Attentional Control, Working Memory and Language Aptitude

A correlational study of the relationship between second language proficiency, attentional control and working memory.

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Abstract

The aim of this thesis is to provide further insight into the somewhat mysterious relationship between language aptitude, working memory and attentional control. As such, a group of Norwegian university students of English were quantitatively tested in English proficiency, working memory and attentional control. A total of eight different tests were conducted, and all participants were tested individually under calm and controlled circumstances so as to prevent any intervening input. The results were subsequently analysed and checked for correlation in the open source software R. Surprisingly, the analysis did not yield any statistically significant results, though some trends were detected. These trends revealed an interesting relationship between one of the measures of phonological short-term memory and L2 proficiency, as well as between attentional control and L2 proficiency. Consequently, the findings of the present study conform to previous research and add weight to hypotheses of working memory, attentional control and language somehow being interconnected. This is highly interesting and somewhat controversial, and thus more research is needed in order to determine the specific characteristics of the relationship between these cognitive mechanisms and language.

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1. Introduction

In learning a second language, some learners seem to acquire the new language with greater ease than others. These learners are by many considered to be equipped with some special talent – a talent which scaffolds the acquisition of language specifically. Over the past few decades, such talent has been argued to conform to the concept of *language aptitude*. What exactly makes up this talent though – what language aptitude actually is – has proved itself challenging to describe. However, the role of working memory in L2 learning has been increasingly recognized, and theories of working memory affecting language aptitude; even theories of working memory *as* language aptitude, have evolved.

As there does not, as of yet, exist a concise and explicit description of language aptitude, research on various cognitive abilities and their correlation with language proficiency is highly interesting. Moreover, the possibility of L2 language skill depending on some other variable is rather controversial, as this would suggest that language acquisition relies on some more generic mechanisms rather than being a separate cognitive system. This is not to say that the relation between working memory and L2 proficiency is not recognized, but rather that research on the extent of the effect of the prior on the latter have yielded somewhat inconclusive results.

Alan D. Baddeley is one of many researchers who have looked into the relationship between working memory and language proficiency/aptitude. Research on patients with short-term memory deficits has shown that they tend to struggle with complex sentences, which leads Baddeley (2003) to argue that the phonological loop of the working memory may "have evolved in order to facilitate the acquisition of language" (ibid, p. 194). Similar research on patients with specific language impairment shows a correlation between the SLI and a simple working memory task. Correlations between language aptitude and working memory was also found by Robinson (2002), O'Brien et al. (2006; 2007) and Hummel (2009). However, such correlation does not mean causation. How can we know whether the correlation between the variables ultimately means that one depends on the other? And, additionally, how to determine the direction of causation?

Such questions regarding causation are as of yet unanswered, and require a great deal of research in order to be discussed. For one to be able to handle such problems, one must first establish the extent of correlation. As mentioned, correlation has indeed been found by several researchers, though the entirety of working memory has not yet been studied in a language aptitude context. Put differently, working memory is componential and only some of its components have been correlated with language proficiency. As such, there is a gap in the research material regarding if only some, or in fact all, the components of working memory may correlate with language aptitude.

The primary purpose of this study is to explore the characteristics of the relationships between the different parts of the working memory and second language proficiency, following the hypotheses of correlation claimed by other researchers. As such, the study will look into a somewhat unexplored issue to the extent that not only the working memory system for storing verbal material (the phonological loop) is in focus, but also the system for processing and storing visual and spatial information (the visuospatial sketchpad), as well as the system regulating the overall attentional control of the working memory system (the central executive). Additionally, a separate test on auditory attentional control is included. Moreover, both simple and complex working memory tasks will be employed in order to achieve as extensive a result as possible. Keeping previous research findings in mind, the explicit hypotheses for this study are, firstly: to find correlations between both the simple and complex working memory tests on the phonological loop and language proficiency, secondly: that such correlations will not be as evident between visuospatial working memory and language proficiency, and thirdly: that there will also be correlation between L2 proficiency and attentional control.

Due to the scope of the study and the respective tests being rather time-consuming, the sample was limited to 30 participants. The participants were 30 students enrolled in an English master's programme at a university in Norway. Their linguistic background was identified by means of a background questionnaire at the beginning of the study. All participants completed two different tests on English proficiency, five on working memory, and one on attentional control. All tests are quantitative in nature, making the methodological approach in this study a quantitative one. The test results were subsequently processed and analysed using the open source software R. Despite the somewhat small size of the study's sample, consistent results may still be representative and thus contribute to the discussion of working memory and language aptitude, in addition to encouraging further research on the issue – for instance via including a qualitative approach.

The thesis consists of six chapters including this introduction. Chapter 2 reviews theoretical perspectives and research literature that motivates the research questions addressed in this thesis. Moreover, the various studies and the inconclusive findings presented in the chapter illustrate the controversy on the matter. Chapter 3 follows with a depiction of the methodological approach adopted in the present study. In addition, the major research instruments are identified and the procedure of data collection and analysis is outlined. Key findings from analyses of the research data are subsequently presented in Chapter 4. These findings are further discussed in detail in Chapter 5, which also draws parallels to relevant findings in previous research. Finally, Chapter 6 summarizes the main findings and arguments and also addresses limitations of the study. The chapter closes with recommendations for further research.

2. Theoretical Background

In this chapter, a review of theoretical perspectives and research literature is provided. For the chapter to be as lucid as possible, it has been divided into four sections: theoretical perspectives of working memory, theoretical perspectives of language aptitude, an overview of (other) essential factors in language learning, and finally previous research on working memory, attentional control and language aptitude. The chapter closes with a short discussion on the state of working memory – that is, whether it is a constant or dynamic entity.

2.1 Short-term Memory and Working Memory

In this section, I will discuss some of the various properties of human short-term memory and working memory. My starting point will be the model presented by Richard C. Atkinson and Richard M. Shiffrin in 1968, known by many as the *multi-store model*. This model was later adapted and further developed by Alan Baddeley and Graham Hitch so as to include the aspect of *working memory*. As such, I will first briefly discuss the sensory register, the short-term store, and the long-term store as presented in the Atkinson-Shiffrin memory model, before moving on to Baddeley and Hitch's working memory.

2.1.1 The Atkinson-Shiffrin Memory Model

Atkinson and Shiffrin (1968, p. 90) distinguish between two different parts of the human memory: one that is categorized by "permanent, structural features of the system", and one that is subject of modification by the individual. The first entails what Atkinson and Shiffrin call fixed "built-in processes", whilst the second entails control processes which are actively used by the individual, and may as such vary significantly from one task to another. A further distinction is made between *sensory register, short-term store* and *long-term store* – all of which are a part of both the permanent features of human memory as well as the modifiable control processes.

In terms of sensory register in the permanent, structural features of the memory system, one automatically registers sensory stimuli: there is a more or less immediate response to the stimuli by the appropriate sensory dimension. Put differently, the sensory stimuli enters our memory via the sensory register after being detected by our senses. Moreover, each sensory modality arguably has its own register, consequently rendering the sensory register to comprise of multiple registers. No matter the type of stimuli and register, the stimuli is not, however, immediately stored in our *long-term memory.* Atkinson and Shiffrin (1968, p. 95) argue that the sensory registration of a visual image leaves a photographic trace in our memory, though it decays “during a period of several hundred milliseconds” in addition to being subject of replacement by successive stimulation. As such, fresh input appears to be temporarily stored in the short-term store, though not necessarily processed in the sensory register. However, the rate of decay is difficult to estimate due to a great influence by subject-controlled processes (ibid, p. 92). This aspect will be further discussed in the following section on working memory.

Though much of the registered stimuli is neither processed nor actually remembered, some of it may be further attended to by the *short-term store*. In the short-term store, information retrieved via the senses can be processed, such as in recollection exercises. Without any form of rehearsal, the information is lost quite rapidly (15-30 seconds), whilst the adding of a rehearsal element greatly increases the duration of the memory (Atkinson & Shiffrin, 1968, p. 102-103). Such a rehearsal element would include intentional repetition of the stimuli, whether in the sense of repeating uttered linguistic information, or a more abstract form of for instance visual memory. Furthermore, the rehearsal as such need not be in the same modality as the sensory input: one can, for instance, create a mental image so as to better remember a sequence of words. Once the information stored in the short-term store is no longer of use for the individual, the information may well be lost – or it can be transferred to the *long-term store*.

According to the Atkinson-Shiffrin memory model, transfer from the short-term to the long-term store takes place throughout the period that the information resides in the short-term store. As such, logic dictates that the longer a piece of information resides in the short-term store, the more likely it is for this specific information to transfer to the long-term store. Moreover, “long-term memory exists in each of the sensory modalities; this is shown by subjects’ recognition capability for smells, taste, and so on” (Atkinson & Shiffrin, 1968, p. 104). It should further be mentioned that not all long-term information originates from any of the sensory modalities. Nonetheless, long-term memory is “the final store component” in which, inter alia, “all the words a speaker knows are stored” (Vulchanova et al., 2014, p. 87).

2.1.2 The Baddeley-Hitch Memory Model

Baddeley and Hitch suggested adding *working memory* to the Atkinson-Shiffrin model, and described it as the part of the short-term memory system “which is involved in the temporary processing and storage of information” (Gathercole & Baddeley, 1993, p. 2). Consequently, the working memory arguably plays an important role in numerous cognitive activities such as reasoning and language comprehension. They originally found the working memory (WM) to consist of three components, which was later extended to four. The original three are *the central executive, the phonological loop,* and *the visuo-spatial sketchpad*, whilst *the episodic buffer* was added by Baddeley some years later. In the following, each of the components will be looked into in turn. However, the phonological loop will be discussed somewhat more deeply than the others, as this is of greater importance in this thesis.

The Central Executive

The central executive (CE) regulates the information flow within WM and also the retrieval of information from other parts of the human memory system. Put differently, the CE has "overall attentional control of the working memory system" (Henry, 2012, p. 21). As such, the CE arguably has the most important functions in WM, and, in fact, Baddeley and Hitch refer to the phonological loop (PL), the visuo-spatial sketchpad (VSS), and the episodic buffer (EB) as the CE's *slave systems* (see figure 1). The capacity of the CE is limited, however. Its efficiency and capacity depends on how many demands are placed on it at the same time, and consequently its efficiency decreases with the number of demands.

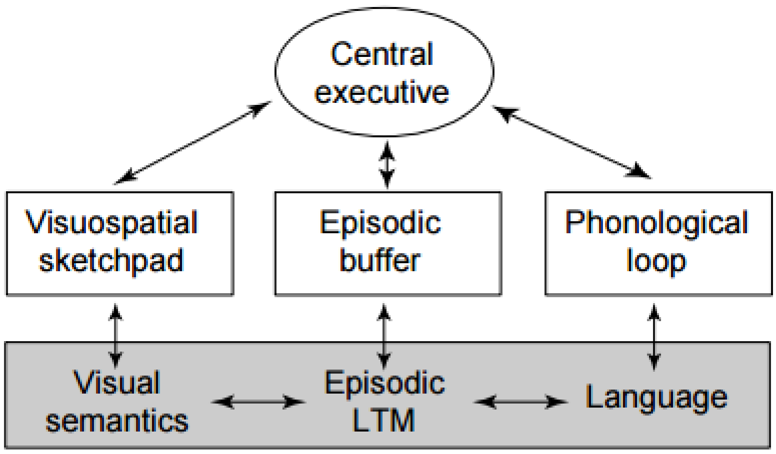

Figure 1: The revised WM-model as presented in Baddeley, A. D. (2000) p. 421

Though the CE has *attentional* control of the WM, it does in fact not have any capacity for storage. Consequently, the CE merely allocates attention within the WM via for instance dividing, focusing and switching attention. This enables us to carry out tasks we have never encountered before, where we must utilize potentially new approaches and new behaviour.

The Phonological Loop

One of the so-called *slave systems* of the central executive is the phonological loop (PL). Put simply, the PL system is specialized for storing verbal material and, unlike the CE, it does not have "any capacity for controlling attention or decision-making" (Henry, 2012, p. 5). The PL stores short-term phonological information and enables us to remember smaller portions of heard information for a short time. Furthermore, the PL comprises two components: the phonological store and the subvocal rehearsal. The first represents the heard information in a phonological code which fades over time. Such fading is commonly referred to as "trace decay", as the information in the phonological store is designated as "memory trace". According to Henry (2012, p. 6), the trace decay is so rapid that only "around two seconds' worth of speech-based material can be held", which is about enough time to remember a phone number before dialling it.

The second component, the subvocal rehearsal, "serves to refresh the decaying representations in the phonological store" (Gathercole & Baddeley, 1993, p. 8), which means that memory items can indeed be maintained. Put differently, the subvocal rehearsal extends the time for which we can hold phonological information via repetition – enabling us to hold the phone number for several more seconds. Such repetition is, nonetheless, not the only role of the subvocal rehearsal as it also recodes non-phonological input – such as printed words and pictures – into their respective phonological form (ibid.). In other words, information perceived by the senses as being non-phonological is transformed into phonological information and stored as such in the short-term phonological memory (STPM).

The Visuospatial Sketchpad

Yet another "slave system" of the central executive is the visuospatial sketchpad (VSS). Whereas the phonological loop is specialized for storing verbal material, the VSS processes and stores visual and spatial information in addition to verbal material encoded as some form of imagery (Gathercole & Baddeley, 1993, p. 17). Put differently, the VSS scaffolds the remembrance of "what" and "where": the visual characteristics of an object and where in space this object was located (Henry, 2012, p. 16). As such, there is according to Gathercole and Baddeley (1993) little indication that the VSS plays any significant role in language. However, recent research has revealed a potential relationship between bilingualism and selective attention during visual search tasks (Friesen et al., 2015). Such tasks arguably greatly rely on processing in the VSS, thus challenging Gathercole and Baddeley's 1993 hypothesis. The research in question will be further discussed in the section "previous research".

Nonetheless, the VSS is described in this section in the interest of providing an overall account of working memory. Moreover, an individual's competence in the VSS affects the competence on the WM in total – thus rendering the VSS significant in terms of a hypothesis of the total capacity of WM affecting language aptitude.

The Episodic Buffer

As mentioned, the episodic buffer (EB) is the most recent addition to the WM model. The EB provides "temporary storage of information held in a multimodal code, which is capable of binding information from the subsidiary systems" (Baddeley, 2000, p. 417). As such, the EB integrates information from a number of sources, and it is episodic in the sense that "it holds episodes whereby information is integrated across space and potentially extended across time" (ibid, p. 421). The EB is thus a slave system which provides some sort of temporary interface between the other slave systems (the PL and the VSS) and long-term memory, and it deals with information from different modalities. Put simply, different information about a scene may be both visual, spatial and auditory; it is the EB that joins this information together into a coherent memory episode (Henry, 2012, p. 31). In addition to uniting pieces of information from different parts of the human memory, the EB acts as a link between the CE and long-term memory. Such a linkage enables us to access and actively use previously stored knowledge while doing memory and processing tasks.

The process of binding and long-term memory activation may either be controlled by the CE, or it may occur rather automatically. Nonetheless, the EB can arguably act as a "backup store" to supplement the other slave systems as well as providing a linkage to long-term memory. To provide a concrete example: individuals often find it easier to remember strings of words if the words share some relation of meaning, than if they do not – or if they are non-words. As such, semantic information may scaffold remembrance. According to Henry (2012, p. 33), the mechanism through which information such as semantics can improve recall, is hypothesised to be the episodic buffer: we utilize previously stored information (here semantics) during memory and processing tasks.

2.2 Language Aptitude

The concept of language aptitude has been discussed at length over the past decades, and though one seems to agree on the basics of the concept, the details regarding its definition remain somewhat imprecise. However, language aptitude's role in L2 learning has been increasingly recognized as an important factor. In this section, I will present some of the suggested features of language aptitude as well as its relation to the critical period hypothesis (CPH).

2.2.1 Defining Language Aptitude

In a generic conception, language aptitude may be defined as *language learning ability*, which according to Carroll and Sapon (1959, p. 14) consists of "basic abilities that are essential to facilitate foreign language learning". Such a definition is, however, not very productive due to its genericity. Bylund, Abrahamsson and Hyltenstam (2010, p. 447) are a bit more concise in their description of the concept, as they describe it as "an innate, relatively fixed talent to acquire and process language structure". Consequently, one can understand language aptitude as being a set of innate abilities that scaffold the learning of second languages – giving some individuals a more beneficial starting point in L2 learning than others. The question to be answered is, thus, what this starting point consists of; what are these abilities that make up an innate talent for learning languages?

Skehan (2015) argues that language aptitude is componential and further refers to Carroll's (1965) proposition that there are four sub-components of aptitude:

> phonetic coding ability (the ability to analyse unfamiliar sound so that it can be retained); grammatical sensitivity (the capacity to identify the functions that words fulfil in sentences); inductive language learning ability (the ability to formulate new language extrapolating from a sample of that language); and associative memory (the capacity to make links between L1 and L2 words) (Skehan, 2015, p. 368).

Based on these four proposed components, Carroll and Sapon developed the Modern Language Aptitude Test (MLAT) whose purpose is to predict individuals' rate of learning languages. However, theoretical advances have taken place since the development of the MLAT. For instance, Skehan (2002; 2012; 2015) suggests a view of L2 acquisition as a series of repeated stages of processes such as noticing, sound processing and automatization. Also, there have been suggestions to add focus to learning contexts, and thus analysing the innate abilities in different acquisitional processes. Nonetheless, the MLAT remains a well-known starting point for a discussion of language aptitude.

Considering the sub-components suggested by Carroll, it is not surprising that the degree of language aptitude varies significantly between populations and individuals. According to Bylund, Abrahamsson and Hyltenstam (2010, p. 447), language aptitude also appears to be "relatively unrelated to other individual factors such as general intelligence or personality". As to the question of environmental factors in terms of implicit/naturalistic or explicit learning mentioned above, aptitude tests have, for the most part, been used for predicting success in *instructed learning* (Abrahamsson & Hyltenstam, 2008, p. 486). As such, language aptitude research has focused mainly on foreign language learning in formal settings. However, recent studies (DeKeyser, 2000; Harley & Hart, 2002; Robinson, 1997) have suggested that language aptitude may play a decisive role in naturalistic SLA as well, due to how the process of acquiring a language implicitly may be seen as a greater challenge than learning it explicitly. In addition to the issue of language learning context, there is the issue of age of onset (AO) and the related critical period hypothesis (CPH) which are both prominent in the discussion of language aptitude.

2.2.2 Language Aptitude and the Critical Period Hypothesis

Put simply, the CPH states that individuals who start acquiring an L2 sometime before puberty may reach native-like levels of proficiency, whilst this is not the case for post-puberty learners due to how the brain plasticity decreases with maturation (Abrahamsson & Hyltenstam, 2008). As pointed out by Abrahamsson and Hyltenstam (2008), empirical results do, however, vary regarding the exact scheduling of maturation. Nonetheless, individuals who begin acquiring their L2 as young adults should, based on the CPH, not be able to reach native-like levels of proficiency. However, there are examples of such individuals existing – that is, individuals whose proficiency in the L2 will not be characterized as "foreign" by native speakers. As such, there exists a hypothesis that where the critical period ends, language aptitude takes over, in a sense. Alternatively, the two may somehow work in concert. These hypotheses will be further explored in the following section on previous research.

2.3 Other Essential Factors in L2 Learning

In addition to the age of onset, there are several other factors that arguably affect one's L2 learning. Figure 2 shows an integrated view of such influences, as presented by Moyer (2015).

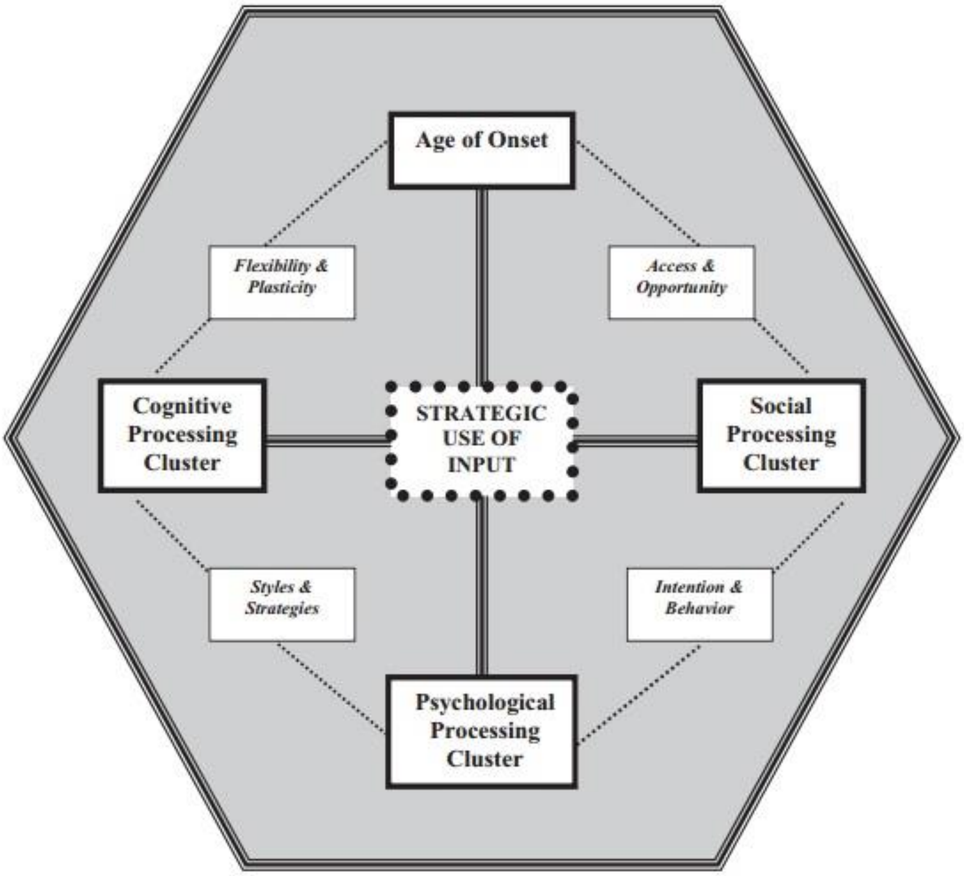

Figure 2: An integrated view of critical influences in SLA (Moyer, 2015, p. 2)

As illustrated in figure 2, the procedure of L2 learning is a complex one. According to Moyer (2015, p. 3), "cognitive, social, and psychological processing all affect how the learner uses input strategically, and these realms are interconnected through specific mechanisms". Nonetheless, the use of input is central and thus the learner's learning strategies, learning styles, motivation and attention are all affecting factors – in addition to age of onset and working memory abilities. Biedroń and Szczepaniak (2009) argue that learning strategies may both facilitate L2 learning as well as increase one's proficiency. A part of such learning strategies may be the aforementioned rehearsal aspect of the phonological loop, in which one manipulates phonological input in order to easier recall it correctly. In addition to such cognitive learning strategies, there are metacognitive, social, and affective strategies as well. These include for instance monitoring and evaluating one's learning, cooperating or asking for help, and emotional self-control (ibid, p. 59). Furthermore, Moyer (2015) argues that an individual's motivation may indeed affect his/her choice of learning strategies, thus resulting in individual differences rooted in motivation.

Biedroń and Szczepaniak (2009, p. 59) explain that learning styles, as opposed to learning strategies, are not chosen by learners but are rather "based internally and often used unconsciously to process input". Moreover, different learning styles – be they cognitive and analytical, or sensory and kinaesthetic – may be equally advantageous, thus eliminating the contribution of individual differences in learning styles to the outcome in L2 learning. Finally, L2 learning via media such as television or computer games should be mentioned. According to Vulchanova (2015, p. 3[1]) "research suggests that such channels are inadequate to provide the kind of input necessary for a child to learn their native language". However, one cannot conclusively exclude such channels as sources of input in implicit learning; though such media may not provide sufficient input, it arguably contributes to the total input bank of the learner. Moreover, reports show that children may acquire language incidentally prior to explicit learning in school via exposure to television and/or computer games (ibid).

2.4 Previous Research

Numerous studies have been conducted on both WM and language acquisition/aptitude, though the correlation of these phenomena remain somewhat unexplained – or at least inconclusive. In the following section, I will account for a selection of previous research on the topical factors – showing that the impact of WM on language aptitude is still a bit mysterious.

2.4.1 Language Aptitude and the CPH

DeKeyser (2000) investigated the "different roles of language learning aptitude for the attainment of near-native L2 proficiency by adult and child learners" (Abrahamsson and Hyltenstam, 2008, p. 487), and hypothesized that the adult learners whose proficiency was comparable to that of the child learners must have high language aptitude. This hypothesis was based on a second hypothesis of language aptitude being a trait that allowed them to learn the L2 successfully. Consequently, the adult learners would serve as counterexamples of the CPH: they started learning their L2 as adults, but still reached near-native proficiency. The hypothesis was tested via a grammaticality judgement test and a language learning aptitude test, and the results showed that all those adult learners who scored within the range of child learners also had high scores on the aptitude test. DeKeyser consequently argued that, if and when implicit language acquisition mechanisms are lost, adults do instead make use of explicit learning

[1] Page numbers correspond to a PDF version of the article available from https://www.researchgate.net/publication/272786099_Pathways_to_language_Same_talent_different_cognitive_profiles

mechanisms to reach high proficiency in their L2. Thus, he concludes that adults develop a high degree of language aptitude, whilst children do not as they still have the ability to learn an L2 naturalistically.

As mentioned earlier, there are cases of adult language learners who have reached native-like levels of proficiency. One such individual is Laura from Ioup et al. (1994), who learned Arabic as an adult, and mainly through extensive formal exposure. Her achieved proficiency in her L2 was of such a level that she passed for a native speaker with actual mother tongue speakers of that language (Abrahamsson & Hyltenstam, 2008, p. 484). Such occurrences may be explained by way of reference to language learning aptitude, as these are apparent exceptions to the critical period.

2.4.2 The Phonological Loop and Language Acquisition

As stated by Baddeley (2003, p. 193), research on patients with STM deficits has shown that they often struggle with longer and complex sentences, which suggests that the PL may have a functional significance as "a backup to comprehension". However, Gathercole and Baddeley (1993, p. 217) argue for a more central role for STM in comprehension based on patients with "more dramatic impairment in comprehension". Moreover, research on patients with pure phonological STM deficits has shown that they struggle to acquire vocabulary of unfamiliar foreign languages, thus making way for a second hypothesis: "that the system might conceivably have evolved in order to facilitate the acquisition of language" (ibid, p. 194).

Over the past few decades, such a hypothesis has been subject to quite a bit of research. When comparing the results of a group of children with a specific language impairment (SLI) on a non-word repetition test, with the results of a group of typical children, Baddeley and colleagues found that the SLI group performed substantially below the other group (Baddeley, 2003). The two groups were matched for age and nonverbal intelligence, though groups of younger language controls were also included. The results showed that the SLI group also performed significantly lower than their younger language controls, rendering the SLI group at a functioning level of 4 years old – 4 years behind their own age. Such results arguably suggest a linkage between the language deficit and poor working memory results, and thus an impact of the phonological loop on language aptitude. However, and as underscored by Baddeley

(2003), correlation does not mean causation. Consequently, one must consider the results of other research in the field in order to gain some reliability.

A relationship between phonological short-term memory and language skills was also found by Vulchanova et al. (2014) in their research on phonological memory and language competence in 10-year-old children. Language competence was tested in the children's L1 and L2, and checked for correlation with phonological short-term memory (PSTM) scores. PSTM, measured by using a forward digit recall test, was found to significantly correlate with language competence and skills in both languages: the higher the PSTM scores, the higher the language skills. Consequently, these results yield further empirical evidence to the hypothesis posed by Gathercole and Baddeley, and suggest "that language development and learning depend on some more general mechanism, such as e.g. verbal memory, irrespective of the status of the language (first or second)" (Vulchanova et al., 2014, p. 94).

2.4.3 Working Memory and Language Skill Correlation

As described in the section on working memory, the phonological loop is largely responsible for the temporary maintenance of acoustic or verbal-based information, and one may thus suggest phonological memory to be a part of language aptitude, given the sub-components defined by Carroll (1965). Several studies have expressed a support for the notion of phonological memory playing a role in L2 vocabulary and grammar learning, and some even suggest that working memory *is* foreign language aptitude.

In terms of working memory playing a role in language aptitude, Sáfár and Kormos (2008, p. 8[2]) refer to a study conducted by Robinson in 2002 in which a moderately strong correlation was found between working memory and language aptitude. Moreover, in 2006-2007, O'Brien and colleagues found PM to be linked to L2 vocabulary use and oral narrative productive skill, as well as PM being associated with increases in function word use. However, PM does not seem to have the same effect at the different stages of learning. In O'Brien et al.'s results, the linkage to L2 vocabulary use and oral narrative productive skill applied to less proficient learners, whilst the association between PM and an increase in use of function words was found in more proficient learners. Hummel (2009) on the other hand, found significant correlations

[2] Page numbers correspond to the preprint PDF version of the article at http://eprints.lancs.ac.uk/10908/1/iral-preprint.pdf

between PM and L2 proficiency in relatively advanced learners, though a more scrutinized analysis of the results revealed the effect to only remain in the lower proficiency subgroup.

It appears that studies investigating the role of phonological memory in language aptitude are more abundant than equivalent research on complex working memory. I share such an observation with Sáfár and Kormos (2008), who raise this issue in their study. One of their hypotheses involved the relationship of WM and language aptitude, and was directed at finding support for the aforementioned hypothesis of working memory *as* language aptitude. Their results support such a hypothesis, as they found a moderate relationship between backward digit span scores and the total HUNLAT score (measures of respectively complex working memory capacity and language aptitude). Moreover, the specific pattern of correlations indicated that "the ability to maintain and manipulate verbal information in working memory influences the efficiency with which students can deduce linguistic rules from the input in a language unknown to the students" (Sáfár & Kormos, 2008, p. 22). They use these results, along with a regression analysis, to further argue for an important role of WM capacity in language learning, and indicate that "working memory is a better predictor of language learning success than the traditional construct of language aptitude" (ibid, p. 23). Nonetheless, some components of the HUNLAT[3] were related to working memory capacity, though they did not overlap. As such, their findings arguably lend support to a hypothesis of language aptitude being componential; working memory being related to one or more of these components.

Like Sáfár and Kormos (2008), Wen and Skehan (2011) also argue that the construct of WM should be incorporated as a component of language aptitude. Through an analysis of previous findings, Wen and Skehan discuss empirical results regarding WM and a number of L2 skills: listening, reading, speaking, writing, and bilingual interpretation. Their discussion lends support to an argument of WM as language aptitude, as there exists empirical evidence of WM affecting all of the L2 skills mentioned above. In terms of listening, Wen and Skehan refer to Gu and Wang (2007), who found that working memory was an "effective predictor of the participants' listening comprehension performance" (Wen & Skehan, 2011, p. 27). Such a result adds to an argument of a higher level of working memory being more conducive to listening comprehension. Regarding speaking, Wen and Skehan refer to the aforementioned study by O'Brien and colleagues, in which one found that WM contributes differently to the development

[3] The Standard Hungarian Language Aptitude Tests consists of four subtests: *Hidden Sounds, Language Analysis, Words in Sentences,* and *Vocabulary Learning*. See Sáfár and Kormos (2008) for further details.

of L2 speaking depending on the L2 stage of the learner. Similar research is being referred to throughout the discussion, before they finally conclude that there are three (pre)conditions to allowing "WM to be the best candidate component of foreign language aptitude" (ibid, p. 35), namely that

> there are variations in WM capacity that are specific to individual L2 learners and these variations can be measured […]; second, WM plays a very important role in various SLA stages and cognitive processes and such effects are constant and pervasive; third, different components of WM […] have been found to be highly correlated with different aspects of L2 performance and developments and specific L2 skills development […] (Wen and Skehan, 2001, p. 35).

2.4.4 Working Memory, Language and Attentional Control

In addition to research showing correlations between language skills and working memory, there is also evidence suggesting a third – though not necessarily separate – affecting factor: attentional control. Kane et al. (2001) argue that WM capacity is interconnected with what they call "controlled-attention", which will here be referred to as attentional control. In order to investigate their hypothesis, they tested participants with high and low working memory spans in a visual-orienting task which measures the participants' attentional control. Their results showed that the two groups differed in their scores on attentional control, the high working memory score group outperforming the other. As a result, they argue that WM capacity appears to be "related to the controlled processing required in responding to interference" (ibid, p. 178), as intervening stimuli was part of the visual-orienting task.

In addition to arguments of working memory and attentional control being somehow connected, there are studies suggesting bilingualism to be related to attentional control – both in the visual and the auditory modality. Bialystok and Martin (2004) compared groups of monolingual and bilingual children on the dimensional change card sort task, which allows for examination of differences in control of attention. A total of three studies were conducted, and the results clearly assert a bilingual advantage in attentional control. Due to the format of the task, Bialystok and Martin's study arguably show a bilingual advantage in *non-verbal* problem-solving tasks, here in the visual modality, and they argue that "early childhood bilingualism modifies children's development of control of attention" (ibid, p. 338), thus indicating causation. Similar results were found in a study on older bilinguals using the Simon task[4], in which the bilingual group outperformed the monolinguals on both the congruent and the

[4] A choice reaction time task in which there is dimensional overlap between the irrelevant stimulus and the response.

incongruent trials of the task (Bialystok et al., 2004). Put differently, the bilingual group were faster on "conditions requiring greater working memory control even in the absence of competing position information" (ibid, p. 302).

With regard to the auditory modality, Bak, Vega-Mendoza and Sorace (2014) examined attentional control in bilinguals using auditory subtests of the TEA[5]. They note that previous research on auditory attention has produced conflicting results, as some researchers "did not find an advantage of bilinguals over monolinguals on an auditory Stroop task, while other authors reported a better performance in bilinguals on dichotic listening and sound encoding" (ibid, p. 2). In terms of their own research, their results confirm previous reports of a bilingual advantage on cognitively demanding attentional control tasks. The bilingual group performed significantly better than monolinguals on a task of selective attention, which Bak, Vega-Mendoza and Sorace argue to indicate an influence of bilingualism on attentional control; specifically selective attention. Moreover, due to the specific task's requirement of inhibition of irrelevant stimuli, they further argue that the results can be compared to visual inhibition tasks like the ones mentioned above.

Whereas Kane et al. (2001) argue for a connection between WM and attentional control, Bialystok and Martin (2004), Bialystok et al. (2004), Bak, Vega-Mendoza and Sorace (2014) argue for a similar connection between bilingualism and attention. Such arguments may lead to speculations about all of the factors being interconnected. An interesting question is how these mechanisms and factors are interrelated, and whether there is some kind of causal relationship between them. Namazi and Thordardottir (2010) explored such speculations by investigating the relationship between working memory and visually controlled attention in bilingual and monolingual children. Specifically, they examined "whether bilingual and monolingual children differ on a visual measure of CA (controlled attention) after potential differences in verbal and visual WM had been accounted for" (ibid, p. 597, *my parenthesis*). Interestingly, they did not observe a bilingual advantage on the attentional control task (Simon Task), but rather found that children with high visuospatial WM scores were more accurate on the attentional control task than were children with lower visuospatial WM. As such, Namazi and Thordardottir's results add controversy to findings of a bilingual advantage in attentional control, and suggest the advantage effect to rather be related to a WM advantage. In other words,

[5] A standardized test battery to assess attentional functions.

one may speculate that attentional control is part of the WM system. Namazi and Thordardottir do, however, note that their findings do not necessarily imply a causal relationship between working memory and attention.

2.4.5 A Constant or Dynamic WM?

An aspect of WM which has not yet been discussed in this chapter, is that of the state of WM – that is, whether it is a constant or dynamic entity. This is a much debated topic, and one does not seem to have a definite conclusion as to whether the WM is in fact a trainable property of the human memory. Holmes, Gathercole and Dunning (2009) assert a common understanding of WM to be that "WM ability is highly heritable and unlike many other cognitive assessments, appears to be relatively impervious to substantial differences in environmental experience and opportunity" (ibid, p. 9). Consequently, recent reports on "generalized and sustained enhancement of WM following an intense WM training program" (ibid, p. 10) have thus received considerable attention.

The hypothesis of WM being susceptible to improvement, is further researched by Holmes, Gathercole and Dunning (2009) in an evaluation of the aforementioned training programme. For a period of at least 20 days, two groups of children with poor working memory abilities engaged in training on "a variety of WM tasks in a computerized game environment" for approximately 35 minutes a day in school. The different tasks tapped both verbal and visuospatial STM and WM. The results of the study showed that the majority of the participants improved their WM scores substantially, which favours the idea of WM as a dynamic rather than constant property. Moreover, the improvements "generalized to independent and validated WM assessments" (Holmes, Gathercole & Dunning, 2009, p. 13), meaning that the gains were not only trained to the specific tests. Consequently, children with poor working memory abilities – which are often accompanied by poor academic learning – may indeed improve these skills via training programmes, and thus overcome the learning difficulties associated with working memory impairments.

In relation to WM and language, the exercise of speaking two or more languages appears to produce differences in cognitive performance (Morales, Calvo & Bialystok, 2013, p. 187). Such an argument is rooted in bilinguals' need to "monitor their attention to the target language in the context of joint activation of the other language" (ibid.). According to Morales, Calvo and Bialystok (2013), this control of attention is partly handled by the executive control system of the WM, which in turn lends support to Namazi and Thordardottir's (2010) correlation between working memory and attentional control. More generally speaking, and as previously mentioned, such cognitive abilities appear to be potential subjects of modification via practice in a particular process. As such, when considering Morales, Calvo and Bialystok's arguments above, practice in the form of bilingualism may be speculated to scaffold development of the executive control in a similar fashion as continuous practice in playing video games may enhance one's visual processing. In this respect, WM (at least the executive control) may be argued to be of a dynamic nature as it is subject of modification via the exercise of speaking two or more languages. What is more, the relationship between WM and language may be bi-directional as any direction of causation is yet to be determined.

3. Methodology

This chapter introduces and discusses the methodological approach and research design of this correlational research study. A strictly quantitative approach is proposed in order to best examine the respective hypotheses. Following this proposal, I will provide an overview of the research design. This overview includes a description of the sample, an account of the specific methods as well as a discussion of the validity and reliability of the different methods. In the subsequent section, I will account for the specific process of data collection, before proceeding with an overview of the methods used for data processing and analysis.

3.1 Methodological Approach

As explained by Angouri (2010, p. 31), the choice of methodological approach and techniques in any research project depends "upon the questions and the focus of the researcher". However, the choice of approach is not necessarily strictly instrumental; an interest in quantitative research questions does not dictate the approach to be strictly quantitative. Put differently, one may also consider philosophical and conceptual debates in choosing the methodological approach. Moreover, one often combines different approaches as "mixed methods designs arguably contribute to a better understanding of the various phenomena under investigation" (ibid, p. 33). That is not to say that mixed methods research designs yield "better" research, though it allows for a more diverse method.

In the case of this study, specific variables and their potential patterns of correlations are of interest. As such, quantitative methods are favourable in the definite measuring of the variables and the subsequent analysis of their correlations. Qualitative measures such as interviews might scaffold a deeper understanding of the statistical results, though this would undoubtedly be rather time-consuming. Consequently, such an interview was rather compressed to a short questionnaire which provides relevant background information about the participants. Moreover, as the issue of working memory as language aptitude is still at a somewhat speculative and preliminary stage, it is of greater interest to identify the variables affecting aptitude; a deeper understanding of the correlations may in stead be the issue of further research once the specific variables have been established. Triangulation is consequently achieved technically rather than methodologically: more than one sampling method is applied for data collection, though they are all quantitative.

3.2 Research Design

In this section, I will discuss the research design of the project, beginning with the sample – or more specifically: the participants. The subsequent sections deal with the different instruments of data collection and their respective validity and reliability.

3.2.1 Participants

The participants in this project were 30 Norwegian University Students of English – all from the same university. They all had Norwegian as one of their native languages, though all participants were arguably bilinguals in the sense that they used two languages (Norwegian and English) in their everyday lives, as is a fairly common understanding of the concept bilingualism (Grosjean, 2004, p. 34). The participants were provided with an information sheet which included a consent form (see appendix 1). The sheet informed about the project in general, in addition to explaining the formalities regarding anonymity and the opportunity to withdraw from the study at any time. As all of the students were above eighteen years of age, no parental consent was needed. Subsequently, all students who agreed to participate in the study were asked to fill out a questionnaire on their language background, which included years of education in English, long-term stays abroad, approximate exposure to English and the like (see appendix 2). As such, only the students who handed in both of these forms partook in the project.

The study has been reported to and accepted by the Norwegian Social Science Data Service (NSD). In order to ensure the participants' anonymity in the final study, each participant was identified via a participant number. Consequently, the results were linked to these numbers only – not to the participants' proper names. The list containing the linkage between the assigned numbers and the participants was stored separately and could only be accessed by myself and my supervisors.

Materials

The background questionnaire showed the average year of birth of the participants to be 1991 – rendering an average age of 24 years. In terms of education, the average participant had 3-4 years of education in English at a university level, and rated their overall skills in English (reading, writing, speaking, and listening) as advanced/fluent. In addition to describing the average participant, the main interest in the background questionnaire was to gain information on some selected relevant factors regarding the participants' L2 acquisition. Such information was subsequently applied in the process of excluding participants who would not be suitable for the purpose of this project. Exclusion of this kind was rooted in diagnoses potentially relevant to language acquisition, hearing loss and other learning difficulties. Moreover, participants who were Norwegian/English bilinguals from an early age – meaning that English was one of their first languages – were excluded on the basis that the project researches L2 aptitude, thus requiring participants for whom English is an L2 and not an L1. Participants whose native languages included other non-Scandinavian languages were also excluded. A total of 4 participants were excluded on these bases, resulting in a total of 26 participants being included in the final results: 18 females and 8 males.

3.2.2 Tests

Language Proficiency

All participants were asked to do two different tests on language proficiency (the dependent variable in the study): one on grammar and one on vocabulary. The vocabulary test, called "wordORnot", was developed by the Centre for Reading Research at Ghent University of Belgium, and is available online. When doing the test, the participants are exposed to 100 letter sequences – one at the time – and asked to indicate which of the sequences are existing English words and which are not, using different keys on the computer keyboard. Moreover, one is penalized if saying "yes" to a non-word, which is meant to discourage guessing. When the vocabulary test is completed, one is presented with an estimated percentage of English words the participant knows. As the participants are not required to produce any words themselves during the test, the test is a measure of receptive vocabulary.

As part of the proficiency tests, the participants were additionally asked to complete a grammar test. Like the test on vocabulary, the grammar test is also an online one. The test is provided by Exam English and is a practice test for the Cambridge Proficiency exam at a C2 level of difficulty. The test itself is a cloze test, in which participants are asked to choose between four different options to fulfil a given sentence. The options are all suggestions as to what should be "filled into the blank" of the respective sentence. Each test-taker is presented with a total of fifty sentences which are the same for every test. As such, each participant is exposed to the exact same questions in the test. The test result is presented as a mere quantum of correct answers. As the grammar test has this type of multiple choice format, there is always a chance that the test-takers are merely guessing at some, or more, of the fifty sentences. Therefore, the grammar test is not necessarily a reliable measure in itself – an issue which will be further discussed in the following.

Reliability and Validity

When considering the construct validity of second language research, this may be hard to determine due to the variables being so loosely defined – if defined at all. Such variables include language proficiency, aptitude, linguistic representations and the like. Due to the variables being rather abstract, they are all the more difficult to measure; they are not fixed entities and cannot be measured in a direct or fixed way. However, Mackey and Gass (2005, p. 108) argue that the construct validity of research dealing with such variables may be enhanced "when multiple estimates of a construct are used". As such, the use of both the vocabulary and the grammar test presumably enhances the validity of the overall proficiency measure.

In addition to the variables being challenging to measure, the designs of the tests may be somewhat inaccurate as well. Although one is penalized for saying "yes" to a non-word during the vocabulary test, this does not necessarily prevent the participants from guessing – and as such receive a percentage score higher (or lower) than their actual level of vocabulary knowledge. As mentioned, the grammar test also shows some weaknesses in design in terms of the possibility of merely guessing the answers. Consequently, the results of the respective proficiency tests are more suggestive than conclusive on their own – though the two results combined arguably make a more reliable measure. This is explicable by the tests' ability to reinforce one another if the results from each test more or less correspond.

Working Memory

Due to the complexity of the human working memory, several tests are necessary in an attempt to test the working memory span in both the phonological loop, the visuospatial sketchpad, and the central executive – which are the components of interest, and the independent variables, in the current study. In this project, tests on phonological memory are adapted from the Working Memory Test Battery for Children (WMTB-C, see appendix 4) (Pickering & Gathercole, 2001). The battery provides a "theoretically well-based working memory profile that has been validated against educational achievement and standardised across a range of ages" (ibid, p.

vii). In the following, I will account for these different test methods for working memory and comment on their possible strengths and weaknesses.

Word/Non-Word List Recall

The tasks of word and non-word list recall are two of the measures for assessing the participants' abilities to store and immediately recall sequences of spoken items. According to Gathercole et al. (2004), such tasks are common measures of the phonological loop, in which short-term phonological information is stored. The word list recall and the non-word list recall in this research project are adapted into Norwegian from the standardized English version in Pickering and Gatherchole (2001). The adaptation was carried out by the Language Acquisition and Language Processing Lab group, NTNU (Vulchanova et al., 2011) and followed the same basis of construction as the original.

The word list recall and the non-word list recall share the same outline. The participants are presented with spoken sequences of words (or non-words) which they are then asked to recall in correct serial order. All words and non-words are monosyllabic, and presented at the rate of one word/non-word per second. The sequences are constructed randomly and without replacement, and six lists are presented at each length. For the word list recall, the first list consists of three words; gradually increasing up to a maximum length of seven words. The non-word list recall, on the other hand, starts at a length of only one word and has a maximum length of five non-words. The stimuli are never repeated, and the list items must be "recalled with full accuracy" (Gathercole et al., 2004, p. 180); all phonemes must be correct for the participant to receive a point for the respective sequence. However, the participants' response may deviate from the presented input in terms of dialectic/sociolectic differences in pronunciation. In order to ensure as close to an identical stimulus for all participants as possible, they are all presented with the same test and all of the lists are tested for, no matter the participants' response. Put differently, the test does not end after a participant has made a certain number of errors – the test is completed regardless of erroneous responses. Finally, the number of lists correctly recalled is scored.

Benefits of Non-Word List Recall

Gathercole and Baddeley (1993) favour the non-word list recall over the word list recall and the two digit recalls (see below) as a measure of phonological short-term memory. This has to do with the fact that there are no long-term lexical representations available of the non-words – whereas the opposite is most likely the case for genuine words. When asked to repeat a list of actual words, the participants may (subconsciously) utilize the episodic buffer to access their already existing lexical knowledge to supplement phonological short-term memory (ibid, p. 48). Put differently, the participants may use for instance semantic knowledge to easier recall a list of words, which somewhat alleviates the job of the short-term memory. Nonetheless, Gathercole and Baddeley are explicit in that they "do not wish to deny here the undoubted value of tasks such as digit and word span as measures of phonological memory skill" (ibid, p. 49). Moreover, the results of the different tests are significantly correlated with one another, making the combined results all the more reliable and valid.

Forward/Backward Digit Recall

As opposed to the word lists, the digit recall tasks have not been adapted or altered in any way from the original in the WMTB-C. As such, the digit recall tests are standardized measures of assessing participants' phonological loop, and share the same procedure as the word list recall tasks. The digit recall tasks only differ from the word lists in that the list items are digits rather than words/non-words. Also, where the word list is contrasted with the non-word list, the "counterpart" of the digit recall is the backward digit recall. In the latter, the participant is presented with a spoken list of digits and asked to recall it in reverse order. Such backward digit recall is a more complex WM task than the others, as this task not only requires the participant to remember the stimuli, but also to process it and produce a new output. Put differently, the backward digit recall taps both the storage- and processing element of WM.

Corsi Block-Tapping Test

The Corsi Block-Tapping test is part of the Psychology Experiment Building Language (PEBL) test battery (Mueller, 2011), and is carried out on a computer. The test is a standardized measure of the visuospatial sketchpad, and is in fact quite similar to the word and digit recall tests. Instead of presenting the participants with spoken words or digits, they see several blocks on a computer screen which ignite in turn. Each box illuminates for one second, and after the respective sequence ("list") is finished, the participants must click on the boxes in the same order in which they were ignited. The test starts with sequences of two boxes, before escalating to a maximum of nine boxes. The adding of lit boxes follows the span procedure outlined above.

Dichotic Listening

The dichotic listening test is a measure of lateralization and auditory attentional control, and is carried out via an app developed by the Bergen fMRI Group (2011), called iDichotic. In this test, the participants are equipped with headphones, and two similar (though not always identical) monosyllabic sounds are presented orally, one in each ear. The participant will then state which syllable he/she heard by tapping this syllable on the iPad-screen. The app includes two conditions: one in which the participant is merely asked to listen and select the syllable heard out of a set of six potential sounds, and another where the participant is asked to concentrate on the sounds in either the right or the left ear. According to van den Noort (2007, p. 20), the tendency is for the sounds to be "detected more easily in the right ear in participants with a language-dominant left-hemisphere". He further explains this by referring to the assumption that "contralateral auditory input dominates over ipsilateral input in dichotic listening" (ibid). Nonetheless, the participants' answers are noted and stored in the app and subsequently transferred to a computer for analysis.

Reliability and Validity

Theoretically, both the word/non-word list recall and the forward/backward digit recall activate the WM's phonological loop and the central executive. These tasks require the participant to receive the information, process it via encoding the words/non-words/digits, recalling and sequencing them, and finally vocalizing the information (Groth-Marnat & Baker, 2003, p. 1209). The backward digit recall is more advanced, as the digits must be held for a longer time in the memory loop, in addition to being manipulated to a different sequence, and as such is considered a proper measure of working memory capacity. All of the tasks are, according to Conway et al. (2005, p. 769), among the most widely used measurement tools in cognitive psychology. Moreover, they argue that "estimates of reliability based on internal consistency […] are typically in the range of .70 - .90 for span scores, where values can range from 0 (*no reliability*) to 1 (*perfect reliability*)" (ibid, p. 776). Conway et al. further debate that "WM span tasks are reliable in the sense that the rank order of span scores are stable *across* time" (ibid.), as testing and retesting have been conducted with an intermission of minutes, weeks, and three months with test-retest correlations of 0.70 - 0.80. With regard to validity, measures of working memory capacity seem to predict performance on numerous tasks for which control of attention and thought are important, inter alia reading and listening comprehension and complex-task learning (ibid, p. 778). Such correlations between performance on WM span tasks and other cognitive tasks arguably show considerable construct validity.

Regarding the task for visuospatial WM, "[t]he Corsi block-tapping task has enjoyed extensive use in clinical and experimental studies [...] and is arguably the single most important nonverbal task in neuropsychological research" (Berch, Krikorian & Huha, 1998, p. 317). However, as one has been lacking a standardized version of the test, there have been several variations in procedure and scoring. A standardization was nonetheless proposed in a study by Kessels et al. (2000), in an attempt to ensure more unified procedures of scoring. This study included instructions, specific trials, scoring measures and more, which were all included in the implementation of the test in the PEBL battery. As to the validity and reliability of computerized versions of the Corsi block-tapping task, its field of usage is somewhat debated. Moreover, Claessen, van der Ham and van Zandvoort (2014) argue that although the original version of the Corsi Task and a computerized one yield rather similar results, there might still be differences regarding accuracy. This is arguably to be expected, as there will be differences between the two versions as a result of the procedure of administration, and using digital technology and typing. Nonetheless, computerized versions of the Corsi Task are widely used as measures of the visuospatial sketchpad.

With regard to the iDichotic app, this form of dichotic listening has been argued to have the same reliability as equivalent testing in laboratory settings. Bless et al. (2013) have evaluated the validity and reliability of the app in controlled laboratory settings, as well as having investigated whether the app version of the test produces robust results when applied to the general population. They found that the iDichotic app produces highly reliable results, with an intraclass correlation of 0.78 (ibid, p. 4[6]). Moreover, the validity appears to be high as there was a strong correlation between the results of the standard PC version of the test and the application for smartphones (ibid).

3.2.3 Pilot study

Before initiating the study, a small pilot study was carried out on four people. Such a pilot study is meant to be a small-scale trial of the selected methods and materials, so as to be able to adapt

[6] Page numbers correspond to a PDF version of the article available from: http://journal.frontiersin.org/article/10.3389/fpsyg.2013.00042/abstract

and revise the procedure. Consequently, any potential problems may be addressed before the main study is carried out (Mackey & Gass, 2005, p. 43). In the case of this study, the amount of lists in the word list recall was slightly reduced after the trials, as well as the scoring methods being somewhat altered: participants are not penalized for all phonemic errors in the word list recall. This has to do with the test being carried out in the participants' native language, and is consequently subject to differences in dialects as well as sociolects. As such, the participants are only scored with zero points if they do not recall the words in the correct order, or if they add or delete words from the lists. For instance, erroneous pronunciation of similar phonemes such as /ʃ/ and /ç/ do not count as a wrongful answer.

3.2.4 Procedure

As mentioned, all tests on phonological memory in this thesis share the same outline. Consequently, it is natural for these tests to share the same procedure of administration and scoring as well. Thus, I presented the participants with the respective stimuli at the same rate in the word/non-word list recall and the forward/backward digit recall – approximately one word/non-word/digit per second. Moreover, the participants had to recall the stimuli in the correct order in order to receive a point for the list in question. As previously mentioned, the words/non-words must additionally be phonologically correct. The administration of the tests in this study deviates somewhat from the original WMTB-C, as I did not operate with neither a "move on" nor a "discontinuation" principle: I did not "move on" to the next list if the participant responded correctly to four trials within a block, nor did I stop the test if three or more errors were made within a block. As explicated earlier, this procedure was rooted in a wish to expose all participant to a similar amount of stimuli.

In the case of calculating the memory span for the respective tests, I followed the procedure suggested by Pickering and Gathercole (2001). The procedure is based on the discontinuation principle, as the span of a particular test equals "the number of words making up the trial sequences in the last block before the discontinuation rule came into force" (ibid, p. 49). Put differently, the span equals the last block with fewer than three errors. Regarding the physical surroundings of the test situation, all tests were carried out in a quiet room with only me (and/or an assistant) and the participant present in order to promote a tranquil and controlled test situation.

3.2.5 Data Processing and Analysis

Due to the nature of the data being a quantitative one, there is a need for statistical treatment and analysis. Consequently, all of the collected data material were coded and subsequently transferred into an Excel worksheet. The Excel sheet provided a lucid basis for a descriptive analysis, in the sense that potential patterns were located. Subsequently, the data were processed using the open source software R so as to further analyse the (potential) patterns from the descriptive analysis. Put differently, R was used in an inferential statistical analysis through which it was attempted to determine "whether there really [was] some meaningful correlation" (Levon, 2010, p.70) between the different variables, and whether the patterns were statistically significant – that is, not merely coincidental. In the case of this study, the analysis focused on potential dependencies between the dependent and the independent variables – that is, between L2 proficiency and working memory/attentional control scores.

4. Results

An analysis of research data gathered via one-to-one quantitative testing of the participants is presented in this chapter, and the hypotheses posed in Chapter 1 are reiterated and addressed. The data are presented categorically, so as to better scaffold a lucid review of the results. First, the descriptive analysis of both dependent and independent variables – language proficiency and working memory/attentional control, respectively – is presented. Second, quantitative results from an inferential analysis conducted in R are examined and explained. Illustrations and tables are provided where necessary.

4.1 Descriptive Analysis

My hypotheses revolved around correlations between the dependent variable of L2 proficiency and the independent variable of working memory/attentional control, hypothesizing positive correlations between the two. This section presents the descriptive analysis which was carried out in an attempt to detect potential patterns which could be further investigated in the subsequent inferential analysis.

4.1.1 Mean Raw Scores and Standard Deviations

All of the data were coded and transferred into an Excel sheet, in which a descriptive analysis was conducted. Such an analysis in terms of means and standard deviations of all variables is illustrated below.

Variable	**Mean score**	**Maximum obtainable score**	**Standard Deviation**
Gram	0,84	1	0,09
Voc	0,63	1	0,12
WLR	4,77	8	0,65
NWLR	2,81	5	0,57
FDR	5,96	9	1,08
BDR	4,92	7	1,02
CBTT	5,50	9	0,72
NFRC	16,12	30	4,41
NFLC	10,62	30	4,25
FRR	19,81	30	3,84
FRL	7,50	30	2,92
FLR	11,96	30	6,24
FLL	12,85	30	4,29

Table 1: Mean scores and standard deviations of all variables: grammar test (Gram), vocabulary test (Voc), word list recall (WLR), non-word list recall (NWLR), forward digit recall (FDR), backward digit recall (BDR), Corsi block tapping test (CBTT), dichotic listening: non-forced right correct (NFRC), non-forced left correct (NFLC), forced right right correct (FRR),

forced right left correct (FRL), forced left right correct (FLR), and finally forced left left correct (FLL). The values for Gram and Voc are decimals of the equivalent percentages.

The mean score and standard deviation of the participants' scores were performed in an Excel sheet, using the simple commands of AVERAGE and STDEV. The mean scores show the typical score of the sample, whereas the standard deviation scores measure how widely the individual scores are dispersed from the mean score. With this is mind, Table 1 shows that there is little variation between the individual scores on English proficiency and the majority of the working memory variables, whilst the variation is somewhat greater for the iDichotic listening variables. This indicates that the scores tend to be relatively close to the expected value for the tests on proficiency and phonological and visuospatial working memory, whereas the data points are spread across a wider range of values for the dichotic listening. Notice how the mean scores of the forced right condition (FRR/FRL) are much more skewed than for the forced left condition (FLL/FLR). In other words, when asked to attend to the right ear the average participant retrieved a significant majority of information from the right ear, whilst when asked to attend to the left ear a relatively similar amount of information was retrieved from both ears.

In relation to the maximum obtainable scores, this project's sample performed rather well on both the grammar test and the vocabulary test, with an average of 84% and 63% of their respective answers being correct. The fact that the average scores are this high, may indicate a ceiling effect. Considering that the proficiency variables serve as dependent variables, a ceiling effect may mask potential effects of the independent variable (Lammers & Badia, 2005). In order to control for such an effect, a t-test was performed for both variables. The tests returned very low p-values (p<0,05), thus suggesting a rejection of the null hypothesis of the aforementioned average values corresponding to the ceiling value.

As to potential patterns detected in the descriptive analysis, there seemed to be correlations between proficiency scores and working memory scores for *some* of the participants, though this was not a striking feature overall. Nonetheless, the potential correlations were more scrutinizingly looked into in an inferential analysis in R.

4.2 Inferential Analysis

As mentioned in the previous chapter, R was used in an inferential statistical analysis through which it was attempted to determine "whether there really [was] some meaningful correlation" (Levon, 2010, p.70) between the different variables, and whether the patterns were statistically significant – that is, not merely coincidental. Before checking for correlations, however, the dataset was checked for normality using the Shapiro-Wilk test[7]. This was done for each variable individually (see Table 2), and the results showed p-values above the chosen alpha-level for the proficiency variables and the iDichotic variables – thus indicating this data to be normally distributed. This was further checked for by plotting the data into histograms, like the one below for the grammar variable.

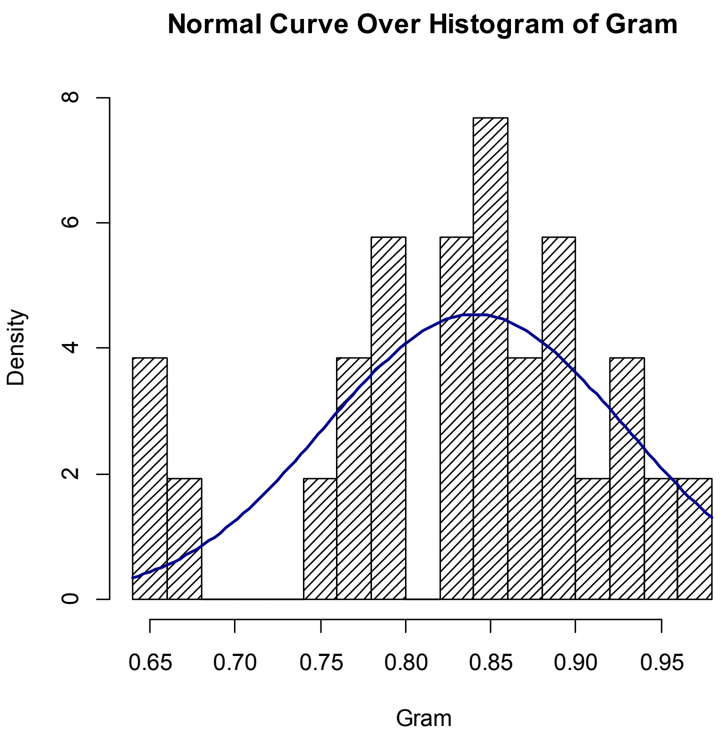

Figure 3: Histogram with normal curve of the grammar variable, showing the data to be normally distributed.

Variable	Shapiro-Wilk	Distribution
Gram	0,1526	Normal
Voc	0,07421	Normal
WLR	9,304e-05	Non-normal
NWLR	1.728e-05	Non-normal
FDR	0,007827	Non-normal
BDR	0,03447	Non-normal
CBTT	0,005546	Non-normal
NFRC	0,7595	Normal
NFLC	0,1137	Normal
FRR	0,3404	Normal
FRL	0,2176	Normal
FLR	0,5314	Normal
FLL	0,3638	Normal

Table 2: Results of the Shapiro-Wilk test for all variables.

For the working memory variables however, the Shapiro-Wilk test yielded p-values below the alpha-level of 0,05 which suggests the data for these variables to be non-normally distributed. When plotting these data into histograms, some data were revealed to be bimodally distributed

[7] The Shapiro-Wilk test utilizes the null hypothesis principle to check whether the sample came from a normally distributed population.

in the sense that two values appeared more often in the data, whilst others were more randomly sorted. Though normality is not a formal requirement for running correlational tests, the non-normality of the data must be considered in the subsequent interpretation of the correlational analyses. This has to do with potential *type 1 errors* in which the null hypothesis is wrongfully rejected, an error which is partially controlled for by adjusting the alpha-value of significance (Midtbø, 2007, pp. 64-65).

4.2.1 Correlational Analysis

Once the distribution of the data sample had been established, correlational tests were run using the *Hmisc* and *corrgram* packages of R. Once having loaded all of the raw data into R, both a Pearson and a Spearman correlational test were applied to the dataset. The correlational coefficient *Pearson's r* measures "the linear correlation between two continuous variables" (Midtbø, 2012, p. 84, *my translation*), meaning to what extent the change in one variable is associated with a proportional change in the other. The correlational coefficient *Spearman's rho*, on the other hand, evaluates the monotonic relationship between the variables. In such a relationship, the variables do tend to change together, though not necessarily at a constant rate. Each analysis yields a set of correlation coefficients in addition to values of significance (p-values), tables of which are presented in Table 3 and Table 4.

Pearson's r

Pearson's *r*	Gram	Voc	WLR	NWLR	FDR	BDR	CBTT	NFRC	NFLC	FRR	FRL	FLR	FLL
Gram	1.00	0.64	0.28	0.07	0.25	0.14	0.20	-0.02	0.13	0.10	0.06	0.10	0.36
Voc	0.64	1.00	0.54	0.22	0.23	0.22	0.15	0.05	0.05	0.23	-0.12	0.03	0.53
WLR	0.28	0.54	1.00	0.31	0.50	0.21	-0.09	0.05	0.18	0.11	0.04	-0.14	0.33
NWLR	0.07	0.22	0.31	1.00	0.51	0.53	-0.15	0.22	-0.25	-0.07	0.16	0.23	-0.06
FDR	0.25	0.23	0.50	0.51	1.00	0.47	0.10	0.14	0.11	0.06	0.18	0.11	-0.02
BDR	0.14	0.22	0.21	0.53	0.47	1.00	0.00	0.64	-0.50	0.23	-0.01	0.17	0.04
CBTT	0.20	0.15	-0.09	-0.15	0.10	0.00	1.00	0.18	-0.20	0.07	0.02	0.01	-0.01
NFRC	-0.02	0.05	0.05	0.22	0.14	0.64	0.18	1.00	-0.88	0.38	-0.31	-0.02	0.04
NFLC	0.13	0.05	0.18	-0.25	0.11	-0.50	-0.20	-0.88	1.00	-0.14	0.19	0.00	0.00
FRR	0.10	0.23	0.11	-0.07	0.06	0.23	0.07	0.38	-0.14	1.00	-0.89	-0.28	0.35
FRL	0.06	-0.12	0.04	0.16	0.18	-0.01	0.02	-0.31	0.19	-0.89	1.00	0.24	-0.29
FLR	0.10	0.03	-0.14	0.23	0.11	0.17	0.01	-0.02	0.00	-0.28	0.24	1.00	-0.52
FLL	0.36	0.53	0.33	-0.06	-0.02	0.04	-0.01	0.04	0.00	0.35	-0.29	-0.52	1.00

Table 3: Correlation coefficients, Pearson's r

The Pearsons's *r* coefficient values range from -1 (perfect negative correlation) to +1 (perfect positive correlation); when the correlation coefficient is 0, there is no correlation between the two variables in question. The analysis showed a varied degree of correlation between the different variables, with some coefficients above 0.5 and others closer to 0. This will be further discussed in the following chapter.

P-values	Gram	Voc	WLR	NWLR	FDR	BDR	CBTT	NFRC	NFLC	FRR	FRL	FLR	FLL
Gram		0.0005	0.1610	0.7435	0.2257	0.5101	0.3215	0.9272	0.5284	0.6260	0.7672	0.6321	0.0746
Voc	0.0005		0.0044	0.2824	0.2572	0.2836	0.4696	0.8189	0.8271	0.2618	0.5505	0.8989	0.0056
WLR	0.1610	0.0044		0.1257	0.0093	0.2947	0.6793	0.8032	0.3703	0.5943	0.8382	0.4883	0.0992
NWLR	0.7435	0.2824	0.1257		0.0075	0.0055	0.4744	0.2868	0.2228	0.7237	0.4429	0.2654	0.7634
FDR	0.2257	0.2572	0.0093	0.0075		0.0148	0.6163	0.5085	0.5919	0.7849	0.3660	0.5874	0.9279
BDR	0.5101	0.2836	0.2947	0.0055	0.0148		1.0000	0.0005	0.0097	0.2544	0.9478	0.4146	0.8345
CBTT	0.3215	0.4649	0.6793	0.4744	0.6163	1.0000		0.3897	0.3220	0.7522	0.9265	0.9731	0.9500
NFRC	0.9272	0.8189	0.8032	0.2868	0.5085	0.0005	0.3897		0.0000	0.0559	0.1201	0.9132	0.8337
NFLC	0.5284	0.8271	0.3703	0.2228	0.5919	0.0097	0.3220	0.0000		0.4890	0.3517	0.9944	0.9876
FRR	0.6260	0.2618	0.5943	0.7237	0.7849	0.2544	0.7522	0.0559	0.4890		0.0000	0.1694	0.0812
FRL	0.7672	0.5505	0.8382	0.4429	0.3660	0.9478	0.9265	0.1201	0.3517	0.0000		0.2322	0.1442
FLR	0.6321	0.8989	0.4883	0.2654	0.5874	0.4146	0.9731	0.9132	0.9944	0.1694	0.2322		0.0067
FLL	0.0746	0.0056	0.0992	0.7634	0.9279	0.8345	0.9500	0.8337	0.9876	0.0812	0.1442	0.0067	

Table 4: Corresponding p-values to the Pearson's r coefficients in Table 3.

Regarding the statistical significance of the reported correlations, the level of significance (alpha) was adjusted by means of the Bonferroni correction so as to lower the chance of false positives. Consequently, the alpha was adjusted according to the number of correlations by dividing the generally interpreted p-value of 0,05 by the number of pairwise tests performed ($0,05/12 \approx 0,0042$). As a result, the p-value must be less than, or equal to, 0,0042 in order to be counted as significant, thus yielding the following correlations to be significant: Voc/Gram, BDR/NFRC, NFRC/NFLC, and FRR/FRL (see Table 4).

Spearman's rho

The results of the Spearman correlation proved rather similar to the Pearson correlation, but a complete table is nonetheless included in the appendices (appendix 3) in order to provide an overall account of the results. Similarly to the Pearson coefficients, the Spearman coefficients show a varied degree of correlation between the different variables: some coefficients suggest very high correlations, whereas others suggest no correlation at all. Compared to the Pearson p-values, the Spearman p-values appear to generally be a bit higher, and the only statistically significant correlation found using Spearman's *rho* which was not also found in Pearson's *r* was that of NWLR/FDR ($p = 0{,}0042$)[8]. However, this correlation was rejected as a false positive upon further analysis (see scatterplot in appendix 3). The false positive may in turn be related to the non-normal distribution.

Correlogram

As a means of illustrating the correlations, the *corrgram* package in R was used to plot a correlogram. The corrgram function in R is based on Pearson's *r* coefficients, but seeing that the two coefficients above (Pearson's *r* and Spearman's *rho*) yield rather similar results, this is arguably not a problem.

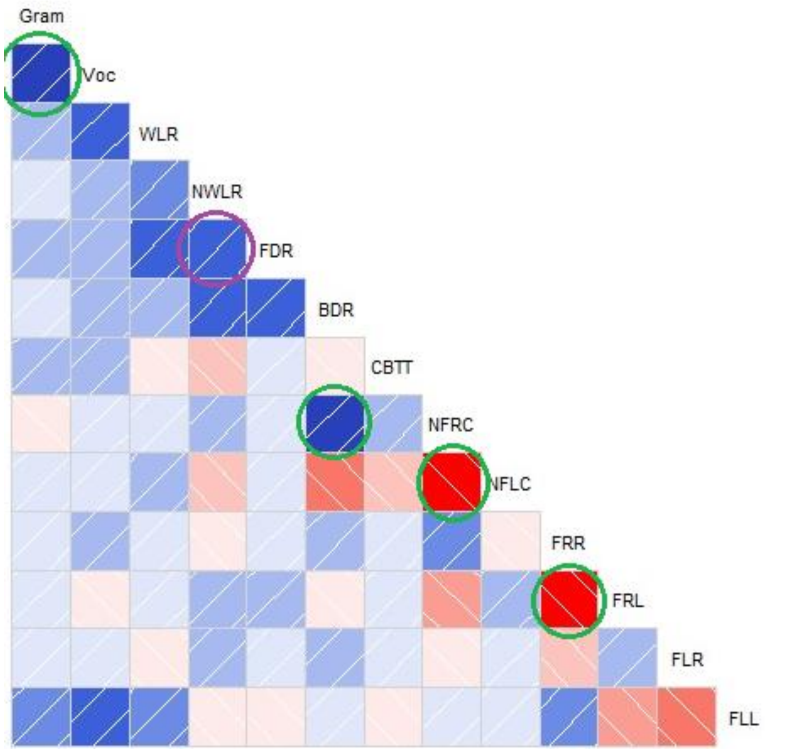

Figure 4: Correlogram of Pearson's r, the statistically significant correlations encircled

The correlogram in the illustration above is meant to visualize the strength of correlation found in Pearson's *r*. The blue colour indicates positive correlation, whilst the red colour indicates negative correlation; the stronger or brighter the colour, the stronger the correlation. Consequently, the correlogram indicates a very strong correlation between the two measures of English proficiency, and also between several of the working memory measures. Notice also the bright blue colour indicating a strong positive correlation between FLL and Voc. In terms of negative correlation, the bright red colour between NFRC/NFLC and FRR/FRL show strong

[8] The detected correlation between NWLR and FDR supports there being a link between the sub-components of working memory. A normal distribution of the data might have provided a proper correlation.

negative correlations between these variables. Regarding significance, the correlations found to be statistically significant (below the corrected p-value) are encircled: the green circles enclose statistically significant correlations from the Pearson correlational analysis whilst the purple circle encloses (the rejected) statistically significant correlation from the Spearman correlational analysis. These significant correlations will be further scrutinized in the following section.

4.2.2 The Statistically Significant Results Scrutinized

The significant correlations may be further investigated in a bivariate correlational analysis supplemented by illustrative scatterplots. "The pattern of the scatterplots say something about the direction, strength and shape of the bivariate relation" (Midtbø, 2007, p. 48, *my translation*), which may further scaffold the results illustrated in the correlogram. A regression line, which summarizes the direction of relation, is added to the scatterplots. Moreover, the regression line is useful in terms of determining the strength of correlation: the higher the density of dots around the regression line, the stronger the correlation.

For the statistically significant correlations found in the Pearson correlation, a linear regression line was applied to the scatterplots (as Pearson's *r* measures *linear* correlation). As can be seen below, the scatterplots and the respective regressions only conform to *some* of the correlational analyses above. There does seem to be a high positive correlation between the two proficiency variables Gram/Voc, whilst there is a very high negative correlation between the dichotic listening variables NFLC/NFRC and FRR/FRL. Regarding the WM variables BDR/NFRC[9], on the other hand, the correlation is not as evident and may indeed serve to illustrate a false positive, potentially caused by the non-normal distribution of BDR.

[9] The detected correlation between BDR and NFRC indicates a link between working memory and a right ear advantage (REA). Had the data been normally distributed, one might have had a better regression line and a proper correlation.

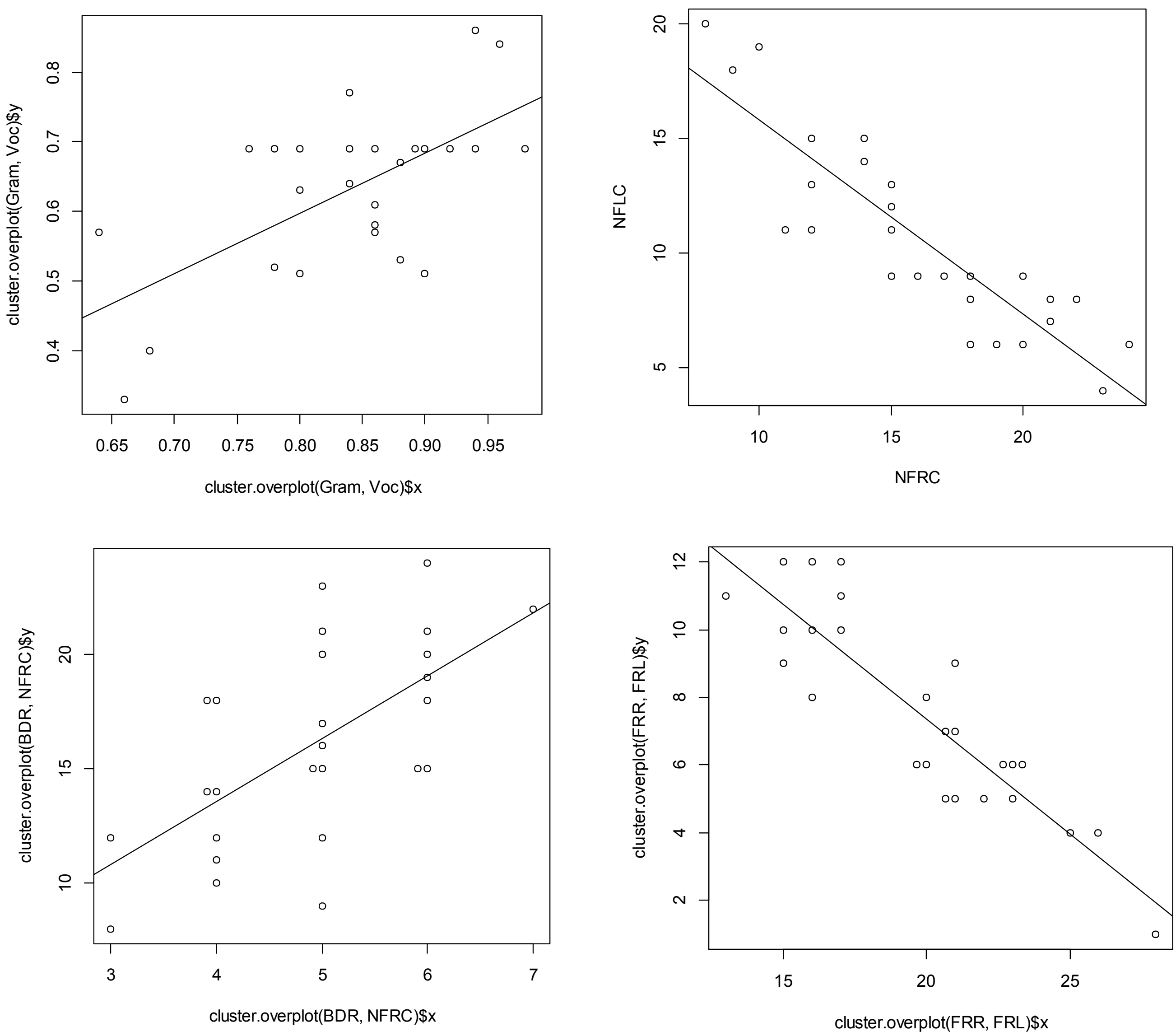

Figure 5: Scatterplots illustrating the direction and strength of correlation between Gram/Voc (top left), NFLC/NFRC (top right), BDR/NFRC (bottom left), and FRR/FRL (bottom right).

In sum, the correlations found to be statistically significant after running correlational tests and corresponding scatterplots are Gram/Voc, NFLC/NFRC, and FRR/FRL.

5. Discussion

This chapter provides a detailed analysis of key research findings presented in the previous chapter, with reference to the research questions in addition to previous research and methodology. The descriptive analysis will not be discussed in any detail, but will rather serve to supplement the discussion of the inferential analysis. Moreover, some of the different tests and measures applied in the procedure will be debated in terms of validity, reliability and sufficiency.

5.1 Statistically Significant Correlations

My hypotheses for this project were to find correlations between the participants' working memory/attentional control scores and their L2 proficiency. Such correlations (both positive and negative) were found in a Pearson correlational analysis, however only a handful of the correlations turned out to be statistically significant. As mentioned in the previous chapter, the variables between which a statistically significant correlation was found were Gram/Voc, NFLC/NFRC and FRR/FRL.

As to the correlation between Gram and Voc – the dependent variables of English proficiency – such a correlation is to be expected in the sense that the two variables are different sub-measures of the same skill, namely L2 proficiency. Moreover, and as debated in Chapter 3, the two tests for proficiency are more suggestive than conclusive on their own, whilst their combined results may be more reliable. A strong correlation between these two variables thus suggests the combined results of the proficiency tests to be a reliable indicator of the participants' proficiency level. However, the tests only touch upon two aspects of proficiency – grammar and vocabulary. Other aspects such as skills in reading and writing are not included in the measure, nor is any complex form of L2 comprehension. Put differently, the Gram and Voc variables may be reliable and valid measures of grammar and vocabulary knowledge, though not necessarily sufficient measures of proficiency. On the other hand, it would arguably be more accurate to speak of the Gram and Voc measures as *indicators* of the participants' grammar and vocabulary knowledge due to the tests' low degree of sensitivity. That is, the tests may not correctly identify highly proficient participants and/or result in false positives. As previously discussed, this may be caused by the possibility of the participants guessing the answers on the different tests, despite such guessing being discouraged. In order for the proficiency measures to be more sensitive, further research should arguably utilize several and more complex measures of proficiency, thus enabling a more in-depth analysis of the participants' L2 proficiency. In terms of this project, some correlations may go unnoticed due to a lack of sensitivity in the proficiency measures. Moreover, one cannot generalize any correlations in this study between Gram/Voc and working memory to be valid for any other aspects of L2 proficiency; thus, the correlative results cannot predict the participants' further L2 skills.

Regarding the correlations found between NFLC and NFRC, and FRR and FRL, these are rather obvious due to the iDochotic test's design. NFLC and NFRC are two measures of the first part of the dichotic listening test, and provide information on how much input was detected by the participant's left (NFLC) and right (NFRC) ear, and thus processed by respectively the right and left hemisphere of the brain. Consequently, there will be a strong negative correlation between the two: the more input was picked up by the left ear (and processed in the right hemisphere), the less was picked up by the right ear (and processed in the left hemisphere). The same logical reasoning applies to the equivalently strong negative correlation between FRR and FRL. As such, these correlations do not yield any information other than the fact that the iDichotic test was carried out properly and that the overall results from the dichotic listening test appear to be reliable.

5.2 Trends

Though there were no statistically significant correlations between L2 proficiency and working memory/attentional control in this project's dataset, a discussion of detected trends may be fruitful. Note, however, that these correlations are just that – trends – *not* statistically significant results. Such trends are, in this case, represented by p-values close to the specific corrected threshold of $\alpha = 0{,}0042$. When operating with the uncorrected threshold of 0,05, many consider trends to be those results with p-values between 0,05 and 0,1. Such a range would be more complex to determine when operating with a corrected alpha, and consequently it appears more prudent to discuss only the results – and potential trends – relevant to my hypotheses and previous research, and whether these respective results support previous findings. With that said, the following paragraphs will investigate the detected trends in correlations between L2 proficiency and the different working memory variables in parallel with that found in previous research.

5.2.1 Non-Word List Recall

As mentioned in Chapter 2, Baddeley and colleagues compared the results of a group of SLI children on a non-word repetition test, with the results of a group of typical children (Baddeley, 2003). The comparison showed the SLI group to perform substantially below the other group, indicating a linkage between the language deficit and working memory results. Hypothesizing that the results of the non-word repetition test are directly linked to language proficiency, one may argue that individuals with a high level of proficiency should also obtain higher scores on a non-word repetition test; thus rendering a positive correlational relationship between the two.

Such positive correlations were found by Hummel (2009). Specifically, Hummel found correlations between the non-word test and both the grammar and the vocabulary subtests of L2 proficiency. In the analyses performed in the present project, a low correlation was found between the non-word list recall and the vocabulary subtest (r = 0,22) whereas a very low correlation was found between grammar and non-word list recall (r = 0,07). In terms of significance, both cases produced very high p-values (p > 0,2) which disqualifies any interpretation of these results as “trends”. Consequently, these findings provide rather opposite results to that found in previous studies. Such a result breaks with expectations, and may be caused by several factors.

Firstly, the proficiency tests of this project do not correspond to those used in Hummel (2009), and as formerly discussed, they may be insufficient measures of overall L2 proficiency. Secondly, the distribution of the non-word list recall test is non-normal. The distribution of the data in Hummel (2009) is, however, not established though a lack of explicit discussion of the distribution suggests it to be normal. Whether normally distributed data is a requirement for using Pearson’s r is, nonetheless, somewhat debated, and Bishara and Hittner (2012) argue that non-normal data may cause the Pearson correlation to be underpowered in addition to inflate Type 1 error rates. Consequently, a Spearman correlation was also conducted in this project as such a correlation is often argued to be more valid than Pearson’s test when the data are non-normal (ibid, p. 400). However, the Spearman’s *rho* showed similar results to Pearson’s r, and does as such not yield any evidence in favour of a correspondence with that found by Hummel.

5.2.2 Word List Recall

In contrast to the results on the correlation between proficiency and non-word list recall, the results do indicate a trend towards positive correlation between the vocabulary subtest and the word list recall (r = 0,54, p = 0,0044). This is slightly puzzling, as both the word and the non-word list recall are measures of phonological short-term memory; thus, one would expect the two variables to show rather similar results. On the other hand, and as discussed in Chapter 3, the word list recall allows for the participants' lexical knowledge to assist in recalling the words, which may in turn result in the participants remembering words easier than non-words. Gathercole and Baddeley (1993) argue that such supplementation of already existing knowledge does not necessarily invalidate a word span measure, as the test tends to correlate with similar non-word tests. However, the Pearson test showed no such correlation between the two variables, as the p-value was well above the set significance level (p > 0,2). Such lack of correlation might be related to the construction of the non-words, as Gathercole (1995) reported that a non-word's degree of wordlikeness affects participants' ability to accurately recall the non-word: high-wordlike non-words are easier recalled than low-wordlike non-words. This does in turn yield further support to the aforementioned argument of the word list recall tapping long-term memory in addition to the phonological memory, whilst low-wordlike non-words would arguably be a pure measure of working memory (Gathercole, 1995, p. 89).

Nonetheless, the correlation found between the word list recall test and the vocabulary subtest, conforms to previous research suggesting language proficiency and phonological short-term memory to be interconnected. The fact that the memory test only correlates with the vocabulary part of the proficiency tests is particularly interesting, especially considering the significant correlation between the two proficiency measures. On the other hand, this is consistent with O'Brien and colleagues' results, in which phonological memory was explicitly connected to vocabulary use. Though the tests applied in O'Brien et al. (2007) vary from those in this project, the tests aim at measuring the same qualities. Moreover, the sample looked into by O'Brien and colleagues is rather similar to the one in this study: both groups are adult students of their respective L2s with an average age in the early twenties. The samples differ, however, in terms of proficiency level as O'Brien et al.'s sample was at "the novice and intermediate levels of proficiency" (ibid, p. 576), whilst this study's sample is highly proficient. Despite these slight differences, the results of the two studies largely coincide, thus supporting an argument of the present study adding empirical evidence to the previously documented relationship between phonological memory and adult vocabulary proficiency – no matter the level of proficiency.

O'Brien et al. (2007, p. 577) further speculate that there might be similar correlations between phonological memory and L2 grammar skills, though this was not investigated in their study. The present study yields no evidence to such speculation, as there are no trends in correlation between the grammar variable and the working memory variables. That is not to say that a relationship between the two variables is unthinkable, especially considering the discussed lack of sensitivity of the grammar test. Consequently, it would be very interesting to investigate the relationship between L2 grammar skills and phonological memory using a more sensitive and complex measure of grammar.

A relationship between an individual's phonological short-term memory and L2 proficiency moreover makes sense due to the possible transfer from short-term to long-term memory. As discussed in Chapter 2, logic dictates that the longer a piece of information resides in the short-term store, the more likely it is for this specific information to transfer to the long-term store. As such, individuals who are able to hold auditory input for a longer time in the phonological short-term memory are more likely to transfer this information to the long-term memory. These individuals' phonological loop may consequently be more "active" which may result in them easier remembering and thus learning new aspects of a language than individuals whose phonological loop is not equally active. The found correlation between scores on word list recall and vocabulary supports such an argument, and thus provides further evidence to the hypothesis of working memory – specifically the phonological loop – being an important part of language aptitude.

5.2.3 Forced Left – Left Correct

Yet another interesting trend, is that between vocabulary and the iDichotic "forced left – left correct" variable. The results indicate a trend between the participants' vocabulary knowledge and their ability to pay attention to and correctly recall syllables presented to their left ear (p = 0,0056). Such correlation between these two variables is consistent with Hugdahl et. al's (2009, p. 16) hypothesis that bilinguals may have "superior attentional and/or cognitive control abilities". Such a hypothesis is rooted in bilinguals' experience in language switching, which may in turn scaffold their ability to focus on certain aspects of the input (in this case: that from the left ear). This is interesting due to a more common right ear advantage (REA), in which people tend to easier retrieve information from auditory input to the right ear. Such an REA was prominent in the dichotic listening component in which the participants were not asked to focus on input from a particular ear, as well as in the forced right condition (see mean scores of

FRR/FRL). However, this REA appears to have transformed into a left ear advantage in the forced left (attentional control) condition. These results are consistent with Bak, Vega-Mendoza and Sorace's (2014) findings in which bilinguals outperformed monolinguals on a task of selective attention.

The claim that bilinguals are more skilled in demanding attentional control tasks than monolinguals has been empirically supported by several studies, and a common presumption appears to be that bilingualism affects attentional control (Bialystok, 1999; Bak, Vega-Mendoza & Sorace, 2014; Bialystok & Martin, 2004). However, the relationship between the degree of L2 proficiency and attentional control has not been substantially investigated. The findings from the dichotic listening test in the present study do, however, suggest that the bilingual's level of proficiency trends towards significant correlation with attentional control. Considering the much discussed Noticing Hypothesis in which it is theorized that "SLA is largely driven by what learners pay attention to and become aware of in target language input" (Schmidt, 2010, p. 27), it would only be logical for more proficient bilinguals to excel at such "noticing" and attentional control. If then, attentional control is a part of language aptitude, some individuals would by default have the potential to easier notice certain features in linguistic input which would scaffold their language learning process. Such a hypothesis would be somewhat opposite to that posed in previous research, as attentional control would affect L2 proficiency – not the other way round. However, as is the case with all correlations, there is no way of determining the direction of causation of the variables involved without further research. In other words, it might just as well – at least in theory – be the case that it is the aspect of L2 proficiency which scaffolds the attentional control, but nonetheless they appear to be related. In practice, however, it seems more probable for attentional control to be the independent variable, at least when considering the Noticing Hypothesis.

The relationship between L2 proficiency and attentional control would arguably be even more interesting if compared to the iDichotic results of a non-bilingual group, as one would expect significant differences between the two groups. Interestingly, no trends towards correlation were found between attentional control and other aspects of WM, thus not yielding any evidence supporting Kane et al. (2001) and Namazi and Thordardottir's (2010) results indicating WM to be related to attentional control. On the other hand, attention may still be part of working memory, though potentially serving a different purpose than – and thus, not being directly related to – the other WM components. As such, the details of attentional control and WM remain inconclusive and controversial.

5.2.4 Forward Digit Recall

Regarding the forward digit recall, the results were expected to be consistent with previous findings in correlating with the proficiency measures. Specifically, Vulchanova et al. (2014) found significant correlations ($p < 0{,}05$) between the digit recall test and all subtests of the TOLD-I test of oral language development, thus indicating that overall language competence is related to phonological short-term memory. In the current study, no such significant correlations were found, and neither were any trends ($p > 0{,}1$). There is, however, a trend for the forward digit recall results to correlate with the results of the word/non-word list recall ($p = 0{,}0093/0{,}0075$), which indicates reliable test results.

An interesting difference between the sample of Vulchanova et al.'s study and this project's sample is age. Whereas Vulchanova et al. investigated links between phonological memory and language competence in 10-year-old children, the present study explored similar linkages in university students. Consequently, it may be possible for some parts of working memory to be more prominent in younger age groups – in this case phonological short-term memory. Although a trend towards correlation between phonological memory (word list recall) and L2 proficiency was detected in the present study as well, this PM measure was not a pure WM measure but also tapped long-term memory. As such, the detected relationship between the variables in question is arguably not equally valid and prominent as in Vulchanova et al.'s study. Alternatively, the differences in results may be connected to level of proficiency rather than age *per se*. Put differently, the participants in this project were all highly proficient L2 learners whilst the 10-year-old children were still at a somewhat early stage of L2-learning. Such a hypothesis is consistent with the findings of O'Brien et al. (2006) in which PM was argued to have different effects at different stages of learning. Moreover, due to this study's proficiency measures' low degree of sensitivity, the measures may not have tapped the appropriate L2 skills in terms of correlation. Thus, a more sensitive and complex proficiency measure of advanced L2 learners may reveal linkages to phonological memory in other aspects of L2 proficiency than what was investigated in the present study.

5.3 General Discussion

As discussed in the section above, the results of the present study vary in terms of consistency with previous research. Only the word list recall and the attentional part of the dichotic listening may be argued to trend towards correlation, meaning that only two of the six working memory/attentional control variables show a relationship with either of the proficiency variables. There is thus not sufficient evidence for the entire working memory *as* language aptitude, though the findings support hypotheses of *components* of the WM in addition to attentional control being interconnected with language proficiency.

Due to the results being somewhat unexpected, one may question the validity and reliability of the different measures as a lack of such may lead to erroneous results. As already mentioned, the participants' performance on the grammar test is highly correlated with their performance on the vocabulary test. Accordingly, the two proficiency measures appear valid and reliable though they arguably lack the ability to predict any other L2 skills. The lack of sensitivity in the proficiency measures may, moreover, affect the overall results, as the grammar and vocabulary tests are arguably less complex than corresponding proficiency tests in previous research. Regarding the working memory variables, the results appear reliable due to trends towards intra-correlations. Specifically, the more complex WM measures of non-word list recall and backward digit recall trend towards positive correlation (p = 0,0055), as do the less complex PM measures of word list recall and forward digit recall (p = 0,0093). Such results arguably indicate internal reliability, and thus reliable measures of phonological short-term memory.

The only WM variable that does not show any indication of a relationship with other measures, is the corsi block-tapping test (CBTT). Interestingly, this conforms to the hypothesis, as the CBTT is a measure of the visuospatial part of working memory, and is thus not directly associated with auditory processing *per se*. As such, it is not surprising for the CBTT not to correlate with the measures of phonological memory. Moreover, the fact that the CBTT does not trend towards correlation with the proficiency measures either, suggests the visuospatial part of working memory not to be interconnected with the measures of L2 grammar and vocabulary proficiency. On the other hand, more sensitive and complex proficiency measures may, once again, yield different results. This would be an interesting topic for further research based on Bialystok and Martin's (2004) results on a bilingual advantage in a visual problem-solving task. Given that they found significant differences between a monolingual and a bilingual group, one may expect to find similar differences within a group of bilinguals related to level of proficiency. Moreover, the visuospatial sketchpad may be correlated with other aspects of L2 proficiency in which visual semantics is more prominent. An example of such an aspect could be L2 reading skills, a skill which has been significantly correlated with other aspects of working memory (Wen & Skehan, 2011).

The lack of overall correlation between the working memory variables and the proficiency measures indicates the potential effect of working memory on language to be componential: some WM components may be connected to language, whilst others may not. Such a claim is far from controversial, as it is in accordance with former findings of the phonological loop's significance in language acquisition though it challenges the view of working memory *as* language aptitude. What may be somewhat more interesting is the apparent relationship between L2 proficiency and attentional control. If Morales, Calvo and Bialystok (2013) are right in their argument of attentional control being (partly) handled by the central executive, such a relationship links the central executive – the "head" of WM – to L2 proficiency, and raises a question of whether any of its slave systems really are earmarked for language, or if it is just a matter of attention. Put differently, as the central executive (CE) regulates the information flow within WM and thus is in charge of "activating" the phonological loop, it may be the CE that is the direct link to language – not the phonological loop itself. Maybe it is all about attention?

Finally, the degree of homogeneity within the sample as well as sample size may influence the final results. Specifically, all participants are Norwegian university students of English from the same university. They have consequently followed a rather similar educational programme and interacted with the same lecturers and thus the same teaching strategies. Though their pre-university educational and linguistic background may differ, they have arguably been exposed to rather similar input and L2 learning the past 2-5 years. As such, a more heterogeneous sample – maybe with students from different universities or at different levels of L2 learning – or even a comparative study, may shed more light on how WM affects different aspects of L2 learning. Moreover, a more heterogeneous group may result in normally distributed data, thus eliminating (non-normal) data distribution as a potential cause for lack of correlation and significant results. With regard to sample size, the sample of 26 participants is too small to make any generalizations. Additionally, a larger sample may have produced more statistically significant correlations considering that only trends were detected in this study.

5.4 Other Potentially Contributing Factors

A lack of expected correlations may not only be due to weaknesses in test design, but also other contributing factors to SLA. Though evidence from both the present study and previous research suggests individuals with better performance in WM tasks to easier acquire new languages, other factors also greatly contribute in the process of SLA. In the case of this study's sample, the participants are all university students of English, which indicates an *interest* in learning the language. Such motivation and interest arguably affect the learner's choice of learning strategies (Moyer, 2015), which may in turn affect the learner's overall proficiency in the language. As such, individuals who are not necessarily by default "better equipped" for learning an L2 in terms of WM may still reach higher levels of proficiency by way of motivation and, quite simply, hard work. In the case of such individuals, there will consequently not necessarily be any correlations between working memory and proficiency scores. Put differently, parts of this study's sample may be highly proficient in English due to motivational factors – not working memory.

In addition to motivation, the choice of learning strategies arguably affects one's L2 learning. This is arguably interconnected with motivation, as an individual's motivation may affect his/her choice of learning strategy (Moyer, 2015). Moreover, some learning strategies may be more advantageous than others and consequently lead to individual differences in L2 learning efficiency and ultimately L2 proficiency. As the participants' different learning strategies have not been investigated in the current study, the contribution of such strategies to the participants' proficiency has not been controlled for. Additionally, differences in exposure to implicit/explicit learning is not a part of the present study, though such differences may well have an effect on the participants' L2 proficiency. Accordingly, the factors of both learning strategies and implicit/explicit learning may correlate with L2 proficiency and plausibly be related to language aptitude, and may be the subject of further research.

Moreover, other aspects of language aptitude, which are not accounted for in this study, may have an effect on the participants' proficiency. Such aspects would indeed be challenging to control for due to the somewhat mysterious construct of language aptitude, and accordingly there is a chance of other components of language aptitude manipulating the results of the present study. In order to control for such factors in future research, one may consider the proposed components of language aptitude as presented in the MLAT. This would arguably require more time and resources than what was possible for this project, but would undoubtedly be an interesting contribution to language aptitude research.

In addition to motivational aspects, learning strategies and other language aptitude components, recreational activities such as playing computer games and watching TV-shows may indeed affect the participants' overall English proficiency. Theoretically, however, some individuals will benefit more greatly from such implicit learning than others due to language aptitude. In the case of this sample, the average participant reported to watch English films/TV-shows every day, whereas the equivalent amount for computer games was a couple of times a week. As all participants spent a somewhat similar amount of time watching English films/TV-shows, this would arguably not be a significant factor in terms of differences in proficiency. The reported computer game activity was, on the other hand, a bit more varied which may in turn cause slight differences in proficiency between individuals who often play computer games and individuals who do not. As playing computer games is often a matter of interest, the effect of implicit learning via computer games may have affected some individuals' level of proficiency – independently of their level of working memory. Accordingly, an interest in computer games is yet another factor which might scaffold SLA in individuals with poorer language aptitude/WM, and thus prevent correlations between WM and proficiency in these individuals.

6. Summary and Conclusion

This final chapter reiterates and presents, firstly, the aims of the study and a summary of the key findings of the research, followed by an evaluation of the limitations of the study. Subsequently, the study's contribution to the respective field of study is addressed before the chapter closes with recommendations for further research.

The aim of this study was to investigate the relationship between second language proficiency, working memory and attentional control in a group of Norwegian university students of English. 30 bilingual students with a mean age of 24 were tested in two measures of English proficiency, five measures of working memory, and one measure of auditory attentional control. Based on findings in previous research, the hypotheses were to find correlations between the proficiency measures and measures of phonological working memory and attentional control, whereas no strong correlation was expected between L2 proficiency and visuospatial WM due to this relationship being more controversial than the others. Moreover, these hypotheses were all based on an underlying hypothesis of WM being a component part of language aptitude – that is, the talent some individuals have in terms of learning a second language.

A quantitative analysis of the data revealed three particularly interesting findings: first, none of the investigated relationships turned out statistically significant, second, only one of the measures of phonological WM trended towards correlation with L2 proficiency, and third, attentional control trended towards correlation with L2 proficiency. The lack of statistically significant findings has been discussed in previous chapters, and is argued to be related to weaknesses in some of the tests; particularly the proficiency measures. This particular limitation will be further discussed in the subsequent section. With regard to the remaining two findings, they are both consistent with previous research. The trend towards correlation between L2 proficiency and phonological short-term memory (as measured by the word list recall) yields further evidence to there being a relationship between the two, and thus supports a theory of WM somehow affecting language aptitude. As to the relationship between L2 proficiency and attentional control, this is highly interesting. Previous research on the matter has been rather inconclusive and yielded inconsistent results in terms of whether there is a bilingual advantage in controlled attention or if attention is rather linked to WM. The present study adds evidence to the former, as a trend was only detected between L2 proficiency and attentional control; not between attentional control and other aspects of WM.

Despite having found some interesting results, the study has limitations. The most prominent ones are the insufficient measures of L2 proficiency as well as a small sample size. The proficiency measures were not sensitive enough for the purpose of this study, and may as such have affected the final results. Due to the proficiency tests' lack of complexity, only a small portion of the participants' L2 proficiency was tapped, thus rendering several potential correlations to other language skills unexplored. Moreover, the tests allowed a certain amount of guessing which consequently led to a potential scenario of participants receiving a higher or lower score in proficiency than what was actually the case. With regard to sample size, the sample of the study is too small in terms of making a generalized statement about the role played by WM and attention in second language learning. Furthermore, the small sample may have prevented any statistically significant findings, and rather resulted in statistical trends. The study was further limited by the degree of homogeneity within the sample, as a more heterogeneous group could have resulted in more diverse results and potentially assisted the detection of correlations.

Taking the limitations into consideration, the study still contributes to the research of language aptitude. Though the findings are not statistically significant and cannot be generalized, they nonetheless add empirical evidence to a relationship between language and more generic mechanisms. The trend between L2 proficiency and attentional control is particularly interesting, as this has not yet been the subject of much research as well as previous research yielding somewhat controversial and inconclusive results.

6.1 Recommendations for Further Research

The results of the present study along with its limitations and unexplored issues raise several questions that could be the subject of further research. First of all, there is the limitation of the proficiency measures. It would be interesting to conduct a similar study with more sensitive and complex measures of proficiency in addition to a larger and more heterogeneous sample and see how this would affect the results. Such a study might be able to specify which components of working memory affect certain aspects of L2 proficiency, as well as possibly yielding statistically significant results.

Secondly, questions regarding the effect of learning strategies on proficiency compared with the effect of WM would be interesting. Moreover, potential correlations between WM and learning strategies would be further intriguing. What if WM is not only correlated with L2 proficiency, but also with choice of learning strategy? If so, the theory of WM as a language aptitude component would arguably become even more probable.

Thirdly, studies on what has been termed *the state of WM* in this thesis is necessary in order to make practical and pedagogical implications of results found in correlative studies including WM. If working memory is indeed dynamic and trainable, then linkages between WM and language skills would suggest that WM exercises may ultimately scaffold L2 learning, thus alleviating the learning process for individuals with learning difficulties. Though such a scenario may be slightly over-optimistic, it is still a very fascinating idea.

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Appendices

Appendix 1: Information Sheet and Consent Form for Participants

Forespørsel om deltakelse i forskningsprosjekt

Hei alle engelsk-studenter ved NTNU!
Jeg er mastergradsstudent ved NTNUs institutt for språk og litteratur, og er i prosessen med å skrive en masteroppgave innenfor psykolingvistikk. Under veiledning av mine to veiledere Mila Vulchanova og Giosuè Baggio, vil jeg ta for meg sammenhenger mellom enkelte kognitive funksjoner og språkferdigheter i andrespråk – da spesifikt korttidsminne og engelsk. I den forbindelse ønsker jeg å teste en gruppe studenter i henholdsvis deres engelskferdigheter og korttidsminne, og jeg ønsker med å dette å forespørre deg om du vil delta i prosjektet og dermed delta på tester 1-2 ganger i løpet av høsten/våren (dette avhenger av hva som måtte passe deg best).

Testingen vil foregå ved at du tar en test for engelsk grammatikkforståelse og vokabular, samt en separat test for arbeidsminne. Deler av testingen vil foregå på datamaskin. Den sistnevnte testen vil foregå muntlig, hvor du skal gjenta enkelte ordsammensetninger som jeg presenterer for deg. Begge testene er standardiserte og velutprøvde, og er ment for forskning – ikke for å gradere enkeltstudenters prestasjoner. De respektive testene vil ta høyst 20 minutter hver å gjennomføre per student. Ved testen for arbeidsminne vil jeg trolig ha med meg en medstudent som assistent, slik at vi får en rolig og oversiktlig testsituasjon.

Hva gjelder resultatet av testene vil disse være å regne for statistiske data, og de vil kun håndteres av meg og mine veiledere. De innsamlede dataene vil altså kun brukes i forbindelse med dette prosjektet. Testresultatene vil senere bli behandlet uten direkte gjenkjennende opplysninger, da en kode knytter deg til dine opplysninger gjennom en deltakerliste. Det er kun autorisert personell knyttet til prosjektet som har adgang til deltakerlisten og som kan finne tilbake til informasjonen. All informasjon vil bli anonymisert ved prosjektslutt. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres. Deltakelse i prosjektet er selvfølgelig frivillig, og hvis du ikke svarer på denne forespørselen vil du ikke bli involvert i studien. Dersom du ønsker å delta i prosjektet, kan du selvsagt ombestemme deg senere, og slik reservere deg når som helst. Du behøver heller ikke å gi noen begrunnelse for et eventuelt ønske om å trekke deg fra studien.

Dersom du velger alternativet «ja» under, vil du bli forespurt om å være med i studien såfremt du ikke ombestemmer deg ved en senere anledning. Oppgi også din e-post adresse slik at jeg kan komme i kontakt med deg. Jeg svarer gjerne på eventuelle spørsmål du måtte ha, så ikke nøl med å kontakte meg ☺

Med beste hilsen,
Marianne Christiansen
Mastergradsstudent
NTNU, Institutt for språk og litteratur
E-post: marichr@stud.ntnu.no
Tlf: 47606133

☐ Ja, jeg er over 18 år, og ønsker å delta i forskningsprosjektet.

______________________	______________________	______________________
Studentens signatur	Studentens e-post	Sted, dato

Appendix 2: Background Questionnaire

Bakgrunnsinformasjon for forskningsprosjekt om arbeidsminne og språk

Tusen takk for at du har sagt ja til å delta i mitt forskningsprosjekt om arbeidsminne og språk. I dette skjemaet ber jeg om bakgrunnsinformasjon som er nødvendig for at resultatene fra undersøkelsen skal kunne brukes.

Alle opplysningene du gir her, vil senere bli behandlet uten direkte gjenkjennende opplysninger. En kode knytter deg til dine opplysninger gjennom en deltakerliste. Det er kun autorisert personell knyttet til prosjektet som har adgang til deltakerlisten og som kan finne tilbake til infoen. Del B og C av dette skjemaet vil bare oppbevares med koden. All informasjon vil bli anonymisert ved prosjektslutt. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres.

Legg merke til at skjemaet har **5** sider.
Skjemaet leveres direkte til meg eller sendes på e-post til
marichr@stud.ntnu.no

Med takknemlig hilsen

Marianne Christiansen
Mastergradsstudent
NTNU, Institutt for språk og litteratur
E-post: marichr@stud.ntnu.no
Tlf: 47606133

Del A: Personlig informasjon

Linje/Studieretning: ____
Fødselsår: ________________
Kjønn □ Kvinne □ Mann
Bostedskommune: _____________________________________

Deltakerkode: (Fylles inn av prosjektleder)

Del B: Språklig bakgrunn

Morsmål

Er norsk morsmålet ditt?
□ Ja □ Nei
Hvis ja, har du andre morsmål i tillegg?
□ Ja □ Nei
Hvis ja, hvilke(t) språk? ______________________________________

Hvilket språk bruker dere hjemme? ____________________________________

Hvor ofte leser du tekst skrevet på norsk?
□ hver dag □ flere ganger per uke □ et par ganger i uken □ av og til □ aldri

Hvor ofte skriver du tekst på norsk?
□ hver dag □ flere ganger per uke □ et par ganger i uken □av og til
□ aldri

Engelsk og andre fremmedspråk

Hvor mange år med utdanning i engelsk har du **etter** videregående?
□ ingen □ 1-2 år □ 3-4 år □ 5-6 år □ mer enn 6 år

I **engelsk**, hvordan vurderer du ferdighetene dine på hvert av disse områdene?

	Grunnleggende	**Middels**	**Avansert**	**Flytende**
Lesing				
Skriving				
Snakke				
Lytte				
Totalt				

Har du bodd i, eller hatt lengre opphold i, et land hvor engelsk er hovedspråk?
□ Ja □ Nei
Hvis ja, hvor lenge varte oppholdet/oppholdene?

____

Har du vært på kortere (under 14 dager) reise i et land hvor engelsk er hovedspråk?
□ Ja □ Nei

Har du bodd i, eller hatt lengre opphold i, et land hvor annet enn engelsk er hovedspråk?
□ Ja □ Nei

Hvis ja, hvor var det, og hvor lenge varte oppholdet/oppholdene?

____

Hvilke språk kan du utover morsmålet ditt og engelsk?
(Hvis du ikke snakker andre språk, hopp over dette spørsmålet)

Språk	**Nivå**			
	Grunnleggende	**Middels**	**Avansert**	**Flytende**
Tysk				
Fransk				
Spansk				
- angi språk				
- angi språk				
- angi språk				

Hvor ofte leser du tekster på engelsk?
▢ hver dag ▢ flere ganger pr uke ▢ et par ganger i uken ▢ av og til ▢ aldri

Hvor ofte skriver du tekster på engelsk?
▢ hver dag ▢ flere ganger pr uke ▢ et par ganger i uken ▢ av og til ▢ aldri

Hvor ofte lytter du til/hører du engelsk?
▢ hver dag ▢ flere ganger pr uke ▢ et par ganger i uken ▢ av og til ▢ aldri

Hvor ofte ser du engelskspråklige serier/filmer?
▢ hver dag ▢ flere ganger pr uke ▢ et par ganger i uken ▢ av og til ▢ aldri

Hvor ofte spiller du engelskspråklige dataspill?
▢ hver dag ▢ flere ganger pr uke ▢ et par ganger i uken ▢ av og til ▢ aldri

Hvilken type spill spiller du? ____

Del C: Andre faktorer i språklæring

Har du, eller har du hatt, problemer med synet utover normal brillebruk?

□ Ja □ Nei

Har du, eller har du hatt, problemer med hørselen?

□ Ja □ Nei

Har du, eller har du hatt, språkvansker av noe slag (spesifikke språkvansker, lese-/lærevansker eller lignende)?

□ Ja □ Nei

Hvis ja, spesifiser: ________________________________

Har du, eller har du hatt, andre diagnoser som kan tenkes å påvirke språklæring (ADHD, autisme eller lignende)?

□ Ja □ Nei

Er du venstrehendt?

□ Ja □ Nei

Appendix 3: Supplementary Figures

Spearman's correlation coefficients and p-values

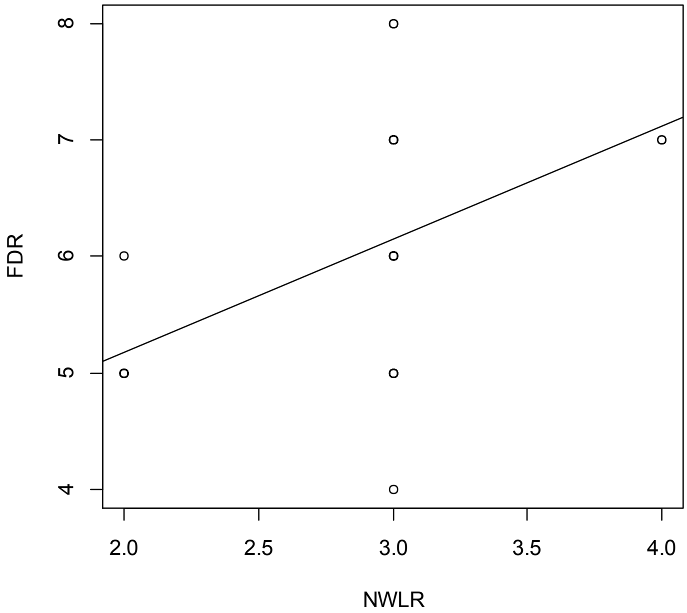
Spearman's rho	Gram	Voc	WLR	NWLR	FDR	BDR	CBTT	NFRC	NFLC	FRR	FRL	FLR	FLL
Gram	1.00	0.49	0.26	-0.03	0.28	0.05	0.18	-0.05	0.11	0.09	0.09	0.04	0.35
Voc	0.49	1.00	0.46	0.06	0.17	0.09	0.20	0.02	0.07	0.24	-0.12	0.03	0.43
WLR	0.26	0.46	1.00	0.27	0.51	0.22	-0.05	0.04	0.18	0.14	0.08	-0.15	0.35
NWLR	-0.03	0.06	0.27	1.00	0.54	0.52	-0.11	0.19	-0.24	-0.07	0.15	0.26	-0.05
FDR	0.28	0.17	0.51	0.54	1.00	0.45	0.12	0.15	0.05	0.14	0.13	0.10	0.02
BDR	0.05	0.09	0.22	0.52	0.45	1.00	-0.01	0.64	-0.49	0.28	0.00	0.13	0.09
CBTT	0.18	0.20	-0.05	-0.11	0.12	-0.01	1.00	0.17	-0.18	0.08	0.02	0.02	-0.09
NFRC	-0.05	0.02	0.04	0.19	0.15	0.64	0.17	1.00	-0.90	0.40	-0.29	-0.05	0.04
NFLC	0.11	0.07	0.18	-0.24	0.05	-0.49	-0.18	-0.90	1.00	-0.21	0.25	0.01	0.04
FRR	0.09	0.24	0.14	-0.07	0.14	0.28	0.08	0.40	-0.21	1.00	-0.85	-0.28	0.46
FRL	0.09	-0.12	0.08	0.15	0.13	0.00	0.02	-0.29	0.25	-0.85	1.00	0.25	-0.37
FLR	0.04	0.03	-0.15	0.26	0.10	0.13	0.02	-0.05	0.01	-0.28	0.25	1.00	-0.54
FLL	0.35	0.43	0.35	-0.05	0.02	0.09	-0.09	0.04	0.04	0.46	-0.37	-0.54	1.00

Correlation coefficients, Spearman's rho: grammar test (Gram), vocabulary test (Voc), word list recall (WLR), non-word list recall (NWLR), forward digit recall (FDR), backward digit recall (BDR), Corsi block tapping test (CBTT), dichotic listening: non-forced right correct (NFRC), non-forced left correct (NFLC), forced right right correct (FRR), forced right left correct (FRL), forced left right correct (FLR), and finally forced left left correct (FLL).

P-values	Gram	Voc	WLR	NWLR	FDR	BDR	CBTT	NFRC	NFLC	FRR	FRL	FLR	FLL
Gram		0.0105	0.2042	0.8933	0.1641	0.8160	0.3715	0.7917	0.6029	0.6462	0.6652	0.8305	0.0839
Voc	0.0105		0.0169	0.7721	0.4091	0.6655	0.3338	0.9222	0.7411	0.2436	0.5538	0.8787	0.0304
WLR	0.2042	0.0169		0.1768	0.0076	0.2873	0.8098	0.8380	0.3720	0.4819	0.7095	0.4507	0.0778
NWLR	0.8933	0.7721	0.1768		0.0042	0.0064	0.5857	0.3529	0.2355	0.7486	0.4655	0.2003	0.7920
FDR	0.1641	0.4091	0.0076	0.0042		0.0201	0.5481	0.4565	0.8053	0.4940	0.5314	0.6204	0.9284
BDR	0.8160	0.6655	0.2873	0.0064	0.0201		0.9581	0.0005	0.0112	0.1584	0.9861	0.5404	0.6616
CBTT	0.3715	0.3338	0.8098	0.5857	0.5481	0.9581		0.4012	0.3751	0.6828	0.9400	0.9208	0.6454
NFRC	0.7917	0.9222	0.8380	0.3529	0.4565	0.0005	0.4012		0.0000	0.0418	0.1527	0.8047	0.8461
NFLC	0.6029	0.7411	0.3720	0.2355	0.8053	0.0112	0.3751	0.0000		0.3050	0.2246	0.9686	0.8450
FRR	0.6462	0.2436	0.4819	0.7486	0.4940	0.1584	0.6828	0.0418	0.3050		0.0000	0.1637	0.0174
FRL	0.6652	0.5538	0.7095	0.4655	0.5314	0.9861	0.9400	0.1527	0.2246	0.0000		0.2264	0.0613
FLR	0.8305	0.8787	0.4507	0.2003	0.6204	0.5404	0.9208	0.8047	0.9686	0.1637	0.2264		0.0048
FLL	0.0839	0.0304	0.0778	0.7920	0.9284	0.6616	0.6454	0.8461	0.8450	0.0174	0.0613	0.0048	

Corresponding p-values to Spearman's rho coefficients in the table above.

Scatterplot of rejected Spearman correlation



The scatterplot rejects the correlation found between FDR/NWLR in the Spearman analysis. This may have been a false positive which may in turn be related to the variables' non-normal distribution.

Appendix 4: Working Memory Test Battery

WORKING MEMORY TEST BATTERY   RECORD FORM

Deltakernummer: ………………………………………………

Dato:

1. WORD LIST RECALL

Span	List								Score (1 or 0)
3	nød	sik	tipp						
	lekk	nøtt	pol						
	lot	malm	fjell						
	park	skjørt	disk						
	mil	der	bønn						
	fin	båt	lur						
4	turn	penn	til	gap					
	mygg	lunsj	hardt	nebb					
	ligg	hit	trøkk	barn					
	fikk	dåp	led	ball					
	tett	mus	hopp	kikk					
	mark	finn	søkk	mett					
5	lokk	sipp	lett	pakk	gøy				
	skrik	vipp	ørn	tau	hund				
	gård	tur	fem	sjekk	kinn				
	dit	men	kapp	duk	ark				
	kokk	fort	mugg	ball	gym				
	dugg	lam	plugg	mann	hjem				
6	først	gass	mot	ris	pakk	troll			

	klikk	bot	folk	kjøtt	pil	knapp			
	natt	kald	mos	papp	damp	tonn			
	treff	rød	knask	svak	rev	skjær			
	knep	saks	bær	ovn	frosk	bok			
	skje	dikt	stol	vind	dør	tråd			
7	nord	ski	flagg	lås	nød	penn	vei		
	rett	jakt	bad	øy	buss	taus	lyd		
	rot	gift	hest	duk	røyk	katt	sur		
	frost	sted	sær	matt	klær	lam	speil		
	sand	hav	kjeks	mer	post	tog	tinn		
	flink	is	brød	seng	tøy	lys	sag		
								Trials correct	
								Span	

2. NONWORD LIST RECALL

Span	List						Score (1 or 0)
1	nerp						
	blonk						
	lisk						
	napt						
	gupp						
	kebb						
2	mart	sidd					
	kaff	jop					
	båp	lank					
	laf	bjem					
	jub	frev					
	lert	gabb					
3	fyt	sirp	dort				
	pabb	tveld	jarm				
	tugl	susk	klomst				
	pær	grakt	stap				
	skupt	krips	spauk				
	olk	kift	vur				
4	gerk	frapp	trak	vå			
	kjot	bjern	kjud	kaf			
	tild pronounce the ”d” at end	srekk	kerp	kjass			
	dav	pev	kolp	kits			

	brost	spomp	rign	spuss			
	kosk	lurp	klat	kni			
5	srubb	kræt	nøsk	skvarg	fimp		
	strimp	fnø	tarn	lelk	kjort		
	krøm	daus	lans	skjog	ki		
	lorm	kimp	føyt	targ	remp		
	spokk	fjøk	krell	tjert	misk		
	baup	dinsk	grals	hisj	jemp		
						Trials correct	
						Span	

3. DIGIT RECALL

Span	List										Score (1 or 0)
3	4	8	3								
	2	6	1								
	7	4	3								
	3	7	6								
	1	8	4								
	6	9	4								
4	5	9	2	6							
	3	1	7	4							
	2	8	5	1							
	9	6	2	7							
	8	5	1	4							
	7	2	8	6							
5	6	1	4	2	5						
	3	2	8	4	1						
	7	4	2	5	9						
	3	7	6	1	4						
	4	9	2	5	7						
	1	5	8	3	6						
6	8	3	9	2	5	1					
	2	9	5	7	1	3					
	1	6	2	5	9	4					
	7	5	9	2	6	4					
	6	8	1	3	7	5					
	5	2	7	3	8	6					
7	4	9	6	3	1	5	2				

	5	8	1	9	2	6	4				
	9	3	7	5	2	8	1				
	2	5	6	3	8	1	4				
	8	3	5	9	1	7	2				
	6	2	8	7	4	9	3				
8	1	7	5	6	9	3	2	4			
	9	2	8	1	7	4	6	3			
	8	6	4	2	9	3	1	7			
	6	1	3	7	2	9	4	8			
	5	2	9	4	7	3	1	6			
	3	8	4	1	5	2	7	9			
9	7	1	6	3	8	4	2	9	5		
	4	6	9	2	8	1	5	7	3		
	9	5	7	3	6	8	4	2	1		
	2	9	4	7	1	6	8	3	7		
	8	3	9	4	7	1	5	2	6		
	1	5	3	9	4	7	2	8	6		
										Trials Correct	
										Span	

4. BACKWARD DIGIT RECALL

Span	List								Score (1 or 0)
2	2	7							
	5	9							
	3	1							
	9	7							
	4	6							
	8	4							
3	8	1	4						
	6	3	7						
	4	6	2						
	2	5	9						
	7	3	5						
	9	4	3						
4	2	7	1	4					
	5	2	7	3					
	6	3	8	4					
	1	5	4	9					
	9	6	5	8					
	8	1	6	2					
5	2	1	4	9	8				
	5	7	1	4	2				
	2	7	4	6	3				
	9	5	1	4	2				

	3	5	8	2	6				
	4	6	3	1	5				
6	5	2	1	7	9	3			
	2	7	6	3	8	5			
	4	8	3	5	2	7			
	8	5	2	9	1	3			
	1	9	5	8	2	4			
	6	1	3	9	5	2			
7	8	3	5	2	9	4	1		
	6	3	1	9	4	7	5		
	5	8	7	2	4	9	3		
	7	9	2	6	1	9	3		
	8	5	2	4	9	3	6		
	9	6	2	8	1	4	7		
								Trials Correct	
								Span	

Appendix 5: The Project's Relevance for the Teaching Profession

As a future teacher of English as a second or foreign language, the work on this thesis is relevant in several respects. Firstly, the experience of doing research on language aptitude has opened my eyes in terms of language learning abilities relying on other more generic mechanisms. The possibility of utilizing working memory and attentional control tasks in a language learning classroom in order to scaffold the language learning process is indeed controversial, though at the same time very intriguing. As such, I hope to stay updated on the further research on language aptitude, such that *if* the hypotheses of working memory being trainable and affecting second language learning are ever confirmed, I will be able to implement relevant teaching strategies in my own classroom. Secondly, working on a larger project has been very instructive in the sense that I have had to apply several different (and new) techniques of writing, which in turn helped me realize the importance of focusing on such techniques in the upper- and lower secondary classroom. The sooner one discovers these different techniques, the better! Finally, the experience of working with a "process approach" to writing has greatly underscored my view of feedback (and "feed forward") as an essential part of improving not only one's writing, but also one's learning strategies.