions should be regarded as neutral (Klein, 2015). The bilingual advantage in executive functions is dependent on the characteristics of the participant and the specific features of the task (Bialystok et al., 2014; Luk, 2015).

Conclusion

The results of this study demonstrate that the effect bilingualism has on executive functions is complex. In particular it appears that some executive functions, such as response inhibition, consistently show a positive affect of bilingualism, whereas other cognitive processes produce more contradictory results. The findings of the current study unfortunately fall into the latter category. In conclusion, the contradictory findings and lack of replication of results within the field of bilingualism and cognition suggests that it is a complex scenario. In order to fully understand the effect bilingualism has on cognitive control processes, and more specifically which cognitive processes bilingualism does effect, more rigorous research is needed.

6. General Discussion

To date, research regarding bilingualism and its affects on executive functions has yielded inconclusive results, with researchers either campaigning for or against the bilingual advantage hypothesis. The studies presented in this thesis addressed the topic of bilingualism and cognitive advantages. The results indicated that bilingualism is a complex subject, where many factors need to be considered and controlled when examining any consequential effects related to executive functions. Discussed below are several factors that have been previously proposed as possible variables that may contribute to the advantages in executive functions seen in bilingualism research.

6.1 Population Sample

Several studies assessing bilingualism and executive functions have taken their group samples from different populations whose country of origin and cultural experiences differ. It has been established that culture does plays a role in the development of executive functioning (Carlson & Choi, 2009; Morton & Carlson, 2014) and in studies where the population of the groups being assessed are matched for native country, culture as well as SES and other demographic factors, the effect of bilingualism on executive functions diminishes. For example, a recent study by Gathercole and colleagues (2014) found that in a sample of bilinguals taken from the North Wales population, there was no clear bilingual advantage on tasks that required executive functions. The sample in this study was comprised of simultaneous and early bilinguals, across 7 different age groups (3-60-years) taken from the North Wales population. Three tasks were conducted with the participants, a Card Sort Task, a Simon Task and a Metalinguistic Task. All the tasks elicited performance that would be predicted, including better performance with age in children and a decrease in performance with age in adults. However, performances on the tasks were not predicted by bilingualism.

The data collected from the North Wales sample of Welsh/English bilinguals yielded no differences between groups, which were also the results of a study conducted in the North Wales area with older adults and the onset of dementia (Clare et al, 2014). It has been established previously that bilinguals develop Alzheimer's disease (AD) later in life than monolinguals (approx., 4-years later). This delay in onset of AD was suggested to be a result of increased cognitive reserve that was a direct by-product of bilingualism (Bialystok et al., 2007; 2010; 2014). Further, following the examination of neuroimaging data, monolingual and bilingual patients with AD performed similarly on all cognitive tasks despite the bilingual group having a greater degree of brain atrophy (Schweizer et al., 2012), which suggests that the experience of bilingualism and the related superior degree of cognitive reserve acts as a buffer against the effects of AD. In these studies with monolingual and bilingual dementia patients, there has been the inclusion of a diverse language background in the bilingual sample, which may place limitations on the results obtained. When the bilingual sample is divided according to language exposure and experience, there are different results seen between the groups that could not be explained by variations in education or socioeconomic status. A significant delay of onset of AD was found in a sample of immigrant bilinguals, but there was a non-significant trend in a sample of non-immigrant bilinguals whose first language was French, and there was not a significant delay in onset of AD in a sample of non-immigrant bilinguals whose first language was English (Chertkow et al., 2010). It would appear that bilingual research with older adults and dementia yields similar inconclusive results as those found in young adults and children.

A study conducted with dementia patients in the North Wales area set out to address these mixed findings (Clare et al., 2014). The bilingual participants in this study were fluent early bilinguals who had spoken both Welsh and English for all or most of their lives. The results of this study found that there was not a significant difference in age at the time of diagnosis, whereby the bilingual group was approximately 3-years older than the monolingual group. However, at the time of diagnosis the bilingual group was significantly more cognitively impaired than the monolingual group. Further, this study found no significant differences in performance between the monolingual and bilingual group on a series of executive function tasks. Although, the bilingual group did show strengths on tasks that required inhibition and conflict management (Clare et al., 2014). These findings indicate that in a sample of fully fluent early bilingual patients, the age of diagnosis of AD is not significantly different to that of monolingual patients. Further, the 3-year difference in age of diagnosis between the two groups may be a reflection of the bilingual group seeking medical assistance later than the monolingual group, as indicated by the bilingual group being more cognitively impaired at the time of diagnosis.

Taken together these studies conducted with older adults and AD indicate that the experience of bilingualism may provide a protective benefit against the onset of dementia. However, the level of cognitive reserve providing the buffer against the onset of dementia and its effects on cognition may vary depending on the type of exposure and experience an individual has with multiple languages. The protective benefit may be greater for those bilinguals who gain a second language later in life such as an L2 bilingual; or who are more likely to switch between their languages, such as non-immigrant bilinguals whose first language is less prevalent in their community than their second language; or those who suppress their dominant language on a more daily basis because they are immigrant bilinguals immersed in a community dominated by their second language. These experiences with bilingual language use may result in a greater degree of cognitive flexibility and an increase in cognitive reserve, compared to fully fluent simultaneous bilinguals whose bilingual language use may be more automatic and less effortful.

In areas such as North Wales and the Basque Country, the bilingual population is exposed to multiple languages whether deliberately or inadvertently. Typically populations such as these contain high proportions of fully fluent bilinguals. In these samples, even when participants are grouped according to estimates of exposure and/or dominance, there does not seem to be significant differences in performance on executive function tasks, unless there is a linguistic element. For example, where other studies have found a bilingual advantage on the Simon Task, the results of the study with fully fluent Welsh/English bilinguals (Gathercole et al., 2014) suggests that whatever the mechanisms associated with better performance in other studies (Bialystok, 2006), in relation to bilingualism, may be less related to simultaneous and early sequential bilinguals. In many previous studies the bilinguals taken from the population are either L2 bilinguals or the bilingual status of the group is not clearly defined (Adesope et al, 2010). The processes involved with acquiring two languages and the relationship between the two languages is clearly different between L2 and simultaneous bilinguals (Zhao & Li, 2010). The use of both languages in the simultaneous bilingual population may be more automatic and less effortful than it is for the L2 bilingual population. Fully fluent simultaneous bilinguals, compared to L2 bilinguals, may have more automatic linguistic knowledge of their languages. To the extent that any switching, monitoring, or inhibiting that is taking place is a function of the contexts of speech, much the same as it is for monolinguals. Where as for less fluent bilinguals and L2 learners this process may require more effortful control in every linguistic choice made. Leading to more demands and greater cognitive load. Much of the literature that has established no bilingual advantage has been conducted with fully fluent bilinguals such as those found in North Wales and the Basque Country (Gathercole et al., 2014; Dũnabeitia et al, 2013).

6.2 Differences in bilingual language use

As bilinguals vary according to when they acquired their languages and how they use them on a daily basis, there is a possibility that these individual differences in language experience may lead to specific cognitive advantages. It may be that there is a link between specific language use and the development of general cognitive ability, and that certain aspects of bilingual language use may introduce advantages in a related aspect of cognitive ability. These aspects of bilingual language use, however, may not be universal to all bilinguals (Prior & Gollan, 2011), It has been proposed that the frequency with which a bilingual switches between their two languages contributes to the bilingual advantage in switching costs. A comparison of Spanish-English and Mandarin-English bilinguals found that the Spanish-English group, who reported that they switched between their two languages more frequently than the Mandarin-English bilinguals, had significantly smaller switching costs in a language switching task (Prior & Gollan, 2011).

The notion that bilinguals can experience aspects of being bilingual to differing degrees (e.g., switching from one language to the other, borrowing from one language, code-switching, a change in language dominance due to higher education), may explain the variability within the bilingual population on tasks relating to executive function, as well as linguistic knowledge. This also provides credence to the suggestion that bilinguals lie on a continuum (Hakuta, 1987). Many studies report that they have chosen balanced bilinguals for their sample, and they report this classification on the basis that the bilingual has spoken both of their languages on a daily basis since infancy (Adesope et al., 2011). However, being a balanced bilingual is not necessarily the same as using both languages on a daily basis (Grosjean, 1994; Grosjean et al., 2003). Truly balanced bilinguals are those individuals who have equal dominance in both languages and those bilinguals are quite rare (Hakuta, 1987). More often than not, a bilingual will be more dominant in one language over the other, and this dominance may switch over the course of an individuals life based upon their linguistic experiences. This, teamed with a lack of knowledge regarding the type of bilingual being tested, can result in unclear information being provided by the experimenter about the participants (Adesope et al., 2011).

If different aspects of bilingual language use do indeed lead to an advantage on those aspects of executive function (i.e. switching), then perhaps a more accurate way of assessing bilingualism and executive function is to consolidate bilingual participant groups according to the specific measures of the executive function being assessed. For example, when evaluating the effect bilingualism has on switching, collect data from each individual participant with regards to how often they use both languages and how often they switch between the two and assess whether the proportion of daily switching predicts performance on a switch task. Or, if assessing whether bilingualism leads to cognitive advantages in suppression, collect data from bilingual participants regarding what their L1 and L2 are, how often they speak both languages daily, whether they consider one language to be more dominant than the other, and therefore how often they suppress their dominant language. It would then be possible to assess whether daily suppression of a dominant language is predictive of more efficient performance on a task that requires suppression of irrelevant information. An example of this would be an individual who has immigrated to a country where their second language is the dominant language of that country. Such bilinguals will need to suppress their dominant first language in order to converse more in their less dominant second language. In turn, this may strengthen the bilinguals' suppression mechanisms and lead to an enhancement in suppression abilities.

Immersion in your L2 due to emigration may be an explanation for the differences found between the early and late bilinguals in Chapter 4. A substantial proportion (63%) of the participants in the late bilingual sample were international students who had moved to the UK to study. For these participants English was their L2, which by studying in the UK they had surrounded themselves with. This immersion into the language and culture of their L2 may be another possible explanation for the differences seen between the two bilingual groups. In this instance a high proportion of the late bilinguals need to inhibit their dominant L1 on a daily basis in order to communicate in their L2 efficiently. In this scenario it could be expected that their inhibitory network may become more adept at dealing with situations, outside of language, that require efficient inhibition and suppression, such as the suppression required to ignore the distracting stimuli in Chapter 4. It would therefore be plausible to look at the data with respect to whether English is the participants L1 or L2 in each of the two bilingual groups. For example, early bilingual L1 English versus early bilingual L2 English and late bilingual L1 English versus late bilingual L2 English. By comparing the groups in this way, it would be possible to ascertain whether the effects seen in the late bilingual group are a result of immersion in the L2 language. Below Figure 1 and Figure 2 illustrate the effects of suppression elicited in response to the distracting stimuli for these newly created participant groups.

Together with the statistics, these new figures demonstrate that immersion in a second language may not necessarily lead to the improved cognitive functions associated with bilingualism. As would be predicted there were no differences within the early bilingual sample when they were grouped according to whether English was the dominant or non-dominant language. For the early bilingual sample, the majority of the participants were fully fluent in Welsh and English, and language dominance would be minimal. Where as in the late bilingual sample, it could be predicted that language dominance and immersion in a non-dominant language may lead to advantages in suppression of attention, as the bilingual in this scenario may have more control over the cognitive processes involved due to frequent and more effortful suppression of a dominant first language. However, for the current sample, there was not a significant difference between the L1 English and L2 English bilinguals in the late group. This is contradictory to previous research with immigrant bilinguals that has shown a bilingual advantage (Chertkow et al., 2010; Engel de Abreu et al., 2012).

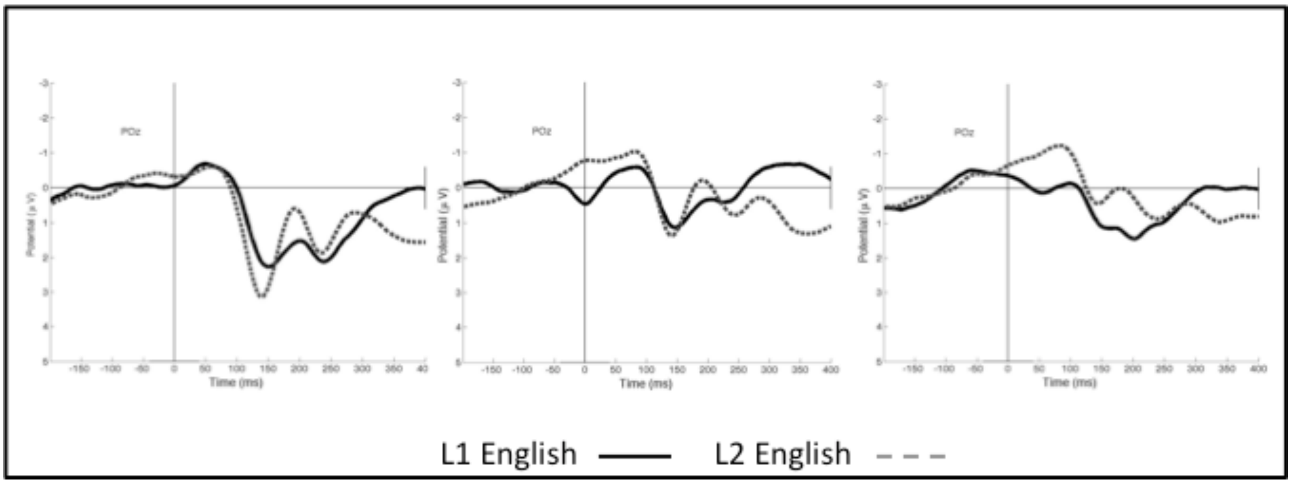


Figure 1. Illustrates the P1 elicited by the early bilingual group when separated into L1 English (N = 11) and L2 English (N = 8). There are no differences between the two early bilingual language groups, F(1,18) = .008 p =.929 η² = .000.

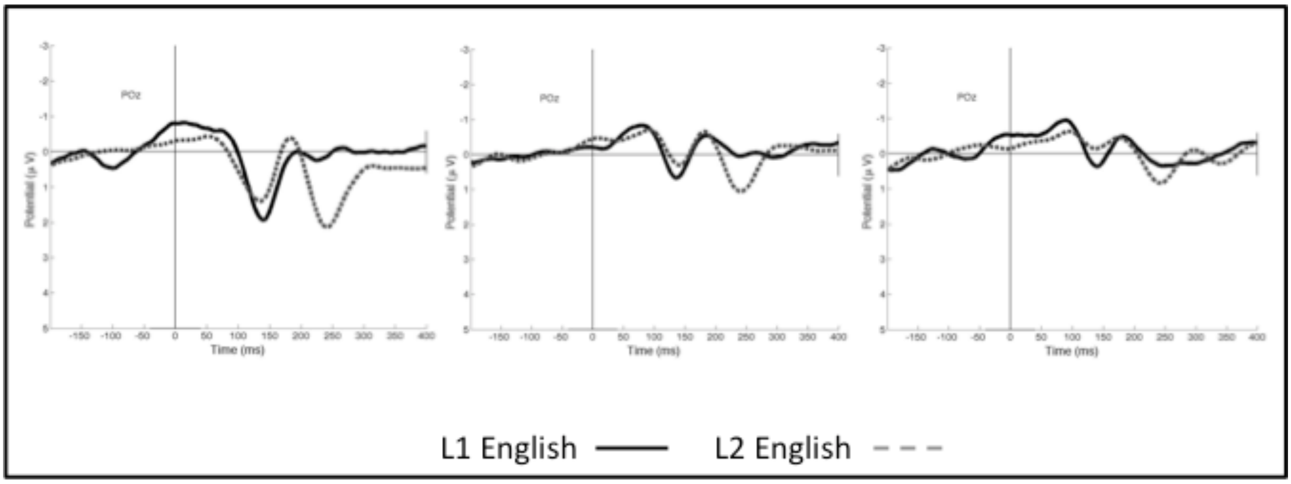


Figure 2. Illustrates the P1 elicited by the late bilingual group when separated into L1 English (N= 7) and L2 English (N = 12). There are no differences between the two late bilingual language groups, F(1,16) = 2.844 p =.111 η² = .151.

In addition to EEG/ERP studies, there have also been MRI studies addressing language usage and experiences, and it’s subsequent effects on the brains plasticity and development. The plasticity of the brain allows it the ability to change structure and function. One of the major contributors to changes in brain structure and function is experience. Experiences such as driving a taxi (Maguire et al.,2003); learning how to play a musical instrument (Gaser & Schlaug, 2003); learning a second language (Mechelli, Crinion, Noppeney, O'Doherty, Ashburner, Frackowiak & Price, 2004) all result in changes to the structure and functionality of the brain. These experiences result in anatomical changes that are correlated with behavioral differences between individuals with and without those changes (Kolb & Whishaw, 1998).

In Chapter 4, electrophysiological differences were discovered between early and late bilingual adults. These differences revealed that the late bilingual group, compared to both the early bilingual and the monolingual group, controlled attention processes more efficiently. These results contradict previous research that has suggested that a bilingual advantage in cognitive processing is only possible if an individual is an early or simultaneous bilingual (Abutalebi, 2007, 2008; Abutalebi et al., 2013). If this was indeed true, it could be expected that acquiring a second language later in childhood would have little effect on brain structure or functionality.

However, a MRI study examining cortical thickness found that when acquisition of a second language (L2) occurs simultaneously with a first language (Age of Acquisition < 3 years) there is no difference in brain structure when compared to monolinguals. However, acquiring an L2 once proficiency has been reached in the first language modifies the brain structure. The later in childhood the L2 is learned the greater the thickness of the left Inferior Frontal Gyrus (IFG) cortex and the thinner the right IFG cortex (Klein, Mok, Chen & Watkins, 2014). The different directions of correlation between Age of Acquisition (AOA) and cortical thickness in the left and right IFG is consistent with patterns of functional lateralization that have been reported previously in bilingual adults (Hull and Vaid, 2007). Bilinguals who learn both their languages by age 6 years show patterns of involvement of both the left and right hemispheres in both languages, but later L2 learners show left hemisphere dominance for both languages. Further, the less proficient an individual is in their L2 the more leftwards the lateralization of function is (Hull & Vaid, 2007). It has been suggested that these structural changes reflect an explicit learning strategy for linking new words to concepts already formed, which is an implicit process when acquiring two languages simultaneously (Richardson et al., 2010).

The association between later acquisition of L2 and thicker cortex in the left IFG may be a result of specific structural changes in brain areas needed to acquire the new skill of speaking a second language, which in turn stimulates new neural growth and connections (Klein et al., 2014). Similar changes in brain areas have occurred when individuals have acquired a new complex motor skill such as juggling (Draganski et al., 2004; Scholz, Klein, Behrens & Johansen-Berg, 2009). Future research should look more closely at the effect learning L2 later in childhood has on brain development. There is evidence that the brains structure and neuronal connections may have the plasticity required to adapt and in turn enhance development of other cognitive functions.

There has been a suggestion that the bilingual advantage that had previously been proposed as the Bilingual Inhibitory Control Advantage (BICA) is better explained as a global Bilingual Executive Processing Advantage (BEPA). This theory was proposed by Hilchey and Klein (2011), who claimed that there is little support in the literature for the BICA proposal, and that the evidence supports a more global executive processing advantage (BEPA), which leads to better performance not only in conflict conditions (incongruous) but also in non-conflict conditions (congruous), particularly for reaction times. The presence of a global advantage has been explained by the proposition that there is a general conflict monitoring system, which is enhanced by bilingualism (Costa et al, 2009). The enhancement of the conflict monitoring system leads to more accurate and faster responses on both congruent and incongruent trials of tasks such as the Simon Task (Paap and Greenberg, 2013).

Although, both the BICA and the BEPA are valid explanations for the presence of a bilingual advantage on executive function tasks, there is data that fails to support both of these theories. The results of a Card Sort Task provided no support for the BICA hypothesis, as there was no bilingual advantage for accuracy or reaction time when the cost of the switch was considered (difference between the first and the second sort). Further, this task found no support for the BEPA hypothesis either, as the there were no differences between bilingual and monolingual groups on the absolute scores for the first versus second sort for both accuracy and reaction time (Gathercole et al., 2014). Additionally, the data collected from a classic Simon Task, also provided no support for the BICA as there was no bilingual advantage for accuracy or reaction time, as all groups performed better on the congruent than incongruent trials (Gathercole et al., 2014). Moreover, no bilingual advantage was found on a Metalinguistic Task that included a grammatical but anomalous (Gm) condition that required a high level of inhibitory control. If the BICA account is correct it could be predicted that bilingual participants would perform better on the Gm condition than monolingual participants due to the demands placed on the inhibitory mechanisms. However, the results demonstrated that the bilingual participants only performed better when the metalinguistic task was conducted in their dominant language, with their home language predicting performance (Gathercole et al., 2014).

6.3 Proficiency and Socioeconomic status

As it has been established there is a degree of individual variability within the bilingual sample. This variability is related to differences in proficiency, culture, SES, education, perennial education, language dominance, and AOA just to name a few. When a bilingual sample contains participants who vary on any number of different demographic factors it is perhaps unwise to attribute any affects of bilingualism found on cognitive tasks solely to experience with multiple languages, as other factors may have contributed to the differences seen between groups (Paap & Greenberg, 2013; Hilchey & Klein, 2011; Valian, 2015).

In Chapter 3, SES, language exposure and linguistic knowledge were predictors of the ERPs elicited during the semantic priming paradigm. For the monolingual group, higher SES predicted a larger amplitude effect, in the 450 - 650 ms time-window time-locked to the picture, for the mismatch condition. Also, the more words the infant produced in English predicted a more negative NSW, in the 200 - 500 ms time-window time-locked to the word, suggesting that the infants who spoke more words were more adept at holding the phonology of the word in working memory. For the bilingual group, SES was positively correlated with condition (both match and mismatch), in the 450 – 650 ms time-window time-locked to the picture, suggesting that SES is a predictor of sematic priming ability in bilingual infants. Also, exposure to Welsh by the mother was also positively correlated with the N400 In the 450 – 650 ms time-window. These results indicate that the amplitude of ERPs elicited during a language task is affected by factors such as SES, language exposure and linguistic knowledge.

In addition to demographic factors such as SES, the amplitude of ERPs elicited during a language task can be affected by linguistic knowledge such as whether the infant has low or high comprehension of the language (Mills & Sheehan, 2007). The level of comprehension the infants had acquired may have affected the results seen in Chapter 3, as there was a large amount of individual variability between infants within each group. Previously, when a working memory component was added to a semantic priming study, 13-month-old infants were unable to hold information regarding the phonology of the word in working memory, resulting in no effects of semantic priming. However, when infant data were grouped according to language comprehension; semantic priming effects were elicited by infants with high comprehension, but not those with low comprehension (Mills & Sheehan, 2007). These results suggest that high levels of comprehension are indicative of a stronger sematic network, as well as suggesting that language processes can affect general cognitive-domain processes such as working memory.

The lack of an interaction between language group and match-mismatch condition in Chapter 3 could perhaps be explained by the variability in the infant sample with regards to levels of comprehension. Figures 3 and 4 illustrate ERPs time-locked to the picture for monolingual and bilingual infants after they have been group according to levels of comprehension. The figures demonstrate that within this current sample, the variability in comprehension within the two language groups cannot explain the lack of an N400 effect within the monolingual and bilingual groups.

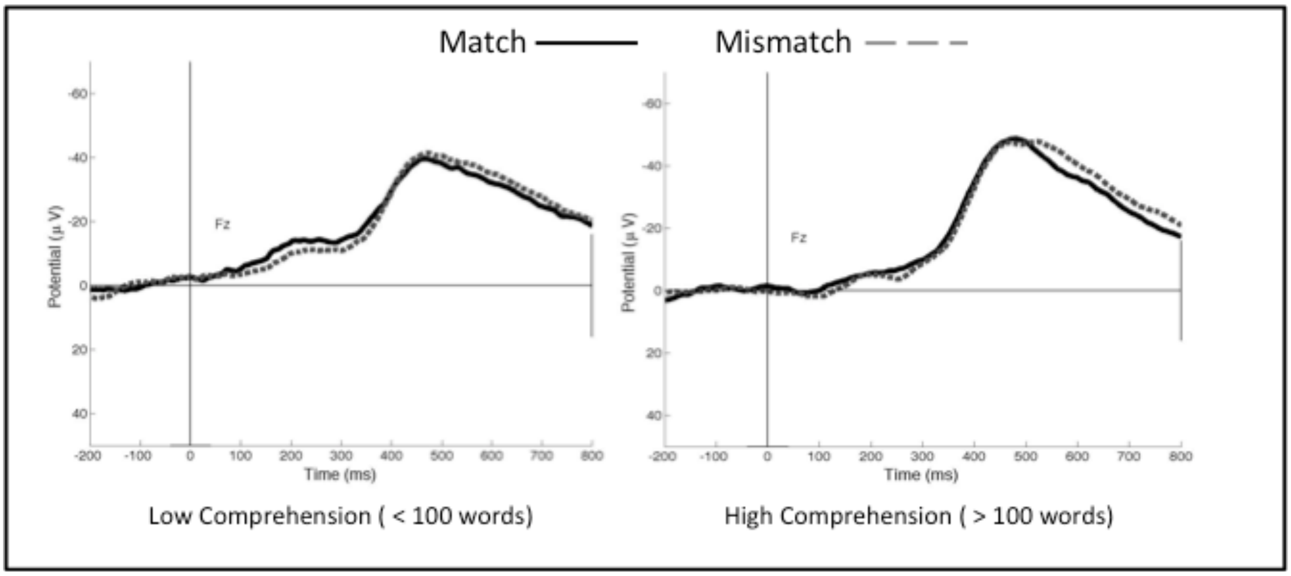


Figure 3. Illustrates the N400 elicited by the monolingual group, when grouped by low (N = 10) and high (N= 16) comprehension.

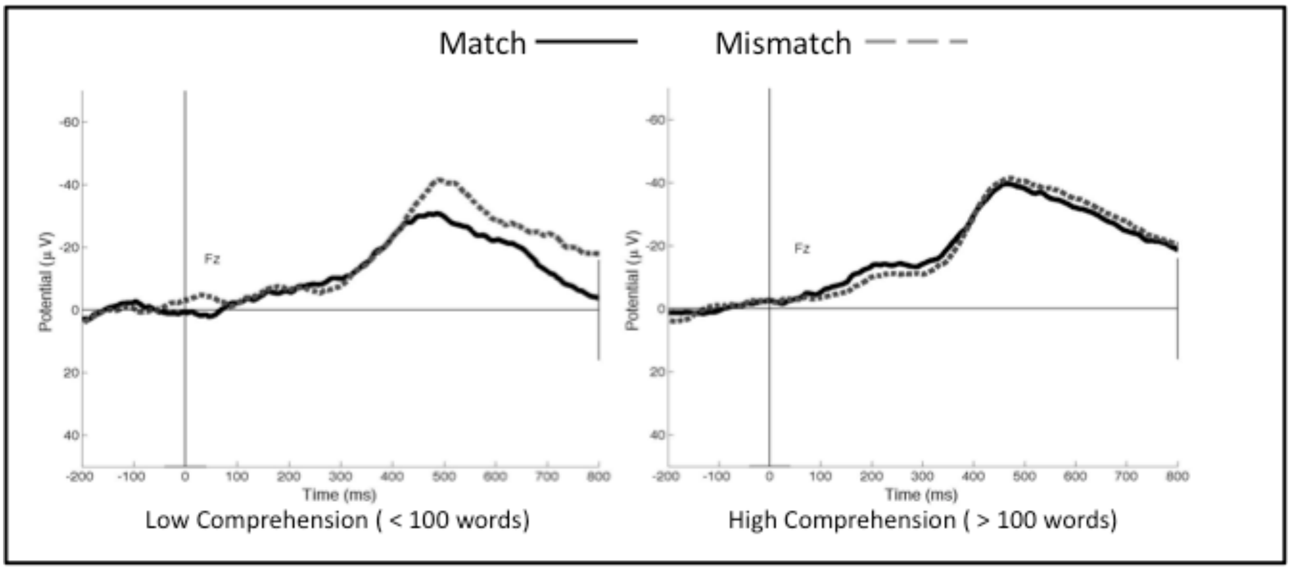


Figure 4. Illustrates the N400 elicited by the bilingual group, when grouped by low (N = 5) and high (N= 21) comprehension.

In a review of the literature Paap and Greenberg (2013) found that there was no bilingual advantage on tasks when highly proficient bilinguals were compared to monolinguals. Although, vocabulary data was not collected from the adult participants in Chapter 4 and 5 (as the task was a non-linguistic task), perhaps information about linguistic knowledge should be collected from participants regardless of whether the task involves a linguistic element. Proficiency may be a significant predictor of language dominance, and it may be that highly proficient bilinguals are those who are the fully fluent early sequential bilinguals whose data has not shown a bilingual advantage (Gathercole et al., 2014; Dũnabeitia et al, 2013). This may perhaps suggest that late bilinguals who have a dominant L1 and a less dominant L2 and therefore are not highly proficient in both their languages may be the bilinguals who will show an advantage on executive function tasks. Therefore, by collecting proficiency scores language dominance may be more accurately gauged, and a better account of bilingual status could be reported. Further, even during non-verbal and non-linguistic tasks such as the Go/No-Go task in Chapter 4 and 5, word familiarity and proficiency may be a modulating factor as individuals may internally vocalize the stimuli involved in the task.

It has been proposed that although fluent bilinguals compared to monolinguals have additional needs for monitoring, switching and inhibitory control, these processes may not be substantial enough to generate group differences in cognitive control (Paap & Greenberg, 2013). Rather, a more plausible alternative is that the advantages bilinguals show in executive functioning are specific to tasks that rely on linguistic representations, as the executive functions bilinguals show an advantage in are located within the language nodule (Fodor, 1983; Frazier, 1987).

A task that taps into both inhibitory mechanisms and the language nodule is the Stroop Task. On the Stroop Task the colour naming effects seen have been related to vocabulary size and proficiency. In a study with Spanish-English bilinguals, the bilingual participants performed equivalently to the monolingual participants except when they were asked to respond in English. Responding in English resulted in slower responses from the bilinguals compared to the monolinguals, and the Spanish dominant were slower than the English dominant and the balanced bilinguals. These results indicate that vocabulary size and proficiency play an important role in performance on the Stroop task, as language dominance affects response time. A study with monolingual and bilingual children in the Basque Country, failed to find any significant differences in performance on a classic verbal Stroop task and a numerical Stroop when the groups were carefully matched for factors such as reading ability, arithmetic, verbal ability, IQ. It appears that performance on a task such as the Stroop, which has been shown to require efficient inhibitory processes to perform successfully, can be affected by language. When participants are matched for linguistic knowledge there does not appear to be a difference in performance on the Stroop task between monolingual and bilingual participants.

Along with proficiency, SES has been suggested to be a possible contributor to previous results reporting a bilingual advantage (Morton & Harper, 2007). Research with children and SES level has demonstrated that SES can have a profound cognitive and neurological effect upon development (Stevens, Lauinger & Neville, 2009). These differences in cognitive and neurological development in childhood, as a result of SES, may contribute to the differences seen between monolingual and bilingual groups on executive function tasks. Prior research that has reported a bilingual advantage on tasks requiring executive functions, has taken its monolingual and bilingual participants from different SES backgrounds (local monolinguals compared to L2 immigrant bilinguals seeking higher education), these differences in SES may contribute to the differences in executive functioning. As the vast differences in SES background of the monolingual and bilingual samples may signify that there are hidden contributing factors within the bilingual data, other than linguistic knowledge, which may lead to differences in performance on executive function tasks (Hilchey & Klein, 2011). When SES, maternal education and perennial education have been considered and controlled for, differences between monolingual and bilingual groups on tasks such as the Simon task and Flanker task are not found (Paap & Greenberg, 2013; Hilchey & Klein, 2011). Across all three studies included in this Thesis, all groups were matched for SES; there were no significant differences between groups and no interactions between the results found and SES or maternal education. It would therefore appear that any differences between groups that have been found could not be attributable to SES. Further, with regards to the results found in Chapter 3, SES may have contributed to the lack of group differences.

6.4 Experience strengthens Cognitive Reserve

During the course of our lifespan we experience changes in cognitive control. The frontal lobes play a key role in cognition, decision-making and executive functions. They are the last cortical areas to fully develop in childhood (Giedd et al., 1999; Casey et al., 2005) and the first to decline in later life (Raz, 2000). It would therefore be appropriate to suggest that executive functions may gradually develop in childhood and similarly show a gradual decline in older adulthood (Diamond, 2002; West, 1996). Essentially executive functions override automatic behaviours and allow an individual the ability to make decisions, selectively attend, and focus on a given task. Resulting in a less salient environment. During the first years of childhood as well as during the older adulthood, individuals are highly influenced by their environment and the ability to refrain from automatic responses is more difficult (Mesulam, 2002). Once executive functions have developed an individual has more control and can be selective about their environment. Taking into account the lifespan of the frontal lobes and the bilingual advantage hypothesis, researchers have been interested in whether bilingualism can delay the cognitive decline associated with aging.

The cognitive reserve hypothesis (Stern, 2003) suggests that over the course of a lifespan individuals engage with experiences that require complex mental activity to perform. This in turn builds a capacity that helps to compensate for neural dysfunction in cognitive domains later in life (Valenzuela & Sachdev, 2006, 2007). By identifying those experiences, whether they are naturally occurring (i.e. bilingualism) or are targeted (i.e. playing video games), that contribute to a stronger cognitive reserve it may be possible to identify the key mechanisms that underlie the benefits associated with these experiences. For example, bilingualism is thought to positively influence cognitive functioning in later life (Bak et al., 2014) and it has been proposed as one factor that may contribute significantly to cognitive reserve, therefore possibly delaying the onset of symptoms associated with AD (Clare et al., 2014).

Other life experiences such as education, and the participation in leisure activities, both intellectual and social, allow some people to cope with AD better than others. Participation in leisure activities throughout the lifespan has been related to slower cognitive decline in healthy elderly and may also reduce the risk of dementia. It has been found that leisure activities result in more efficient cognitive networks and therefore provide a cognitive reserve against AD and and the onset of dementia (Scarmeas & Stern, 2010; Verghese et al., 2006). A 5-year prospective cohort study, found that engaging in a hobby later in life can contribute towards the preservation of cognitive decline (Iwasa et al., 2012).

One such leisure activity that has been shown to provide a cognitive reserve against cognitive decline is playing a musical instrument. It was found that there was a strong predictive effect of high musical activity throughout the life span on preserved cognitive functioning in advanced age (Hanna-Pladdy & MacKay, 2011). Also, a study comparing the performance of monolinguals, bilinguals and musicians on a Simon Task and a Stroop task, found that extended musical experience enhances executive control on a nonverbal spatial task (Simon), as previously shown for bilingualism, but also enhances control in a more specialized auditory task (Bialystok & DePape, 2009).

Physical activity has been found to be positively associated with cognitive reserve (Yaffe et al., 2001). A meta-analytic study found that aerobic fitness training provided robust but selective benefits for cognition, with the largest benefits occurring for executive control processes (Colcombe & Kramer, 2003). Aerobic fitness can come from participating in dancing. Dance provides an individual with an enriched environmental condition, as it not only provides a source of physical activity but also combines it with emotions, social interaction, sensory stimulation, motor coordination and music. It has been found that participating regularly in a dancing schedule into later life can provide protection against decline of cognitive, motor and perceptual abilities (Kattenstroth et al., 2010).

By participating in social, leisure or physical activities individuals are providing themselves with a protective barrier against cognitive decline. It has been shown previously that bilingualism contributes to cognitive reserve (Bak et al., 2014), but other experiences such as dancing, walking, playing the piano can also contribute towards cognitive reserve. Studies with older adults that have established that participating in leisure activities protects against cognitive decline raise the question, do these experiences also contribute towards advantages in executive functioning in young adults and children? Do children who are regularly engaged in a dance class, or young adults who regularly play in an orchestra gain cognitive advantages on cognitive functioning tasks? The results with older adults and cognitive reserve would suggest so.

A simple yet effective paradigm that could be used with different ages to assess whether bilingualism or other experiences leads to advantages in cognitive functions is the Visual working memory (VWM) change detection task. This task would provide information regarding differences both in working memory and cognitive load. During this study subjects are shown an array of objects (e.g. coloured squares) that they must remember. After a delay of about 1 second, the objects reappear and the participant must decide whether the objects are the same or different. This task has been used to assess the storage capacity of the VWM (Luck & Vogel, 1997), how information is represented in the VWM (Alvarez & Cavanagh, 2004; Luck & Vogel, 1997) and the resolution of the information being held in the VWM (Awh et al., 2007). It has been shown that the change detection is a staple measure of VWM. This paradigm used alongside ERPs would provide information regarding the working memory capacity of participants as well as whether cognitive reserve is positively affected by bilingualism. The VWM change detection task, would elicit an early NSW, which would be representative of the retention process occurring during the initial display of the objects. An increase in NSW would be expected as a function of cognitive load, but if there is an advantage of bilingualism on cognitive load then it may be expected that the NSW would not increase to the same extent for the bilinguals as it does for the monolinguals; as they are more adept handling the changes to cognitive load. This paradigm could be used with children, adults and older adults as well as patients because it is such a simple design. Also, it may be interesting to compare monolinguals and bilinguals with individuals who have gained experiences in other domains such as music, dancing and video gaming. If these other experiences also provide an advantage on tasks that require executive functioning then it would be expected that these groups, along with the bilingual group, would show an advantage particularly when cognitive load was high. Further, if advantages in performance are seen from these groups it may interesting to conduct a fMRI study to see if the process of acquiring these different skills changes the structure and neural networks in different ways; and whether the neural networks used to complete the task is different dependent upon the experiences gained.

6.5 Conclusion

To full understand the effect bilingualism has on executive functioning and how the addition of a second language alters brain organization and function, there must be transparency and consistency of information collected and reported regarding those individuals who participate in bilingualism research. As Ernest Hemingway said “If a writer knows enough about what he is writing about, he may omit things that he knows”. Researchers in this field need not align themselves with a particular stand point regarding the bilingualism advantage hypothesis, but must instead align themselves with openness and honesty. As more and more factors relating to demographics and socio-economic status are being considered in this field, those factors need to be regarded as highly as age of acquisition and proficiency in order to fully understand the cognitive mechanisms bilingualism affects.

Further, the results found in the field of bilingualism are not contained to bilingualism. Participating in other experiences such as walking, dancing, music, crosswords, reading can all contribute towards positive changes in cognitive functioning. Experience effects cognitive development, and regularly engaging in experiences such as bilingualism can contribute positively to these changes. It may be that bilingualism, along with other experiences, places demands on cognitive load; and it is the process of managing this cognitive load that results in an advantage on tasks that require executive functioning. Particularly when conflict needs to be resolved.

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8. Appendix

In the following Appendix are copies of the questionnaires and supplementary material used when conducting the three studies.

1. Language Background Questionnaire (Adults)
2. Language Background Questionaire (Infants)
3. List of the words used in the Infant study
4. The Waterloo Handedness Questionnaire
5. A Modified version of the Barratt Simplified Measure of Social Status
6. Communicative Development Inventory
7. 5-Point Likert Scale used for rating the words included in the infant study

QUESTIONNAIRE FOR ADULT PARTICIPANTS

Thank you for agreeing to participate in this study. We would like to get some background information on your language. Please feel free to answer these questions in any way you feel is appropriate, and if there is any question you would rather not answer, that is fine too. Just leave it blank and pass on to the next question.

Name:____
Date of birth:__________________________________
Gender: Male ☐ Female ☐
Place of birth:__________________________________

1. Which languages do you speak? (Please tick all that apply)

☐ English
I began speaking English at age:____________
Please state approximately what percentage of the time you speak English:
A: 100% ☐ B: 75% ☐ C: 50% ☐ D: 25% ☐ E: 0% ☐
Please state approximately what percentage of the time English is currently spoken in the home:
A: 100% ☐ B: 75% ☐ C: 50% ☐ D: 25% ☐ E: 0% ☐

☐ Welsh
I began speaking Welsh at age:____________
Please state approximately what percentage of the time you speak Welsh:
A: 100% ☐ B: 75% ☐ C: 50% ☐ D: 25% ☐ E: 0% ☐
Please state approximately what percentage of the time Welsh is currently spoken in the home:
A: 100% ☐ B: 75% ☐ C: 50% ☐ D: 25% ☐ E: 0% ☐

☐ Other language(s) – please specify:________________________
I began speaking this language at age:____________
Please state approximately what percentage of the time you speak this language:
A: 100% ☐ B: 75% ☐ C: 50% ☐ D: 25% ☐ E: 0% ☐
Please state approximately what percentage of the time this language is currently spoken in the home:
A: 100% ☐ B: 75% ☐ C: 50% ☐ D: 25% ☐ E: 0% ☐

2. Which languages were spoken <u>in your home</u> when you were the following ages? (Including the language used by grandparents and siblings in speaking to you)

A: 100% English
B: about 80% English, 20% Welsh
C: about 60% English, 40% Welsh
D: about 50% English, 50% Welsh
E: about 40% English, 60% Welsh
F: about 20% English, 80% Welsh
G: 100% Welsh
H: other combination (please specify)
I: does not apply or do not know

From birth until I turned two years of age________________
When I was 3 and 4 years of age__________________________
When I was 5 and 6 years of age__________________________

When I was in primary school ______________________________
When I was in secondary school ____________________________
As a younger adult (20 up to 59) ____________________________
As an older adult (60 +) ___________________________________

3. What is your occupation? Please specify:____________________________________

4. Please indicate the highest level of education you have obtained:

Myself:

R 1 2 3 4 5 6	7 8 9	10 11	12 13	1 2 3+	1 2 3+
Primary	Secondary	GCSE	A-level	University	Post-graduate

5. In general, what language(s) can you speak?

Welsh _____ English _____ Other L1: [specify] _____ Other L2: [specify] _____

6. If you know or can remember, approximately when did you begin to speak each language?

Welsh:

a. As long as I can remember: ______

b. Since before going to school: ______

c. Once I started primary school: ______

d. Not until I started secondary school: _____

e. I learnt it as an adult

English:

a. As long as I can remember: ______

b. Since before going to school: ______

c. Once I started primary school: ______

d. Not until I started secondary school: _____

e. I learnt it as an adult

Other language:

a. As long as I can remember: ______

b. Since before going to school: ______

c. Once I started primary school: ______

d. Not until I started secondary school: _____

e. I learnt it as an adult

Please use the following choices to answer the questions below:

W: (almost) always Welsh
MW: more Welsh than English
B: both Welsh and English about equally
ME: more English than Welsh
E: (almost) always English

O: other language

?: I don't know

		Before you went to school	In primary school	In secondary school years	As an adult
7. A.	What language or languages did/does your mother speak to you in the home at the following ages:				
7. B.	What language or languages did/do you speak to your mother at the following ages:				
8. A.	What language or languages did/does your father speak to you in the home at the following ages:				
8 B.	What language or languages did/do you speak to your father at the following ages:				
9 A.	What language or languages did/do your brothers and sisters speak to you in the home at the following ages:				
9 B.	What language or languages did/do you speak to your brothers and sisters at the following ages:				
10 A.	What language or languages did/do your friends speak to you at the following ages:				
10 B.	What language or languages did/do you speak to speak to your friends at the following ages:				

	In nursery [if relevant]	In primary school	In after-school club [if relevant]	In secondary school years	In any further education [if relevant]

11 A.	What language or languages did your teachers use as a medium of education in the classroom at the following ages:					
11 B.	What language or languages did your teachers speak to you outside of the classroom (e.g., on the playground) at the following ages:					
11 C.	What language or languages did you use in response to your teachers in the classroom at the following ages:					
11 D.	What language or languages did you use to speak to your teachers outside the classroom at the following ages:					
	What school(s) did you attend?					

12. Were there any other adults that you frequently interacted with as a child (for example, grandparents, aunts/uncles, etc.)?

How frequently did you see them?

What language(s) did they speak?

Frequency	Language(s)	
a. more than once a wk	W.	(almost) always Welsh,
b. 1/wk-1/mo,	W>E:	more Welsh than English
c. 1/mo or less	B.	both Welsh and English about equally
	E>W:	more English than Welsh
	E.	(almost) always English
	O.	other language
	?:	I don't know

Grandparents (all) ____________ ________________________

Aunts/Uncles (all) ____________ ________________________

Other (carer, neighbour, etc.) (all)

____________ ________________________

13. As a child, did you participate in any of the following activities:

A. Yr Urdd _____

B. Local or national Eisteddfodau _____

C. Cubs/Scouts or Brownies/Girl Guides: (in Welsh mostly) _____, (in English mostly) _____, (in Welsh and English about equally) _____

D. Sports activities (e.g., tennis, football, rugby, hockey, etc.): (in Welsh mostly) _____, (in English mostly) _____, (in Welsh and English about equally) _____

E. Welsh-speaking chapel or church _____

F. English-speaking chapel or church _____

G. Other (please specify): ____(in Welsh mostly) _____, (in English mostly) _____, (in Welsh and English about equally) _____

14. A. On a scale of 1 to 5 (5 highest), how well do you feel you **speak** Welsh?

1	2	3	4	5
Only know some words and expressions		Can carry out basic conversations		Can carry out extended conversations

Comments: ______________________________

B. On a scale of 1 to 5 (5 highest), how well do you feel you **speak** English?

1	2	3	4	5
Only know some words and expressions		Can carry out basic conversations		Can carry out extended conversations

Comments: ______________________________

15. A. On a scale of 1 to 5 (5 highest), how well do you feel you **understand** Welsh?

1	2	3	4	5
Only know some words and expressions		Can understand basic conversations		Can understand all or most conversations

Comments: ______________________________

B. On a scale of 1 to 5 (5 highest), how well do you feel you **understand** English?

1	2	3	4	5
Only know some words and expressions		Can understand basic conversations		Can understand all or most conversations

Comments: ______________________________

16. A. On a scale of 1 to 5 (5 highest), how well do you feel you **read** Welsh?

1 2 3 4 5

I can only read a little	I can read most things reasonably well	I can read almost anything very well

Comments: ______________________________________

B. On a scale of 1 to 5 (5 highest), how well do you feel you **read** English?

1	2	3	4	5
I can only read a little		I can read most things reasonably well		I can read almost anything very well

Comments: ______________________________________

17. A. On a scale of 1 to 5 (5 highest), how well do you feel you **write** Welsh?

1	2	3	4	5
I only know how to write a few words and expressions		I can only write simple things		I can write practically anything I want

Comments: ______________________________________

B. On a scale of 1 to 5 (5 highest), how well do you feel you **write** English?

1	2	3	4	5
I only know how to write a few words and expressions		I can only write simple things		I can write practically anything I want

Comments: ______________________________________

18. A. When you receive bilingual mailings or forms, which language version do you typically read?

a. _____ Always Welsh

b. _____ Usually Welsh

c. _____ Some of both

d. _____ Usually English

e. _____ Always English

B. When you receive bilingual mailings or forms, which language version do you typically fill in?

a. _____ Always Welsh

b. _____ Usually Welsh

c. _____ Some of both

d. _____ Usually English

e. _____ Always English

C. If you phone a telephone helpline that gives you a choice of language [e.g., gas, bank, train], what language or languages do you choose?

a. _____ Always Welsh

b. _____ Usually Welsh

c. _____ Some of both

d. _____ Usually English

e. _____ Always English

19. On a scale of 1 to 5 (5 highest), how confident do you feel speaking Welsh?

a. in formal contexts [e.g., job interviews, speaking to your boss, etc.]

1	2	3	4	5	Not Applicable
Not		Neutral		Very	

confident at all				confident	

b. in <u>informal</u> contexts [e.g., with your friends, at a party, at a football game, etc.]

1	2	3	4	5	Not Applicable
Not confident at all		Neutral		Very confident	

20. On a scale of 1 to 5, how confident do you feel speaking English?

a. in <u>formal</u> contexts [e.g., job interviews, speaking to your boss, etc.]

1	2	3	4	5
Not confident at all		Neutral		Very confident

b. in <u>informal</u> contexts [e.g., with your friends, at a party, at a football game, etc.]

1	2	3	4	5
Not confident at all		Neutral		Very confident

21. Have you ever undergone speech or language therapy?
Yes ☐ No ☐

22. Have you ever been treated for a hearing problem?
Yes ☐ No ☐

23. Have you ever been diagnosed with dyslexia?
Yes ☐ No ☐

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE

Family History and Language Exposure Questionnaire

Dear Parent,
This information is for purposes of our research only and will be kept strictly confidential. You are free to decline to answer any questions you do not want to answer.

Date:_________________

Child's Name:____

Boy or Girl? ________________________

Date of Birth:____

Place of Birth:____

Has your child always resided in North Wales? YES______ NO_______

If your child was born outside of North Wales, or spent some time living in another area, where did s/he live, and at what age did he or she come to North Wales?
____

Parents: Name, Age, Occupation, Highest level of education

Mother:____

Father:____

Address:____

____

Phone Number: _________________________

Marital Status: Married or living with partner_____ Single______ Divorced _____ Separated_____

Handedness: Mother: **LEFT RIGHT** Father: **LEFT RIGHT**

Siblings:

AGE	SEX	HANDEDNESS
	M F	**L R**
	M F	**L R**
	M F	**L R**

If you had to say, does your child prefer to use his/her right or left hand?
____

Language(s) spoken by parents/guardians to the child (Please tick all that apply and fill in percentages):

Mother: Percent of time speaking each language to the child:

_____ English (approximately ____ % of the time)

_____ Welsh (approximately ____ % of the time)

_____ Other (please specify:___________) (approximately _____ % of the time)

Have you always resided in North Wales? If not, please indicate where else you have lived, and when:____

____

Please indicate when you began to speak Welsh: Age ______

Please indicate when you began to speak English: Age ______

Please indicate how well you feel you **speak** (a) Welsh ______, (b) English _____
[Please note, we are only asking about speaking ability, not reading or writing ability.]

A. Native speaker or native-like; can carry out extended conversations
B. Not a native speaker, but can carry out basic conversations
C. Not a native speaker, only know some words and expressions

Comments: ____

Father: Percent of time speaking each language to the child:

____ English (approximately ____ % of the time)

_____ Welsh (approximately ____ % of the time)

_____ Other (please specify:___________) (approximately _____ % of the time)

Have you always resided in North Wales? If not, please indicate where else you have lived, and when:____
____

Please indicate when you began to speak Welsh: Age ______

Please indicate when you began to speak English: Age ______

Please indicate how well you feel you **speak** (a) Welsh ______, (b) English _____
[Please note, we are only asking about speaking ability, not reading or writing ability.]

A. Native speaker or native-like; can carry out extended conversations
B. Not a native speaker, but can carry out basic conversations
C. Not a native speaker, only know some words and expressions

Comments: ____

Language(s) spoken by siblings to the child:

Older siblings:

_____ English (approximately ____ % of the time)

_____ Welsh (approximately ____ % of the time)

_____ Other (please specify:___________) (approximately _____ % of the time)

Younger siblings:

_____ English (approximately ____ % of the time)

_____ Welsh (approximately ____ % of the time)

_____ Other (please specify:___________) (approximately _____ % of the time)

What languages are spoken in the home and by whom? ________________________
____

For languages other than English please specify how many hours per week your child hears each language ____

Is your child exposed to a language other than English outside the home?
Please specify (i.e., language, and how often):_________________________________
____

What was the mother's age at the time of pregnancy?_____________________

Where there any medical problems during this pregnancy?_________________
____

Approximately how many alcoholic beverages per month did the mother drink during this pregnancy? ___________________

Did the mother take any prescription and/or nonprescription medication including antidepressants during this pregnancy? __________________
If yes, what kinds?____

Was the child full term? (please specify number of weeks gestational age at birth) ____
Birth weight___________________
Apgar Score__________________
Birth complications_____________

At what age did your child first sit up on his/her own?________________________

At what age did your child first walk on his/her own?__________________________

At what age did your child say his/her first recognizable word (other than "mama" or "dada")?____

What was the word?____

What was going on when the child said the word?_____________________________

Does your child attend nursery or preschool?_________________________________

Does your child attend day care?____

How frequently does your child attend?_____________________________________

What type of daycare setting does your child attend - in a home or business setting?
____

How many other children attend the daycare? _________________________

What is the ratio of adults to children in the daycare? _____________________

Has your child ever had the below? If yes, describe frequency or duration:
Seizures?____
Prolonged illness?____
Ear infections?____

Has your child ever had problems with hearing?____________________________
If yes describe:____

Has any family member ever had any of the below? If yes, note relation to the child:

Language problems:____

Speech problems:____

Reading problems:____

Hearing problems:____

Autism or autism spectrum disorder __________________________________

Genetic or neurological disorders (please specify) ______________________

Did the mother experience depression during pregnancy?
Yes No

Did the mother experience depression during the child's first year of life?
Yes No

If yes, was this diagnosed by a healthcare professional, and how was the depression treated?
____

Has the mother and/or father EVER been depressed?

Mother (other than pregnancy or postpartum): YES NO

Father: YES NO

If YES, please briefly describe frequency, duration, severity and treatment of episodes.

____
____

Stimuli List for the Infant Study

Airplane
Apple
Ball
Balloon
Banana
Bath
Bed
Bird
Biscuit
Blanket
Book
Bottle
Brush
Bunny
Car
Cat
Cereal
Chair
Cheese
Cup
Dog
Doll
Door
Duck
Ear
Eye
Flower
Foot
Glasses
Hair
Hat
Horse
Juice
Keys
Kitten
Milk
Mouth
Nappy
Nose
Phone
Pram
Shoe
Sock
Spoon
Teddy Bear
Toe
Toothbrush
Toy
Tree
Truck
Tummy
TV
Water

Participant Name:_____________ Participant No.:______Date:_____________

Study Name:_________________ Age:______ Investigator:____________

Eye dominance (slot test):______ Kicking foot:_______

Waterloo Handedness Questionnaire

Which hand would you use when you:

(Circle one response for each item)

	Left always	Left usually	Equal	Right usually	Right always
1. Draw	-2	-1	0	1	2
2. Write	-2	-1	0	1	2
3. Hammer	-2	-1	0	1	2
4. Use a pencil rubber	-2	-1	0	1	2
5. Use a toothbrush	-2	-1	0	1	2
6. Hold a sewing needle	-2	-1	0	1	2
7. Cut bread with a knife	-2	-1	0	1	2
8. Swing a tennis racket	-2	-1	0	1	2
9. Throw a ball	-2	-1	0	1	2
10. Shave with a razor	-2	-1	0	1	2
11. Strike a match	-2	-1	0	1	2
12. Use a fly swatter	-2	-1	0	1	2
13. Use tweezers	-2	-1	0	1	2
14. Roll a marble	-2	-1	0	1	2
15. Use a comb	-2	-1	0	1	2

WHQ score:_______ Group Classification:_______ Overall Classification:_____

The Barratt Simplified Measure of Social Status (BSMSS)
Measuring SES
Will Barratt, Ph.D.

Mark the appropriate box for your Mother's, your Father's, your Spouse / Partner's, and your level of school completed and occupation. If you grew up in a single parent home, mark only the box from your one parent. If you are neither married nor partnered, only mark the box relevant to you. If you are a full time student mark only the boxes for your parents.

Level of School Completed	Mother	Father	Spouse	You
Primary School (Age 11)				
Partial Comprehensive				
Comprehensive School (GCSE)				
6th Form College (AS/A Levels)				
Partial University (at least one year)				
Undergraduate Degree				
Postgraduate Degree				

Mark the appropriate box for your Mother's, your Father's, your Spouse / Partner's, and your occupation. If you grew up in a single parent home, mark only the box for your parent. If you are not married or partnered mark only the box relevant to you. If you are still a full-time student only mark the boxes for your parents. If you are retired use your most recent occupation.

Occupation	Mother	Father	Spouse	You
Day laborer, janitor, house cleaner, farm worker, fast food sales, food preparation worker, or waiter/waitress.				
Refuse collector, fast food cook, taxi driver, shoe sales, assembly line worker, masons, or baggage porter.				
Painter, skilled construction trade, sales assistant, truck driver, cook, sales counter or general office clerk.				
Car mechanic, typist, locksmith, farmer, carpenter, receptionist, construction laborer, or hairdresser.				
Machinist, musician, bookkeeper, secretary, insurance sales, cabinetmaker, personnel specialist, or welder.				
Supervisor, librarian, aircraft mechanic, artist and artisan, electrician, administrator, military enlisted personnel, or buyer.				
Nurse, skilled technician, medical technician, counselor, manager, police				

and fire personnel, financial manager, physical, occupational, or speech therapist.				
Mechanical, nuclear, and electrical engineer, educational administrator, veterinarian, military officer, elementary, high school and special education teacher.				
Physician, attorney, professor, chemical and aerospace engineer, judge, company director, senior manager, public official, psychologist, pharmacist, or accountant.				

Name: ________________________

Date: _________________________

Child's Date of Birth: _____________

Vocabulary Checklist

We would like to know how familiar your child is to the words that we will use in the experiment. Please go through this list and check under:

"DK" if you DO NOT KNOW whether s/he understands or says the word
"1" if you are sure s/he does NOT understand or say the word
"2" if you are fairly sure s/he does NOT understand or say the word
"3" if you are fairly sure s/he DOES understand or say the word
"4" if you are certain s/he DOES understand or say the word

A child probably understands the meaning of a word if s/he reacts to or says it in more than one specific situation. For example, if a child points to or says "cat" in the presence of only one cat, that is less strong evidence for knowing the meaning of a word than if s/he reacts to several different cats in the same way.

If your child uses a different word from the one we have on the list (for example, "nana" instead of "grandma", or "buggy" instead of "stroller") or a different pronunciation of a word (for example, "raffe" instead of "giraffe"), check the word, but write your child's version next to it. We have included many words in the list, but no one child says all of these or even most of them.

	UNDERSTANDS					SAYS					
	DK	1	2	3	4	DK	1	2	3	4	
bird											bird
coat											coat
train											train
table											table
dog											dog
cereal											cereal
tummy											tummy

	UNDERSTANDS					SAYS					
	DK	1	2	3	4	DK	1	2	3	4	
glasses											glasses
bear											bear
bunny											bunny
cat											cat
biscuit											biscuit
bread											bread
carrot											carrot
cow											cow
puppy											puppy
bike											bike
duck											duck
horse											horse
car											car
truck											truck
apple											apple
banana											banana
milk											milk
nappy											nappy
hat											hat
shoe											shoe
eye											eye
foot											foot
hair											hair
hand											hand
nose											nose
toes											toes
ball											ball
bin											bin
boot											boot
book											book
blanket											blanket
bottle											bottle
brush											brush
bus											bus
cup											cup
keys											keys
window											window

	UNDERSTANDS					SAYS					
	DK	1	2	3	4	DK	1	2	3	4	
spoon											spoon
(tele)phone											(tele)phone
toothbrush											toothbrush
chair											chair
door											door
TV											TV
flower											flower
cake											cake
clock											clock
teeth											teeth
baby											baby
bath											bath
tomato											tomato
tractor											tractor
trousers											trousers
ear											ear
pram											pram
balloon											balloon
teddy(bear)											teddy(bear)
airplane											airplane
bed											bed
bib											bib
block											block
bubble											bubble
cheese											cheese
doll											doll
finger											finger
head											head
juice											juice
kitten											kitten
lorry											lorry
mouth											mouth
sock											sock
stairs											stairs
toy											toy
tree											tree
water											water

Welsh English Bilingual

Communicative Development Inventory

Annwyl Rhiant,

Yn dilyn, ceir rhestr o eiriau Saesneg a Chymraeg sydd yn codi'n aml yng ngeirfa plant. Os mai dim ond yr un iaith y mae eich plentyn yn ei glywed, yna llenwch y darnau hynny sy'n berthnasol i'ch plentyn yn unig. Os yw eich plentyn yn deall neu'n dweud y geiriau Cymraeg a Saesneg_ e.e "ci a "dog"mae angen nodi'r ddau air hynny. Mae plentyn mwy na thebyg yn *deall* ystyr gair os yw'n ymateb i'r gair mewn mwy nag un sefyllfa benodol gyda sawl esiampl wahanol. Pan fo plant yn dechrau siarad, mae ganddynt eu ffordd eu hunain o ddweud gair yn aml. Os yw eich plentyn yn defnyddio gair neu ynganiad gwahanol i'r un sydd ar y rhestr (e.e "bici am fisged neu "teli" am deledu), gwiriwch y gair ond ysgrifennwch fersiwn eich plentyn nesaf ato.

A wnewch chi farcio'r geiriau hynny y credwch chi y mae eich plentyn un ai'n eu deall **NEU'n** eu deall ac yn eu dweud yn y naill iaith neu'r llall, neu'r ddwy iaith.

O ran y geiriau y credwch chi y mae eich plentyn **yn eu deall yn Gymraeg ond ddim eto yn eu defnyddio,** rhowch farc yn y golofn gyntaf, wedi'i labelu "D"(Dallt)

	D	**D/D**
bwrdd	●	○

O ran y geiriau y credwch chi y mae eich plentyn **yn eu deall ac yn eu dweud yn Gymraeg**, rhowch farc yn yr ail golofn, wedi'i labelu **"D/D**" (**D**allt / **D**weud).

	D	**D/D**
bwrdd	○	●

O ran y geiriau y credwch y mae eich plenty **yn eu deall yn Saesneg ond ddim eto yn eu dweud,** rhowch farc yn y golofn gyntaf, wedi'i labelu U.

	U	**U/S**
table	●	○

O ran y geiriau y credwch chi y mae eich plentyn yn **eu deall and ac yn eu dweud yn Saesneg** gosodwch farc yn yr ail golofn wedi'i labelu "**U U/S**" (**D**eall / **D**weud).

	U	**U/S**
table	○	●

Mae'r stocrestr hwn yn gatalog eang o eiriau sy'n cael ei ddefnyddio gan lawer o blant wahanol ar draws ystod eang, felly peidiwch â phoeni os mai dim ond ychydig ohonynt y mae eich plentyn yn ei wybod ar hyn o bryd!

Os oes gennych unrhyw sylwadau neu wybodaeth ychwanegol y tybiwch y dylem eu hystyried, yna ychwanegwch rheini ar ddiwedd y stocrestr hwn.

Diolch yn fawr

*Mae'r inventory hwn wrthi'n cael ei ddatblygu ar hyno bryd fel addasiad awdurddedig o Stocrestr Datblygiad Cyfathrebol Mac-Arthur Bates(CDI).Am ragor o wybodaeth a chopïau gwreiddiol o CDI MacArthur-Bates, yna cysylltwch â'r Labordy Seicoleg Ddatblygiadol, Prifysgol Talaith San Diego, San Diego, CA 92182, UDA.

Welsh English Bilingual

Communicative Development Inventory

Dear Parent,

Following is a list of English and Welsh words that often occur in children's vocabularies. If your child hears only one language, simply fill out the sections that apply to your child. If your child understands or says both the Welsh and English words (for example, "ci" and "dog") please mark both words.

Children often understand many more words than they say. A child probably *understands* the meaning of a word if s/he reacts to the word in more than one specific situation or with several different examples. When children start to talk they often have their own way of saying a word. If your child uses a different word or pronunciation from the one we have on the list (for example, 'bickie' for biscuit, or 'telly' for television), check the word, but write your child's version next to it.

Please mark the words you believe your child either understands **OR** understands and says, in either or both languages.

For words that you believe your child **understands in Welsh but does not yet say**, please place a mark in the first column labelled "**D**" (**D**allt).

	D	D/D
bwrdd	●	○

For words that you believe your child **understands and says in Welsh**, please place a mark in the second column labelled "**D/D**". (**D**allt / **D**weud).

	D	D/D
bwrdd	○	●

For words that you believe your child **understands in English but does not yet say**, please place a mark in the first column labelled "**U**" (**U**nderstands).

	U	U/S
table	●	○

For words that you believe your child **understands and says in English**, please place a mark in the second column labelled "**U/S**" (**U**nderstands / **S**ays).

	U	U/S
table	○	●

This inventory is a comprehensive "catalogue" of words that are used by many different children across a wide age range, so do not worry if your child knows only a few of them at the moment!

If you have any additional comments or information that you think we should consider, please add these at the end of this inventory.

Thank you very much!

*This inventory is currently under development as an authorized adaptation of the MacArthur-Bates Communicative Development Inventory (CDI). For information and original copies of the MacArthur-Bates CDI, please contact the Developmental Psychology Lab, San Diego State University, San Diego, CA 92182, USA.

Welsh English Bilingual

Communicative Development Inventory

Participant code ....

Eich enw: ....
Enw'r plentyn: .... Gwryw/Benyw: ....
Dyddiad geni'r plentyn: ....../....../........ Dyddiad heddiw: ....../....../........
Yn y cartref ydy eich plentyn yn clywed yn bennaf:
Cymraeg....... Saesneg......... Cymraeg a Saesneg............ Ieithoedd eraill.......................................

PART I EARLY WORDS

A. ARWYDDION CYNTAF BOD Y PLENTYN YN DEALL

Cyn i blant ddechrau siarad, maent yn dangos arwyddion eu bod yn deall iaith trwy ymateb i eiriau ac ymadroddion cyfarwydd. Isod ceir rhai enghreifftiau cyffredin. Ydy eich plentyn yn gwneud unrhyw un o'r rhain?

	Ydi	Nac Ydi
Ymateb pan elwir ei enw (e.e. trwy droi ac edrych ar y person sy'n siarad).	O	O
Ymateb i "na na" (trwy stopio beth mae'n ei wneud, o leiaf am eliad).	O	O
Ymateb i "dyna mami/dadi" trwy edrych o'i gwmpas.	O	O

B. YMADRODDION

Yn y rhestr isod, marciwch yr ymadroddion y mae eich plentyn fel pe bai yn eu deall.

	D		D		D
Wyt ti isio bwyd?	O	Paid â chyffwrdd.	O	Agor dy geg.	O
Wyt ti wedi blino/eisisu cysgu?	O	Coda.	O	Eistedd.	O
		Rho fo i Mam.	O	Poera fo allan.	O
Bydd yn ofalus.	O	Ty'd i gael hyg/ ty'd i gael mwytha.	O	Paid.	O
Bydd ddistaw.	O			Amser bei-beis/amser gwely.	O
Curo dwylo.	O	Rho sws i mi.	O	Tafla'r bêl.	O
Newid Clwt.	O	Dos i nôl_____.	O	Eisiau mynd am dro?	O
Ty'd yma/ty'd yn dy flaen.	O	Hogan dda/ hogyn da.	O		
Mae Dadi/Mami adre.	O	Sa'n llonydd	O		
Wyt ti isio mwy/rhagor?	O	Amser bei-beis.	O		
Paid â gwneud hynna.	O	Yli/Drycha/Sbia.	O		

C. DECHRAU SIARAD

1. Weithiau mae plant yn hoffi dynwared pethau maen nhw newydd eu clywed, fel parot (mae hyn yn cynnwys geiriau newydd maen nhw'n eu dysgu, ac/neu rannau o frawddegau, er enghraifft, ailadrodd "gwaith rŵan" ar ôl i'r fam ddweud "Mae Mam yn mynd i'r gwaith rŵan".) Pa mor aml mae eich plentyn yn dynwared geiriau?

Byth	Weithiau	Yn aml
○	○	○

2. Mae rhai plant yn hoffi mynd o gwmpas yn enwi neu'n labelu pethau, fel pe baen nhw'n falch eu bod yn gwybod yr enwau ac yn dymuno dangos hyn. Pa mor aml mae eich plentyn yn gwneud hyn?

Byth	Weithiau	Yn aml
○	○	○

Welsh English Bilingual

Communicative Development Inventory

Participant code ....

Your name: ....
Childs name: ....
Birth date of child: ....../....../........
Male/Female: ....
Today's Date: ....../....../........
At home does your child predominantly hear:
Welsh .... English .... Welsh and English .... Other Languages ....

PART I EARLY WORDS

A. FIRST SIGNS OF UNDERSTANDING

Before children begin to speak, they show signs of understanding language by responding to familiar words and phrases. Below are some common examples. Does your child do any of these?

	Yes	No
Respond when name is called (e.g. by turning and looking at source).	O	O
Respond to "no no" (by stopping what he/she is doing, at least for a moment).	O	O
React to "there's mommy'daddy" by looking around for them.	O	O

B. PHRASES

In the list below, please mark the phrases that your child seems to understand.

	U		U		U
Are you hungry?	O	Don't touch.	O	Open your mouth.	O
Are you tired/sleepy?	O	Get up.	O	Sit down.	O
Be careful.	O	Give it to mommy.	O	Spit it out.	O
Be quiet.	O	Give me a hug.	O	Stop it.	O
Clap your hands.	O	Give me a kiss.	O	Time to go night night.	O
Change nappy.	O	Go get ____.	O	Throw the ball.	O
Come here/come on.	O	Good girl/boy.	O	This little piggy.	O
Daddy's mommy's home.	O	Hold still.	O	Want to go for a ride?	O
Do you want more?	O	Let's go bye bye.	O		
Don't do that.	O	Look/look here.	O		

C. STARTING TO TALK

1. Sometimes children like to "parrot" or imitate things that they've just heard (including new words that they are just learning, and/or parts of sentences, for example, repeating "work now" after mother says "Mummy's going to work now.") How often does your child imitate words?

Never	Sometimes	Often
◯	◯	◯

2. Some children like to go around naming or labelling things, as though proud of knowing the names and wanting to show this. How often does your child do this?

Never	Sometimes	Often
◯	◯	◯

D. RHESTR GEIRIAU
VOCABULARY CHECKLIST

Yn dilyn, ceir rhestr o eiriau Saesneg a Chymraeg sydd yn codi'n aml yng ngeirfa plant. Os mai dim ond yr un iaith y mae eich plentyn yn ei glywed, yna llenwch y darnau hynny sy'n berthnasol i'ch plentyn yn unig. Os yw eich plentyn yn deall neu'n dweud y geiriau Cymraeg a Saesneg_ e.e "ci a "dog"mae angen nodi'r ddau air hynny.

Following is a list of English and Welsh words that often occur in children's vocabularies. If your child hears only one language, simply fill out the sections that apply to your child. If your child understands or says both the Welsh and English words (for example, "ci" and "dog") please mark both words.

1. EFFEITHIAU SAIN A SEINIAU ANIFEILIAID
SOUND EFFECTS AND ANIMAL NOISES

	D	D/D		U	U/S		U	U/S
aaw	O	O	baa baa	O	O	ouch	O	O
bab-bab	O	O	choo choo	O	O	quack	O	O
bei-beis	O	O	cockadoodledoo	O	O	uh oh	O	O
brwm-brwm	O	O	grr	O	O	vroom	O	O
iym-iym /nym-nyms	O	O	meow	O	O	woof	O	O
			moo	O	O	yum	O	O

2. ENWAU ANIFEILIAD (GO IAWN NEU DEGAN)
ANIMALS (REAL OR TOY)

	D	D/D		U	U/S		D	D/D		U	U/S
aderyn	O	O	bird	O	O	gwenyn	O	O	bee	O	O
anifail	O	O	animal	O	O	(g)wiwer	O	O	squirrel	O	O
arth	O	O	bear	O	O	gwydd	O	O	goose	O	O
asyn	O	O	donkey	O	O	chwaden/hwyad	O	O	duck	O	O
buwch	O	O	cow	O	O	llew	O	O	lion	O	O
carw	O	O	deer	O	O	llyffant	O	O	frog	O	O
cath	O	O	cat	O	O	llygoden	O	O	mouse	O	O
cath fach	O	O	kitten	O	O	merlen	O	O	pony	O	O
ceffyl	O	O	horse	O	O	mochyn	O	O	pig	O	O
ci	O	O	dog	O	O	oen	O	O	lamb	O	O
ci bach	O	O	puppy	O	O	pili-pala	O	O	butterfly	O	O
crwban	O	O	turtle/tortoise	O	O	pysgodyn	O	O	fish	O	O
cwy/cyw iâr/iâr	O	O	chicken	O	O	pry cop(yn)	O	O	spider	O	O
cwningen	O	O	rabbit/bunny	O	O	tylluan	O	O	owl	O	O
dafad	O	O	sheep	O	O						

Mae rhai eiriau yn swnio'r rhy fath yn Saesneg a Chymraeg, llenwch y cylchoedd sy'n berthnasol i'ch plentyn.
Several words sound the same in Welsh and English—please mark the appropriate circle if your child understansands or says any of these words.

	D/U	D/S		D/U	D/S		D/U	D/S
eliffant/elephant	O	O	mwnci/monkey	O	O	teigr/tiger	O	O
jiraff/giraffe	O	O	pengwin/penguin	O	O	twrci/turkey	O	O

3. CERBYDAU (GO IAWN NEU DEGAN)
VEHICLES (REAL OR TOY)

	D	D/D		U	U/S		D	D/D		U	U/S
awyren/eroplên	O	O	aeroplane/plane	O	O	injan dan	O	O	fire engine	O	O
beic	O	O	bicycle/bike	O	O	beic modur	O	O	motor bike/moto beic	O	O
cwch	O	O	boat	O	O	trên	O	O	train	O	O

	D/U	D/S		D/U	D/S		D/U	D/S
bygi/buggy	O	O	lori/lorry	O	O	tractor/tractor	O	O
bws/bus	O	O	pram/pram/pushchair/coich	O	O	tryc/truck	O	O
car/car	O	O	jac codi baw/JCB	O	O			

4. TEGANAU
TOYS

	D	D/D		U	U/S		D	D/D		U	U/S
llyfr	O	O	book	O	O	tegan	O	O	toi/toy	O	O
pêl	O	O	ball	O	O	ysgrifell/beiro	O	O	pen	O	O

	D/U	D/S		D/U	D/S		D/U	D/S
bybl/bubble	O	O	bloc/block	O	O	dol/doli/doll	O	O
balŵn/balloon	O	O	bric/brick	O	O	tedi bêr/teddy bear	O	O

5. BWYD A DIOD
FOOD AND DRINK

	D	D/D		U	U/S		D	D/D		U	U/S
afal	O	O	apple	O	O	grawnfwyd	O	O	cereal	O	O
bara	O	O	bread	O	O	hufen iâ	O	O	ice cream	O	O
bisged	O	O	biscuit	O	O	llaeth/llefrith	O	O	milk	O	O
bwyd	O	O	food	O	O	menyn	O	O	butter	O	O
cacen/teisen	O	O	cake	O	O	moron/moronen	O	O	carrot	O	O
caws	O	O	cheese	O	O	oren	O	O	orange	O	O
cig	O	O	meat	O	O	pysgodyn	O	O	fish	O	O
creision	O	O	crisps	O	O	sglodion	O	O	chips	O	O
cyw/cyw-iâr	O	O	chicken	O	O	sudd	O	O	jiws/juice	O	O
da-da/fferins	O	O	sweets	O	O	tatws	O	O	potatoes	O	O
diod	O	O	drink	O	O	tê	O	O	tea	O	O
dŵr	O	O	water	O	O	ŵy	O	O	egg	O	O

	D/U	D/S		D/U	D/S		D/U	D/S
banana/banana	O	O	pasta/spageti/spaghetti	O	O	siocled/chocolate	O	O
coffi/coffee	O	O	pitsa/pizza	O	O	tôst/toast	O	O
jam/jam	O	O	pys/peas	O	O			

6. DILLAD/GWISGOEDD
CLOTHING

	D	D/D		U	U/S		D	D/D		U	U/S
botwm	O	O	button	O	O	hêt	O	O	hat	O	O
clwt	O	O	napi/nappy	O	O	hosan	O	O	sock	O	O
côt	O	O	coat	O	O	llopan/llopanau	O	O	boot(s)/bŵts	O	O
crys	O	O	shirt	O	O	menig	O	O	gloves	O	O
esgid	O	O	shoe	O	O	mwclis	O	O	neclis/necklace	O	O
ffrog	O	O	dress	O	O	spectol	O	O	glasses/specs	O	O

	D/U	D/S		D/U	D/S		D/U	D/S
bib/bib	O	O	sip/zip	O	O	siwmper/jumper	O	O
jîns/jeans	O	O	siorts/shorts	O	O	trowsus/trousers	O	O
pyjamas/pyjamas	O	O	siaced/jacket	O	O			

7. RHANNAU O'R CORFF
BODY PARTS

	D	D/D		U	U/S		D	D/D		U	U/S
bawd	O	O	toe	O	O	gwallt	O	O	hair	O	O
boch	O	O	cheek	O	O	gwyneb	O	O	face	O	O
bol	O	O	belly	O	O	llaw	O	O	hand	O	O
botwm bol	O	O	belly button	O	O	llygaid	O	O	eye	O	O
braich	O	O	arm	O	O	pen	O	O	head	O	O
bys	O	O	finger	O	O	pen-glin	O	O	knee	O	O
ceg	O	O	mouth	O	O	stumog	O	O	tummy	O	O
clust	O	O	ear	O	O	tafod	O	O	tongue	O	O
coes	O	O	leg	O	O	troed	O	O	foot	O	O
dant	O	O	tooth	O	O	trwyn	O	O	nose	O	O
gewin	O	O	nail	O	O						

8. DODREFN AC YSTAFELLOEDD
FURNITURE AND ROOMS

	D	D/D		U	U/S		D	D/D		U	U/S
baddon/bath	O	O	bath/bathtub	O	O	grisiau	O	O	stairs	O	O
bwrdd	O	O	table	O	O	gwely	O	O	bed	O	O
cadair	O	O	chair	O	O	lolfa/ystafell fyw	O	O	living room	O	O
cadair siglo	O	O	rocking chair	O	O	oergell	O	O	fridge	O	O
cadair uchel	O	O	high chair	O	O	popty/stof	O	O	cooker/stove/oven	O	O
cegin	O	O	kitchen	O	O	teledu	O	O	TV/television	O	O
corlan chwarae	O	O	play pen	O	O	tŷ bach	O	O	toilet	O	O
drws	O	O	door	O	O	ystafell molchi	O	O	bathroom	O	O
ffenest/ffenestri	O	O	window	O	O	ystafell wely	O	O	bedroom	O	O
modurdy	O	O	garej/garage	O	O						

8. DODREFN AC YSTAFELLOEDD (PARHAD)
FURNITURE AND ROOMS (CONTINUED)

	D/U	D/S		D/U	D/S		D/U	D/S
cot/cot	O	O	poti/potty	O	O	soffa/settee/sofa	O	O
drôr/drawer	O	O	sinc/sink	O	O			

9. EITEMAU BYCHAIN AR GYFER Y TŶ
SMALL HOUSEHOLD ITEMS

	D	D/D		U	U/S		D	D/D		U	U/S
allwedd/goriad	O	O	key	O	O	llun	O	O	picture	O	O
arian	O	O	money	O	O	lamp/golau	O	O	lamp	O	O
blwch	O	O	bocs/box	O	O	llwy	O	O	spoon	O	O
bowlen/powlen	O	O	bowl	O	O	morthwyl	O	O	hammer	O	O
brws dannedd	O	O	toothbrush	O	O	papur	O	O	paper	O	O
ceiniog	O	O	penny	O	O	planhigyn	O	O	plant	O	O
cist/bin sbwriel	O	O	bin	O	O	plât	O	O	plate	O	O
crib	O	O	comb	O	O	potel	O	O	bottle	O	O
cwpan	O	O	cup	O	O	sbwriel	O	O	rubbish	O	O
dysgl	O	O	dish	O	O	sebon	O	O	soap	O	O
ffisig	O	O	medicine	O	O	siswrn	O	O	scissors	O	O
gobennydd	O	O	pillow	O	O	lliain	O	O	tywel/towel	O	O
golau	O	O	light	O	O	oriawr	O	O	wats/watch	O	O
gwagfa	O	O	hoover/vacuum	O	O	ysgub	O	O	broom	O	O
gwydr	O	O	glass	O	O						

	D/U	D/S		D/U	D/S		D/U	D/S
blanced/blanket	O	O	ffôn/phone/telephone	O	O	pwrs/purse	O	O
brws/brush	O	O	fforc/fork	O	O	radio/radio	O	O
cloc/clock	O	O	mwg/mug	O	O	siwg/jwg/jug	O	O
dymi/dummy	O	O						

10. PETHAU ALLANOL A LLEOEDD
OUTSIDE THINGS AND PLACES TO GO

	D	D/D		U	U/S		D	D/D		U	U/S
allan	O	O	outside	O	O	gwaith	O	O	work	O	O
awyr	O	O	sky	O	O	gwynt	O	O	wind	O	O
blodeuyn	O	O	flower	O	O	haul	O	O	sun	O	O
carreg	O	O	stone	O	O	lleuad	O	O	moon	O	O
coeden	O	O	tree	O	O	pwll	O	O	pool	O	O
craig	O	O	rock	O	O	rhaw	O	O	spade	O	O
dŵr	O	O	water	O	O	seren	O	O	star	O	O
eira	O	O	snow	O	O	siglen	O	O	swing	O	O

10. PETHAU ALLANOL (PARHAD)
OUTSIDE THINGS (CONTINUED)

	D	D/D		U	U/S		D	D/D		U	U/S
eglwys	O	O	church	O	O	traeth/glan y môr	O	O	beach	O	O
gardd	O	O	garden	O	O	tŷ	O	O	house	O	O
glaw	O	O	rain	O	O	ysgol	O	O	school	O	O

	D/U	D/S		D/U	D/S		D/U	D/S
bwced/bucket	O	O	sleid/slide	O	O	wal/wall	O	O
fferm/farm	O	O	parc/park	O	O	siop/shop	O	O
ffilm/film	O	O	parti/party	O	O	sŵ/zoo	O	O

11. POBOL
PEOPLE

	D	D/D		U	U/S		D	D/D		U	U/S
athro/athrawes	O	O	teacher	O	O	hogan/geneth	O	O	girl	O	O
brawd	O	O	brother	O	O	hogyn/bachgen	O	O	boy	O	O
chwaer	O	O	sister	O	O	modryb	O	O	aunt	O	O
ffrind	O	O	friend	O	O	nain/naini	O	O	grandma	O	O
meddyg	O	O	doctor	O	O	plentyn	O	O	child	O	O
dyn	O	O	man	O	O	pobl	O	O	people	O	O
dynes	O	O	lady	O	O	taid	O	O	grandpa	O	O
ewythr/wncwl	O	O	uncle	O	O	unigolyn/person	O	O	person	O	O
heddwas	O	O	plismon/ policeman	O	O						

	D/U	D/S		D/U	D/S		D/U	D/S
anti/aunty	O	O	dad/dadi/daddy	O	O	Anti/nani/nanny	O	O
babi/baby	O	O	mam/mami/mummy	O	O			

12. GEMAU AC ARFERION
GAMES AND ROUTINES

	D	D/D		U	U/S		D	D/D		U	U/S
aros	O	O	wait	O	O	ia	O	O	yes	O	O
baddon/bath	O	O	bath	O	O	na	O	O	no	O	O
bei-beis	O	O	night night	O	O	os gwelwch yn dda	O	O	plîs/please	O	O
brecwast	O	O	breakfast	O	O	paid	O	O	don't	O	O
cinio	O	O	lunch/dinner	O	O	pi-po	O	O	peekaboo	O	O
clapio dwylo	O	O	pat-a-cake	O	O	ta-ta	O	O	bye-bye	O	O
cwsg bach	O	O	nap	O	O	tê	O	O	tea	O	O
diolch (yn fawr)	O	O	thank you	O	O	ust/shh	O	O	shh/hush/shush	O	O
eisiau/isio	O	O	want to	O	O						

	D/U	D/S		D/U	D/S	
helo/hello	O	O	hiya/hi	O	O	

13. GEIRIAU GWEITHREDOL
ACTION WORDS

	D	D/D		U	U/S
agor	O	O	open	O	O
anwesu/cwtsio	O	O	cuddle	O	O
arlunio	O	O	draw	O	O
brath/brathu	O	O	bite	O	O
brys/brysio	O	O	hurry	O	O
bwydo	O	O	feed	O	O
bwyta/byta	O	O	eat	O	O
cael/gai	O	O	have / get	O	O
canu	O	O	sing	O	O
cario	O	O	carry	O	O
caru/cariad	O	O	love	O	O
cau	O	O	shut/close	O	O
cerdded	O	O	walk	O	O
chwarae	O	O	play	O	O
chwythu	O	O	blow	O	O
cic/cicio	O	O	kick	O	O
clywed	O	O	hear	O	O
cnwc/bymp	O	O	bump	O	O
cosi/crafu	O	O	scratch	O	O
crio	O	O	cry	O	O
cymeryd/cymryd	O	O	take	O	O
cymorth/helpu	O	O	help	O	O
cyrchu/dod	O	O	bring	O	O
cysgu	O	O	sleep	O	O
dal	O	O	catch	O	O
dangos	O	O	show	O	O
darganfod/chwilio	O	O	find	O	O
darllen	O	O	read	O	O
dawns/dawnsio	O	O	dance	O	O
disgyn/syrthio	O	O	fall	O	O
dweud/deud	O	O	say / tell	O	O
sbio/edrych/ drycha/yli	O	O	look	O	O
galw/galwad	O	O	call	O	O

	D	D/D		U	U/S
glan/glanhau/ chnau	O	O	clean	O	O
cosi	O	O	tickle	O	O
gollwng	O	O	drop	O	O
gorffen	O	O	finish	O	O
gyrru	O	O	drive	O	O
gweld	O	O	see	O	O
gwenu	O	O	smile	O	O
gwneud	O	O	make	O	O
gwthio	O	O	push	O	O
gywbod	O	O	know	O	O
gwylio	O	O	watch	O	O
hitio/taro	O	O	hit	O	O
hoffi	O	O	like	O	O
marchogaeth/	O	O	ride	O	O
mynd	O	O	go	O	O
neidio	O	O	jump	O	O
nofio	O	O	swim	O	O
rhedeg	O	O	run	O	O
rhoddi/rhoi	O	O	give/put	O	O
sblashio/tasgu	O	O	splash	O	O
sgwennu/	O	O	write	O	O
siglo	O	O	swing	O	O
stopio	O	O	stop	O	O
sychu	O	O	dry/wipe	O	O
sws/swsio/ cusanu	O	O	kiss	O	O
syrthio	O	O	fall	O	O
taflu	O	O	throw	O	O
torri	O	O	break/cut	O	O
tynnu	O	O	pull	O	O
ymwasgu/hyg/	O	O	hug	O	O
ymolchi/'molchi/ golchi	O	O	wash	O	O
yfed	O	O	drink	O	O

14. GEIRIAU YN YMWNEUD AG AMSER
WORDS ABOUT TIME

	D	D/D		U	U/S		D	D/D		U	U/S
bore	O	O	morning	O	O	nes ymlaen/ wedyn	O	O	later	O	O
diwrnod/dydd	O	O	day	O	O	nos	O	O	night	O	O
heddiw	O	O	today	O	O	rwan/nawr	O	O	now	O	O
heno	O	O	tonight	O	O	yfory/fory	O	O	tomorrow	O	O

15. GEIRIAU DISGRIFADOL
DESCRIPTIVE WORDS

	D	D/D		U	U/S		D	D/D		U	U/S
bach	O	O	small/little	O	O	gwag	O	O	empty	O	O
blino	O	O	tired	O	O	Gwâr/tyner	O	O	gentle	O	O
brifo	O	O	hurt	O	O	gwlyb	O	O	wet	O	O
budr/afiach	O	O	dirty	O	O	gwyrdd	O	O	green	O	O
cas	O	O	nasty	O	O	hapus	O	O	happy	O	O
coch	O	O	red	O	O	hen	O	O	old	O	O
cyflym	O	O	fast	O	O	llwglyd/eisiau bwyd	O	O	hungry	O	O
cysglyd	O	O	sleepy	O	O	mawr	O	O	big	O	O
da	O	O	good	O	O	melyn	O	O	yellow	O	O
del	O	O	pretty	O	O	neis	O	O	nice	O	O
dirwy	O	O	fine	O	O	oer	O	O	cold	O	O
drist/trist	O	O	sad	O	O	poeth	O	O	hot	O	O
drwg	O	O	naughty/bad	O	O	sal	O	O	sick	O	O
dychryn	O	O	scared	O	O	sych/sychu	O	O	dry	O	O
esmwyth/meddal	O	O	soft	O	O	efo syched/eisiau	O	O	thirsty	O	O
galed/caled	O	O	hard	O	O	toredig/wedi torri	O	O	broken	O	O
glan/glanhau	O	O	clean	O	O	tywyll	O	O	dark	O	O
glas	O	O	blue	O	O	wedi mynd	O	O	all gone	O	O
gofalus	O	O	careful	O	O	ych a fi	O	O	yucky	O	O
gwael	O	O	poor/bad	O	O	yng nghwsg	O	O	asleep	O	O

16. RHAGENWAU
PRONOUNS

	D	D/D		U	U/S		D	D/D		U	U/S
chi/ti/chdi	O	O	you	O	O	hi/fo	O	O	her/him	O	O
ei/eu	O	O	her/his	O	O	fy	O	O	my	O	O
eich	O	O	your	O	O	hwn/hon	O	O	this	O	O
fi	O	O	mine	O	O	hwnnw/honno	O	O	that	O	O
fi/mi	O	O	me/I	O	O	nhw	O	O	them	O	O

17. GEIRIAU SY'N GOFYN CWESTIWN
QUESTION WORDS

	D	D/D		U	U/S			D	D/D		U	U/S
lle/ble	O	O	where	O	O		pryd	O	O	when	O	O
pa/be/beth	O	O	what/which	O	O		pwy	O	O	who	O	O
pam	O	O	why	O	O		sut	O	O	how	O	O

18. ARDDODIAD A LLEOEDD
PREPOSITIONS AND LOCATIONS

	D	D/D		U	U/S			D	D/D		U	U/S
allan	O	O	out	O	O		i mewn	O	O	inside/in	O	O
acw/yno	O	O	there	O	O		o dan	O	O	under	O	O
ar/ymlaen	O	O	on	O	O		oddi ar	O	O	off	O	O
i ffwrdd	O	O	away	O	O		tu ôl	O	O	behind	O	O
i fyny	O	O	up	O	O		yn ôl	O	O	back	O	O
lawr/i lawr	O	O	down	O	O							

19. MEINTIOLWYR
QUANTIFIERS AND ARTICLES

	D	D/D		U	U/S			D	D/D		U	U/S
arall	O	O	another	O	O		llall/lleill	O	O	other(s)	O	O
cwbl/holl/i gyd	O	O	all	O	O		mwy	O	O	more	O	O
dim	O	O	not/none	O	O		rhai	O	O	some	O	O
eto	O	O	again	O	O		yr un (fath)	O	O	same	O	O

RHAN II GWEITHREDOEDD AC YSTUMIAU

A. YSTUMIAU CYFATHREBU CYNTAF

Pan fydd babanod yn dysgu cyfathrebu gyntaf, yn aml maent yn defnyddio ystumiau i gyfleu'r hyn maen nhw eisiau. Edrychwch ar bob eitem isod, a marciwch y rhai sy'n disgrifio beth mae eich plentyn yn ei wneud ar hyn o bryd.

	Dim eto	Weithiau	Yn aml
Yn estyn ei (b)fraich i ddangos rhywbeth yn ei (l)law.	O	O	O
Yn ymestyn ac yn rhoi tegan i chi neu ryw eitem arall sydd yn ei law.	O	O	O
Yn pwyntio (a'r fraich a'r bys cyntaf yn ymestyn) at wrthrych neu ddigwyddiad diddorol.	O	O	O
Yn chwifio ta-ta ar ei ben ei hun pan fydd rhywun yn ymadael.	O	O	O
Yn estyn ei (b)freichiau i'r awyr i ddangos ei fod eisiau cael ei godi.	O	O	O
Yn ysgwyd ei (ph)ben "Na".	O	O	O
Yn nodio ei (ph)ben "ie".	O	O	O
Yn gwneud ystum "ust" trwy roi ei (b)fys ar ei wefusau	O	O	O
Yn gofyn am rywbeth trwy ymestyn ei (b)freichiau ac agor a chau ei (l)law.	O	O	O
Yn chwythu swsys o bellter.	O	O	O
Yn cau ei (g)wefusau mewn ystum "iym, iym" i ddangos bod rhywbeth yn blasu'n dda.	O	O	O
Yn codi ei ysgwyddau i ddangos "wedi mynd" neu "lle mae o/hi wedi mynd".	O	O	O

B. GEMAU AC ARFERION

Ydy eich plentyn yn gwneud unrhyw rai o'r canlynol?

	Ydi	Nac Ydi
Chwarae pi po.	O	O
Play patty cake.	O	O
Chwarae "mor fawr".	O	O
Chwarae gemau 'mynd ar ôl".	O	O
Canu	O	O
Dawnsio.	O	O

C. GWNEUD PETHAU GYDA GWRTHRYCHAU

Ydy eich plentyn yn gwneud unrhyw rai o'r canlynol?

	Ydi	Nac Ydi
Bwyta gyda llwy neu fforc.	O	O
Yfed o gwpan.	O	O
Cribo neu brwsio ei (g)wallt ei hun	O	O
Glanhau dannedd.	O	O
Sychu gwyneb neu dwylo gyda thywel neu clwtyn.	O	O
Gwisgo het.	O	O
Gwisgo esgid neu hosan.	O	O
Gwisgo mwclis, breichled neu watsh.	O	O

PART II ACTIONS AND GESTURES

A. FIRST COMMUNICATIVE GESTURES			
When infants are first learning to communicate, they often use gestures to make their wishes known. For each item below, mark the line that describes your child’s actions right now.			
	Not Yet	**Sometimes**	**Often**
Extends arm to show you something he/she is holding.	O	O	O
Reaches out and gives you a toy or some object that he/she is holding.	O	O	O
Points (with arm and index finger extended) at some interesting obeject or event.	O	O	O
Waves bye-bye on his/her own when someone leaves.	O	O	O
Extends his/her arm upward to signal a wish to be picked up.	O	O	O
Shakes head "No".	O	O	O
Nods head "Yes".	O	O	O
Gestures "hush" by placing finger to lips.	O	O	O
Requests something by extending arm and opening and closing hand.	O	O	O
Blow kisses from a distance.	O	O	O
Smacks lips in a "yum yum" gesture to indicate that something taste good.	O	O	O
Shrugs to indicate "all gone" or "where'd it go".	O	O	O

B. GAMES AND ROUTINES		
Does your child do any of the following?		
	Yes	**No**
Play peekaboo.	O	O
Play patty cake.	O	O
Play "so big".	O	O
Play chasing games.	O	O
Sing.	O	O
Dance.	O	O

C. ACTIONS WITH OBJECTS		
Does your child do any of the following?		
	Yes	**No**
Eat with a spoon or fork.	O	O
Drink form a cup containing liquid.	O	O
Comb or brush own hair.	O	O
Brush teeth.	O	O
Wipe face or hands with towel or cloth.	O	O
Put on hat.	O	O
Put on a shoe or a sock.	O	O
Put on a necklace, bracelet, or watch.	O	O

C. GWNEUD PETHAU GYDA GWRTHRYCHAU (parhad)		
Ydy eich plentyn yn gwneud unrhyw rai o'r canlynol?		
	Ydi	**Nac Ydi**
Rhoi pen ar ddwylo a chau llygaid yn dynn fel pe bai'n cysgu.	O	O
Chwythu i ddangos bod rhywbeth yn boeth.	O	O
Dal awyren degan a gwneud iddi "hedfan".	O	O
Rhoi'r ffôn wrth ei glust / ei chlust.	O	O
Ogleuo'r blodau.	O	O
Gwthio car neu lori tegan.	O	O
Taflu'r bêl.	O	O
Tywallt hylif smalio o'r naill gynhwysydd i'r llall.	O	O
Troi'r hylif smalio mewn cwpan neu badell gyda llwy.	O	O

D. ESGUS BOD YN RHIANT		
Dyma rai pethau y mae plant ifanc yn eu gwneud weithiau gydag anifeiliaid neu ddoliau wedi eu stwffio. Nodwch y gweithredoedd y gwelsoch eich plentyn yn eu gwneud.		
	Ydi	**Nac Ydi**
Rhoi yn y gwely.	O	O
Rhoi blanced drosto	O	O
Bwydo gyda photel.	O	O
Bwydo gyda llwy.	O	O
Brwsio/cribo ei gwallt.	O	O
Patio ei gefn neu gael gwared â gwynt.	O	O
Gwthio mewn coets/pram/coets fach	O	O
Siglo.	O	O
Cusanu neu gofleidio	O	O
Ceisio rhoi esgid neu hosan neu het arno.	O	O
Sychu ei wyneb neu ei ddwylo.	O	O
Siarad gydag ef.	O	O
Ceisio rhoi clwt arno/arni.	O	O

E. DYNWARED PETHAU ERAILL MAE OEDOLION YN EU GWNEUD (GAN DDEFNYDDIO OFFER GO IAWN NEU RAI TEGAN)		
Ydy eich plentyn yn gwneud unrhyw rai o'r canlynol?		
	Ydi	**Nac Ydi**
Ysgubo gyda brwsh neu olchi gyda mop.	O	O
Rhoi allwedd yn y drws neu'r clo.	O	O
Colbio gyda morthwyl neu ordd.	O	O
Ceisio defnyddio llif.	O	O
"Teipio" wrth deipiadur neu fysellfwrdd cyfrifiadur.	O	O
"Darllen" (agor y llyfr, troi'r tudalen).	O	O

C. ACTIONS WITH OBJECTS (CONTINUED)		
Does your child do any of the following?		
	Yes	No
Lay head on hands and squeeze eyes shut as if sleeping.	O	O
Blow to indicate something is hot.	O	O
Hold plane and make it "fly".	O	O
Put telephone to ear.	O	O
Sniff flowers.	O	O
Push toy car or truck.	O	O
Throw ball.	O	O
Pour pretend liquid from one container to another.	O	O
Stir pretend liquid in a cup or pan with a spoon.	O	O

D. PRETENDING TO BE A PARENT		
Here are some things that young children sometimes do with stuffed animals or dolls. Please mark the actions that you have seen your child do.		
	Yes	No
Put to bed.	O	O
Cover with blanket.	O	O
Feed with bottle.	O	O
Feed with spoon.	O	O
Brush/Comb its hair.	O	O
Pat or burp it.	O	O
Push in a pram/buggy.	O	O
Rock it.	O	O
Kiss or hug it.	O	O
Try to put shoe or sock or hat on it.	O	O
Wipe its face or hands.	O	O
Talk to it.	O	O
Try to put nappy on it.	O	O

E. IMITATING OTHER ADULT ACTIONS (USING REAL OR TOY IMPLEMENTS)		
Does your child do any of the following?		
	Yes	No
Sweep with broom or mop.	O	O
Put key in door or lock.	O	O
Pound with hammer or mallet.	O	O
Attempt to use saw.	O	O
"Type" at a typewritter or computer keyboard.	O	O
"Read" (opens book, turns page).	O	O

E. DYNWARED PETHAU ERAILL MAE OEDOLION YN EU GWNEUD (GAN DDEFNYDDIO OFFER GO IAWN NEU RAI TEGAN)(PARHAD)

Ydy eich plentyn yn gwneud unrhyw rai o'r canlynol?

	Ydi	Nac Ydi
Hwfro.	O	O
Rhoi dŵr i'r planhigion.	O	O
Chwarae offeryn cerdd (e.e. piano, trwmped).	O	O
"Gyrru" car trwy droi'r olwyn yrru.	O	O
Golchi llestri.	O	O
Glanhau gyda chlwtyn neu ddwster.	O	O
Ysgrifennu gyda beiro, pensil neu farciwr.	O	O
Palu gyda rhaw.	O	O
Rhoi sbectol ymlaen.	O	O

F. GWRTHRYCHAU ESGUS

Pan fydd plant yn chwarae, weithiau byddant yn defnyddio gwrthrych i gymryd lle un arall. Er enghraifft, gallai plentyn sy'n dymuno rhoi bwyd i dedi bêr gymryd arno fod blocyn pren yn afal. Gallai plentyn esgus bod powlen yn het. Ydych chi wedi gweld eich plentyn yn defnyddio gwrthrychau i gynrychioli pethau eraill fel hyn?

◯ **Ydi** ◯ **Nac Ydi**

Os ydych, rhowch nifer o enghreifftiau:

Sylwadau eraill:

E. IMITATING OTHER ADULT ACTIONS (USING REAL OR TOY IMPLEMENTS) (CONTINUED)		
Does your child do any of the following?		
	Yes	**No**
Vacuum.	O	O
Water plants.	O	O
Play musical instrument (e.g. piano, trumpet).	O	O
"Drive" car by turning steering wheel.	O	O
Wash dishes.	O	O
Clean with cloth or duster.	O	O
Write with a pen, pencil, or marker.	O	O
Dig with a shovel.	O	O
Put on glasses.	O	O

F. PRETEND OBJECTS

During play, children sometimes use an object as a replacement for another. For example, a child wishing to feed a teddy bear might pretend that a block is an apple. A child might pretend that a bowl is a hat. Have you seen your child make substitutions of this kind? ◯ **Yes** ◯ **No**

If yes, please give several examples:

Other comments: