Early literacy in the digital age

Relationships between visual attention, digital exposure and emergent literacy

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Once you learn to read,
you will be forever free.

Frederick Douglass

Abstract

The emergence of digital technology has brought about children being exposed to digital text from a very young age. To explore how this potentially shapes reading development, there is the need to investigate whether it is necessary to identify digitally-relevant predictor skills of reading alongside other more traditional literacy precursor skills. While phonological decoding has repeatedly been shown as a strong predictor of reading success (Snowling, 2000; Vellutino et al., 1991), visual attention has only more recently been recognised as important moderator of reading performance (Franceschini et al., 2012). With an increasingly rapid move away from standardised typographic text formats (Picton, 2014), individual variation in visual attention skills is likely to be an important moderator of reading performance.

This study explored longitudinal relationships between children's exposure to digital devices, visual attention development, traditional predictors of reading and their relative impact on word reading after the first school year. UK children from a normative group of emerging readers (N = 140) were recruited at the beginning of Reception (4;7 years) and reassessed at the start of Year 1. Participants were tested on their visual attention and other traditional literacy precursor skills, including: phonological awareness, letter-sound knowledge, receptive vocabulary, short-term memory, and non-verbal ability. Further, information was gathered on children's digital exposure. Cross-sectional data at both time points demonstrated moderate correlations between visual attention and traditional precursor skills of reading, but no relationships between children's digital exposure and their visual attention. Within regression analyses, visual attention, while contributing variance longitudinally to single word reading after one year of schooling, was not found to be a unique predictor of single word reading after other variables were entered into the model in a prior step. The relevance of these findings, as well as related theoretical and practical implications are discussed.

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Publications arising from this thesis

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Presentations and Invited Talks

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"Visual attention and early literacy in the digital age: The DigiRead project"

2016 **Department of Human Communication Sciences (University of Sheffield) PGR conference – poster presentation**
"Visual attention and early literacy in the digital age: a pilot study"

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List of Abbreviations

A & EF	attention & executive function
C	visual short-term memory (VSTM) processing speed
D	decoding
K	visual short term memory (VSTM) capacity
LC	listening comprehension
LK	letter knowledge
LRM	lexical restructuring model
LSK	letter-sound knowledge
NVIQ	non-verbal intelligence quotient
NWR	non-word repetition
PA	phonological awareness
PR	partial report
RAN	rapid automatised naming
RC	reading comprehension
RV	receptive vocabulary
SES	socioeconomic status
STM	short-term memory
SVR	Simple View of Reading
TVA	Theory of visual attention
VA	visual attention
VSTM	visual short-term memory
WR	whole report

Introduction

The emergence of digital technology over the past few years has brought about permanent changes to many aspects of day-to-day life, with children being exposed to digital devices from a very young age. In addition, teaching and learning, not least literacy instruction in UK schools and elsewhere, is being increasingly designed around computer and tablet technology (Burnett, 2016). However, while research on teaching methods for early literacy has been extensive, it has so far been mainly concerned with the importance of systematic phonic approaches embedded within a language-rich classroom environment (Ofsted, 2010; Rose, 2006). The potential impact of text presentation – modality (digital instead of paper), including the resulting size, spacing and line length of text – on reading achievement on the other hand has so far been relatively unexplored. This research study endeavours to contribute new knowledge to this area by gaining a better understanding of the complex interplay between visual attention, digital exposure and established literacy predictor skills in relation to emerging reading in young children.

In order to get a better sense of how the exposure to digital devices potentially shapes children's development of reading during the first formal school year, there is first a need to find out whether the introduction of digital technology makes it necessary to identify specifically digitally-relevant predictor skills of reading alongside other more traditional precursor skills of reading. Phonological awareness – defined as the ability to reflect and manipulate phonological units within a word, – has repeatedly been shown to be a strong predictor of reading success (Snowling, 2000; Vellutino, Scanlon, & Tanzman, 1991). While at a gross level, a well-functioning visual system is essential to the ability to read, the role and importance of more specific aspects of visual processing, for example, visual attention span, has only more recently been recognised (Franceschini et al., 2012). Visual attention span determines the maximal string of characters that can be simultaneously processed within a single fixation (Valdois, Bosse, & Tainturier, 2004). With an increasingly rapid move away from standardised typographic formats of printed books (Picton, 2014), individual variation in visual attention skills is likely to be an important moderator of reading performance. This study therefore wanted to investigate whether visual attention could be seen as potential digitally-relevant predictor skill of reading alongside other more traditional and established literacy precursor skills. It also wanted to find out whether digital exposure in the early years had an impact on an individual's visual attention skills when entering school.

For this reason, the current study comprises of a smaller-scale study that investigated the reliability of a newly adapted visual attention assessment and a main study. The main study then adopted a longitudinal design with assessments at two time points (beginning of Reception Year and beginning of Year 1) to investigate the development of visual attention skills in children by comparing their performance at school entry and after one year of schooling alongside other more traditional predictor skills. To meet this aim the study tested children on a number of cognitive and linguistic literacy predictor skills including phonological awareness, letter-sound knowledge, receptive vocabulary, short-term memory, as well as single word reading. In addition, digital exposure was investigated by conducting a survey with parents at time point 1 (beginning of Reception) and by gathering information from students themselves at time point 2 (beginning of Year 1). This was carried out in order to investigate possible links between digital exposure and children's visual attention skills. The relative contribution of visual attention in comparison to the cognitive and linguistic literacy predictor skills to explain individual differences in children's single word reading performance was evaluated in the final step.

Chapters 1 and 2 of this thesis will provide a review of relevant literature, used as theoretical foundation for the current work. Chapter 1 will discuss literacy development, and in particular explores four cognitive and linguistic skills that have been shown to predict children's single word reading after one year of schooling. Chapter 2 will review available research on visual attention, with an emphasis on Bundesen's (1990, 1998) Theory of visual attention (TVA), will discuss the potential influence of visual attention on reading, as well as the impact of digital exposure in the early years on emergent literacy skills, and will conclude with research aims and questions. Chapter 3 will present the smaller-scale study which was conducted during the first year of the research project to evaluate a newly adapted visual attention assessment for 4- to 5-year olds which was subsequently adopted in the main study. The main study will be the centre of attention henceforth, with methods used being set out in Chapter 4, followed by Chapters 5 and 6 presenting the results of this study. Specifically, Chapter 5 will consider the performance and development of children on the visual attention assessment at the start and after one year of schooling. Chapter 6 will present the performance and development of traditional predictor skills in children at both time points, and will discuss findings regarding children's digital exposure, before incorporating all results, including Chapter 5 findings, in correlational and hierarchical multiple regression analyses. Through these analyses the relationships between visual attention, cognitive and linguistic skills will be explored, as well as their role in explaining individual differences in single word reading outcomes for children after one year of schooling. Finally, Chapter 7 will provide a general discussion of the findings presented in Chapters 5 & 6, followed by the strengths and limitations, practical implications, and overarching conclusions from this work.

Chapter 1 – Linguistic and cognitive predictor skills for the development of word reading

Reading skills are a fundamental prerequisite for academic achievement (Storch & Whitehurst, 2002). Failing to develop these skills is suggested to be linked with behavioural difficulties, increasing risk of homelessness, and poverty later one in life (e.g. Herbers et al., 2012; Miles & Stipek, 2017). Thus, supporting children in acquiring reading proficiency is arguably one of the key goals of primary school education. While children are in general able to develop oral language skills with very little explicit instruction, quite the opposite is the case when it comes to acquiring reading skills, as our brains are not necessarily wired for reading. Before school entry many children will have some exposure to print at home, for instance through shared story book reading, or through learning to write their own name. Systematic reading instruction however, usually begins later, when children start formal schooling. In order to effectively raise literacy levels in children, gaining a full understanding of the processes leading to reading proficiency needs to remain a priority (Department of Education, 2011). Over the past decades much effort and energy has gone into the research of literacy development (Walczyk, Tcholakian, Igou, & Dixon, 2014), resulting in a considerable, solid, and steadily growing knowledge base used by researchers to explore questions regarding children's literacy acquisition across a range of different languages. Given the large number of theoretical accounts concerning literacy development, this chapter cannot provide an exhaustive evaluation of all the models. Instead, the *Simple View of Reading* developed by Gough and Tunmer (1986) will be introduced as one model of reading that is arguably the most influential within UK education at the present time (Rose, 2006). It individually considers linguistic as well as cognitive skills thought to be key influential factors to children's literacy acquisition and acted as the foundation for this study. Due to the focus of the current study on word reading skills within the first year of schooling, emphasis will then specifically be put on the development of single word reading, specifically discussed with reference to Ehri's (1992, 2005) four-phase theory of sight word reading. The development of comprehension will be outlined at the end of this section. In the following section, key research studies that explore individual cognitive and linguistic skills as potential predictors to children's literacy development will be discussed. This will be carried out to review what is known about traditional precursor skills of reading and therefore to conceptualise the current study which investigates visual attention as a potential digitally-relevant predictor for reading in the light of children's increased exposure to digital text.

1.1 The Simple View of Reading

The *Simple View of Reading* (SVR), developed by Gough and Tunmer (1986) and Hoover and colleagues (1990), is a conceptual framework that has been widely applied in a range of literacy studies in the English speaking context. It was published at a time when the research community in the US and Canada was divided regarding the role phonological decoding strategies and language skills play in a child's literacy development (Kirby & Savage, 2008). Hence, it can be seen as an attempt at reconciliation, putting an end to arguments of oppositional conceptions regarding the relative contribution of decoding and comprehension in the process of reading development (Gough & Tunmer, 1986).

The key characteristic of the SVR as a simplistic framework is that it defines reading ability – also referred to as reading comprehension – as the product of two components: word reading and language comprehension, characterised by the following equation: '$RC = LC \times D$' (Gough & Tunmer, 1986). *D* for word reading more specifically refers to single word decoding, characterised as the ability to 'read isolated words quickly, accurately, silently' (Gough & Tunmer, 1986, p. 7). In other words, decoding is the reader's ability to recognise words efficiently and context-free by understanding grapheme-phoneme correspondence rules when learning how to read in an alphabetic script. The second component of the equation above, *LC*, stands for language comprehension, defined as the skill to access the meaning of different words, to produce sentences, and to interpret discourses (Gough & Tunmer, 1986; Hoover et al., 1990). While the distinction between decoding and comprehension in reading processes has also been made by other theories of reading (e.g. Calfee & Drum, 1986; Perfetti, 1977), the SVR stands out in that it specifically argues for reading comprehension being the *product* rather than the *sum* of decoding and listening comprehension. Successful reading is therefore only accomplished when both skills – decoding and language comprehension – occur at the same time. If however one of the components is absent, for instance in children who are yet unable to read, or in cases when an able reader decodes nonwords or foreign words (Gough, Hoover, & Peterson, 1996), reading comprehension cannot be achieved. Therefore, the SVR puts emphasis on the fact that first, both elements, *LC* and *D,* are necessary for reading comprehension and that second, while they are both important individually, they are not sufficient on their own, as only their interaction leads to the goal of successful reading comprehension.

In addition, the SVR emphasises that the relationships between decoding and reading comprehension, as well as language comprehension and reading comprehension, are not fixed but instead undergo change over the course of reading development. While children's decoding skills are considered to be strong predictors of reading at the beginning of reading acquisition, the predictive role of language comprehension gets more and more important once children have established basic literacy skills, helping them to become more fluent and accurate in their reading (e.g. Kershaw & Schatschneider, 2012; Storch & Whitehurst, 2002; Vellutino, Tunmer, Jaccard, & Chen, 2007). This temporal predictive capacity of decoding is caused by the fact that as children become better at decoding, the differences between their performances on decoding tasks become less, making it difficult to draw inferences about comprehension. In addition, decoding could be seen as an easier skill to master in relation to language comprehension, as it mainly depends on so-called lower level processes, such as phonological awareness. Language comprehension on the other hand draws on higher level processes, including knowledge about grammar and vocabulary (Vellutino et al., 2007). Finally, when children are exposed to more complex texts later on in school, demands on language comprehension processes increases: If coming across novel words, students are then expected to decode and link them with the word meaning, as well as to understand the structure of a sentence or a paragraph.

The goal of the SVR is to create an empirically testable model that helps to explore a range of reading abilities, as well as to identify struggling readers and their challenges, by characterising their reading comprehension as either lacking word decoding, language comprehension, or both of these skills (Hoover et al., 1990). The SVR has subsequently been used in some studies (e.g. Catts, Hogan, & Fey, 2003) to identify the source of difficulty for struggling readers, to classify students based on their relative skills in word reading and comprehension, and thus to explain heterogeneity within assessed student groups. Ever since its introduction, the framework has been frequently applied and discussed in different areas of research, largely receiving support, but also some criticism. In the following, reasons for the success of the SVR will be put forward, followed by an outline of key arguments discussing the limitations of the framework.

First, support for the classification of struggling readers in either having deficiencies in word decoding or in reading comprehension can be derived from a large body of research studies. On the one hand, this support comes from studies looking at dyslexia, as a specific reading difficulty: While children or adults identified as having dyslexia have good enough language comprehension skills, they experience difficulty with decoding (Catts et al., 2003; Spooner, Baddeley, & Gathercole, 2004). On the other hand, supportive evidence comes from studies exploring a different group of struggling readers, often referred to as 'poor comprehenders' and therefore showing a reverse pattern to dyslexia: While individuals belonging to this group seem to find language comprehension in the context of reading a challenge, their decoding skills are within the normal range (Nation & Norbury, 2005). On the other hand, the distinction between comprehension and decoding is further backed up by studies suggesting that both components of the framework have different cognitive predictor skills (Catts et al., 2003; Muter, Hulme, Snowling, & Stevenson, 2004; Wagner, Herrera, Spencer, & Quinn, 2015).

Second, studies exploring the variability across children in D, LC and RC showed that the relationship between children's performance on decoding and language comprehension tasks and their reading comprehension skills were significant and strong (Hoover et al., 1990; Nation & Snowling, 1997; Vellutino et al., 2007). When evaluating the collective predictive power of both measures, decoding and language comprehension, they have further been found to be good predictors of future reading performance, accounting for 45-48% of the variance in reading comprehension (Adlof, Catts, & Little, 2006; Tilstra, McMaster, Van Den Broek, Kendeou, & Rapp, 2009). In addition, studies evaluated the hypothesis of the SVR that decoding is superseded by language comprehension as a strong predictor of reading success during the course of reading acquisition. Evidence suggests that this is the case, as predictive relationships between the subcomponents and reading comprehension seem to change when comparing younger and older readers (Adlof et al., 2006; Garcia & Cain, 2014). A study conducted by Vellutino and colleagues for instance on 468 students in the US, found that correlations between word reading and reading comprehension went down from a value of .80 for 7- to 9- year olds, to .43 for 11- to 13- year olds. At the same time relationships between language comprehension and reading comprehension rose in significance, with the value being .67 for the younger, and .79 for the older age group tested in the study (Vellutino et al., 2007). Finally, a further source of evidence for the validity of the SVR is provided by research findings supporting the importance as well as the distinctiveness of the two separate components D and LC, showing that the performance on those two different elements of the framework is influenced by distinct environmental and genetic components (Keenan, Betjemann, Wadsworth, Defries, & Olsen, 2006).

Despite the wide application of SVR in the field of literacy research, there has been some criticism, judging the framework as being too simplistic and therefore failing to do justice to the complex mechanisms involved in learning to read (Kirby & Savage, 2008). In addition, there seems to be less consistent validation of the argument that reading comprehension needs to be seen as the product of D and LC, rather than the sum of both elements. Hoover and colleagues (1990) based their argument of defining SVR as a product model on analysing the reading comprehension of young beginning readers from Grade 1 to 4 in the US. However, a study conducted by Chen and Vellutino (1997) with slightly older children in Grade 2 and 6 revealed that the sum as well as the product of D and LC yielded the same predictive power for RC. It has therefore been suggested that the need for the SVR to be multiplicative is only particularly relevant in cases when skills in D and LC are on the ends of the performance spectrum rather than in the middle (Kirby & Savage, 2008). Finally, two further arguments have been brought forward regarding the limits of SVR: First, issues have been identified around the applicability of the SVR for explaining reading acquisition in other languages with more consistent orthographies (Florit & Cain, 2011). Second, criticism has been voiced regarding the missing recognition of reading fluency and its impact on reading comprehension within the framework (Joshi & Aaron, 2000; Kershaw & Schatschneider, 2012; Kirby & Savage, 2008).

It is important when discussing the SVR as a useful framework for thinking about the elements included in the reading process, to see it as a model developed in and for the English speaking context. Consequently, the majority of research studies that have evaluated the validity of the model were also conducted with English speakers. However, since it could be suggested that English in comparison to other Germanic or Romance languages, is rather unique in terms of its orthography (Seymour, Aro, &

Erskine, 2003), the applicability of the framework to other languages may be more limited. A meta-analysis conducted by Florit and Cain (2011) looking at how word decoding and language comprehension contributes to reading across a range of languages found that decoding has less predictive power in languages with consistent orthographies. As mastery in decoding is achieved relatively quickly in these languages, language comprehension is the main precursor for reading even in unexperienced readers. However, while word decoding seems to have *less* impact on the process of reading development in languages with consistent orthographies, study results have shown that its influence upon reading comprehension is still notable (Tobia & Bonifacci, 2015).

In addition, critical voices have been raised regarding the role of reading fluency in the SVR, based on the fact that since its release around 30 years ago, a considerable number of studies have explored and suggested the causal relationship between reading fluency and reading comprehension (e.g. Pikulski & Chard, 2005). While the SVR mentions the importance of reading speed together with reading accuracy as key aspects of reading proficiency, it has only done so at the single word level. Consequently, studies looked into whether the incorporation of reading fluency into the framework would have a positive impact on the overall predictive power of the model and yielded inconclusive results. While some studies did not find reading fluency to explain unique variation in reading comprehension when taking reading accuracy into account (Adlof et al., 2006; Georgiou, Das, & Hayward, 2009), others suggested the opposite, claiming that fluency is a unique predictor in reading comprehension (Aaron, Joshi, & Williams, 1999; Johnston & Kirby, 2006; Joshi & Aaron, 2000; Kershaw & Schatschneider, 2012; Meyer & Felton, 1999; Tilstra et al., 2009). Further research is therefore needed to reach a full understanding of the relationship between reading comprehension and reading fluency.

In summary, while the SVR has been critiqued regarding its multiplicative character and its potential limitations in applicability for studies looking at consistent orthographies, or exploring reading fluency and its relation to reading comprehension, it is found that the large amount of evidence proving the validity of the model outweighs the named limitations. Furthermore, when considering one of the aims of this study – exploring the word reading skills of English speaking children after the first year of schooling –the

SVR is considered suitable for providing a theoretical foundation for understanding the underlying processes involved in the early stages of reading development.

1.2 The development of reading

While the previous section outlined the theoretical framework of reading adopted for the current study, the second part of this chapter will discuss different stages in reading development. Since single word reading skills of beginning readers after one year of formal education was the outcome variable of the study presented in this thesis, the development of word reading skills will be considered first, followed by a less extensive section on the development of language comprehension.

1.2.1 The development of decoding and word reading

Arguably, the mapping of a word's graphemic representation with its phonologically based representation is the main challenge that needs to be overcome by a beginning reader. Mastering this process – also referred to as *decoding* – allows the reader access to meaning-related information about that word, which has been attained through oral language acquisition (Hoover & Tunmer, 1993). The term decoding as already discussed in the section above, is further used as one of the elements of the SVR equation, and is characterised as the ability to read words accurately and fluently (Gough & Tunmer, 1986). It is thus important to note that within the SVR model, *decoding* has a slightly broader definition than just letter-sound decoding, and also encompasses more automatic, holistic word recognition, also known as 'sight word reading'. Within this understanding of the decoding process, emphasis is put on the level of automaticity, as well as on reading fluency: Only if readers have reached a sufficient level of proficiency in decoding or recognising words, their attention can be focused on the goal of reading, the comprehension of a text (Perfetti, 1985). However, while reading words efficiently is necessary for the development of reading comprehension, the first is not a sufficient condition for the latter (Gough & Tunmer, 1986; Perfetti, Landi, & Oakhill, 2005).

A large body of research has explored how beginning readers develop from decoding letter by letter to reading effortlessly and fluently, and therefore how individuals turn into highly proficient readers. Many of these theoretical accounts share similar views regarding single word reading development, and were evaluated by Ehri (2005): The pattern emerging from these different theories seems to be that the development of single word reading is divided into stages or phases. Theories referring to stages are based on the opinion that reading development follows consecutive and 'fixed' steps, in the sense that the progression to a next stage is only possible by the successful completion of the preceding stage. Theories considering children progressing through different phases during their reading acquisition on the other hand, have a less restricted view and consider phases as overlapping, making it possible for children to enter more advanced phases, even if they still apply strategies from preceding phases in some instances. In current debates the latter approach is favoured, as it is felt that this presentation is considered to be closer to children's behaviour when learning how to read (Ehri, 2005; Stuart, Stainthorp, & Snowling, 2008).

When reviewing theories on the development of word reading in alphabetic languages, all of them agree that starting to use a strategy to decode words based on the understanding of the alphabetic principle – certain letters standing for certain sounds (phonemes), with words consisting of different letters (graphemes) – is the prerequisite skill for becoming a successful reader (Snowling & Hulme, 2007; Stuart et al., 2008). Some studies conducted in this field not only described how key processes and skills come to the surface, change and develop during children's reading development but additionally explored possible factors, referred to as external and internal causes, that initiate progression from one phase to the other (Ehri, 2005). External causes are closely related to a child's environment and are connected to experiences including reading practices, as well as both formal and informal reading instruction. Internal factors on the other hand are characterised as skills the reader needs to acquire in the process of learning how to read including linguistic, cognitive, and memory skills (ibid).

One of the key and most referred to theories for developing fast and accurate single word reading skills is Ehri's four-phase theory of sight word reading (Ehri, 1992, 2005). Consisting of four phases an individual is progressing through during word reading acquisition, this theory assigns one favoured strategy of forming a connection between the written word and other memory properties to each phase. Evidence that English speaking children acquire word reading skills by progressing through these four proposed phases was provided by Ehri (2005) and Harn and colleagues (2008). By creating this theory, Ehri (2005) wanted to give teachers and other educators a tool to identify a child's literacy level, which in turn enables them to tailor their support to the child's abilities. The different phases of the theory can be characterised as follows:

In the first 'pre-alphabetic phase', children have, as the name suggests, yet to acquire the alphabetic principle and therefore are still unaware of the systematic connections between print and sounds of words. However, they still might recognise certain words by using contextual or visual connections. These can for example include certain characteristics of the environment a word is situated in (for instance the logo of a restaurant chain, or a popular soft drink), or salient visual cues of the word itself (such as the same letter twice, 'll', in the middle of the word), making it possible for the individual to recognise and to 'read' a word, albeit being entirely dependent on their visual memory (Ehri, 2005; Harn et al., 2008). While some researchers have therefore suggested that children use these pre-alphabetic strategies to read words in this phase, others (Stuart & Coltheart, 1988; Wimmer & Hummer, 1990) argued that they would not be necessary for learning how to read.

As soon as children acquire some letter knowledge, and therefore reach an understanding of letter-sound correspondences, they transition into the subsequent 'partial alphabetic phase'. In this phase children are able to identify the phonemes of initial and final letters of spoken words which helps them to make connections between spellings and pronunciations and thus to decipher some printed words (Ehri, 2005). Given that children in this phase continue to develop using their letter knowledge when reading words, mistakes in decoding such as mixing up similar words with the same first or final letter still occur, but compared to the preceding stage, reading attempts are not haphazard, but rather guided by approximations (Stuart et al., 2008). As a result, fast and accurate word reading cannot be achieved in this phase. The following 'full alphabetic' phase is entered, when children have first, fully acquired knowledge of the alphabetic principle and second, succeed in applying a consistent decoding strategy to analyse words (Ehri, 2005). Successful decoders cannot only read familiar words, but also novel words with regular spelling pattern by mapping letters sequentially onto sounds and blending the sound sequence into a word (Stuart et al., 2008). The resulting robust and full representation of the word in memory reduces the possibility of confusing words with similar spelling during the reading process. In addition, children in this phase have the ability to learn and remember novel words very quickly (Ehri, 2005).

The final 'consolidated alphabetic' phase is reached through continued exposure to print, consistent practice and thus growing experience in reading. Children in this phase have acquired the skill to successfully and reliably link letters with their pronunciations, based on a well-established knowledge base of all possible grapheme-phoneme correspondences. Subsequently, individuals are no longer focused on identifying individual letter-sound correspondences, but rather become more and more skilled with identifying larger word units like morphemes or syllables. This increasing ability to decode unknown words fast and fluently is needed as a solid foundation for reading comprehension (Ehri, 2005; Harn et al., 2008).

The outlined phases of Ehri's theory suggest that only through the process of transforming printed words into its phonological form, orthographic representations are developed that enable fluent reading. This has led to the widely shared agreement, that phonic methods are most effective in supporting children with their reading acquisition in alphabetic orthographies (Rose, 2006). However, given that the most frequent words in English written language are often irregular and therefore either not decodable or difficult to decode with beginning readers' limited grapheme-phoneme knowledge, success in decoding English words is not necessarily followed by successful reading. This caused some (e.g. Seymour & Elder, 1986) to suggest the need for combining a whole word with a phonics teaching approach to successfully support children in their reading development. This suggestion seemed to have found an echo as many children in English speaking countries over the past decades have been exposed to formal literacy instruction with this combined mode of instruction (e.g. Ellefson, Treiman, & Kessler, 2009). However, a study conducted by Vousden and colleagues (2011) evaluating this approach reached the conclusion that while whole-word representations would help children when the number of words read was still small, graphemic representations would have the highest utility for mapping print to sounds in the long run (Vousden, Ellefson, Solity, & Chater, 2011). As such, the first year of formal schooling can be considered as an interesting period to explore for literacy researchers, as children are encouraged to acquire two skills: to decode but also to adopt sight word reading for frequent words (Shapiro, Carroll, & Solity, 2013).

1.2.2 The development of comprehension

The longitudinal study discussed in this thesis could only look at single word reading skills and not reading comprehension, as children after the first year of schooling in the UK have yet to master reading full sentences. Nevertheless, a brief discussion of the fundamental characteristics of both spoken and written comprehension will be provided in this sub-section to give a complete account of the development of reading.

In comparison to decoding and sight word reading, comprehension of spoken and written language is high in complexity and takes longer to reach full development. Reading comprehension is very similar to listening comprehension since both are defined as someone's ability to construct meaning from communication that's either been read or heard (Duke & Carlisle, 2011). This is supported by a study conducted by Nation and colleagues which investigated 236 8- year old children and concluded that difficulties in understanding written text often go hand in hand with deficits in comprehending spoken language (Nation, Clarke, Marshall, & Durand, 2004). Whereas this might lead to the impression that comprehension is a passive activity of receiving information, it is rather an active process in which the individual needs to create an understanding of a message by the application of knowledge and skills, which is also characterised as forming a mental model (Kintsch, 1998; Perfetti, 2007). Further, successful comprehension of written or spoken messages depends on two factors: an individual's background knowledge and linguistic skills summarised as internal factors, and external factors, defined as the characteristics of a message, such as its content, language, structure and context (Duke & Carlisle, 2011).

The successful comprehension process can be divided into two steps entailing interactions between multiple factors and therefore further highlighting its complexity: The first goal is local coherence, defined as the understanding of the meaning of individual words and subsequently individual sentences by the application of grammar and vocabulary knowledge. The second goal is global coherence reached by the application of background knowledge and long-term memory to the already established local coherence. Skills in comprehension monitoring and inferencing, as well as knowledge of story structure further assist this process (Cain & Oakhill, 2006; Duke & Carlisle, 2011; Oakhill & Cain, 2008).

While listening and reading comprehension are similar at their core, a closer comparison reveals significant differences: When compared to listening comprehension, reading comprehension could be considered as more difficult, since it often expects the interpretation of language without the contextual support usually provided in verbal communication. Further, the syntactic or other linguistic structures of written text are often more advanced and complex than those of spoken language a child is usually exposed to, which results in reading comprehension relying on a more advanced vocabulary and grammar knowledge. Another qualitative difference between reading and listening comprehension is that while written text allows the reader to consult previous passages, spoken language gives the opportunity to ask questions in instances when clarification is needed for successful comprehension. (Cain & Oakhill, 2006; Perfetti, Landi, & Oakhill, 2005). It could therefore be argued that highlighted dissimilarities in these two cognitive skills can also potentially lead to differences in the relative strength of their predictor skills. However, while this cannot be contested when considering both modes of comprehension, the authors of the SVR (Gough et al., 1996) argue that differences were outweighed by the shared commonalities of listening and reading comprehension, and therefore should be considered as united by a shared underlying process.

When looking at potential precursors of comprehension skills, the quantity and quality of language exposure children are exposed to in the early years are named as significant influential factors (Duke & Carlisle, 2011; Hart & Risley, 1995). It is further important to consider that different components of comprehension develop at different points in time: While grammatical and vocabulary knowledge start to develop from birth, comprehension monitoring can only happen after linguistic skills have been established to a certain extent, which might even coincide with the process of learning how to read (Oakhill & Cain, 2008). Related to this is the predictive power of vocabulary skills on comprehension: Children's reading comprehension is better in those with broad vocabulary knowledge, with this relationship growing stronger with age (Snow, 2002; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997). In addition, children's exposure to books and their reading experience in the early years is considered to impact on their understanding of story structure (Perfetti, 1994), which later on also has a potential influence on their understanding of narratives (Oakhill & Cain, 2008).

When comparing children with good and poor reading comprehension skills, differences are identified in terms of listening comprehension, as well as skills in lexical semantics, morphology and syntax (Nation et al., 2004). Further, good comprehenders can integrate information from different text passages better than their less able peers (Markman, 1977), succeed in monitoring their own comprehension (Hacker, 1997), and are skilled in producing inferences used to transform content of a written text into an accurate mental model (Cain & Oakhill, 1999). Interestingly, children's ability to make inferences, as well as the types of inferences they can make, is changing over time and grows independently of children's knowledge of the world (Barnes, Dennis, & Haefele-Kalvaitis, 1996).

The development of children's listening and reading comprehension skills are therefore underpinned by the development of a range of different factors. Succeeding in acquiring and combining both, comprehension skills and formerly discussed decoding skills, define a skilled reader. In the following section, cognitive and linguistic skills considered as reading readiness skills and therefore potential predictors of children's reading acquisition during the first year of schooling will be evaluated.

1.3 Traditional predictors of early literacy

Investigating different cognitive and linguistic skills as potential predictors of early reading in English speaking children from preschool age has been the aim of a large body of research published over the past decades.

Kirby and colleagues evaluated evidence available from six predictor skills of reading, which they refer to as causal factors for the development of reading: phonological awareness, phonological decoding, naming speed, orthographic processing, morphological awareness, and vocabulary (Kirby, Desrochers, Roth, & Lai, 2008). While all listed skills are important for both aspects of reading according to the SVR, phonological awareness, phonological decoding, morphological awareness and naming speed are more likely to be precursor skills for children's decoding skills, with vocabulary arguably being more relevant for language comprehension. Further, Kirby and colleagues (2008) describe how these precursor skills are theoretically connected with word reading. Results of their review revealed that there was considerable evidence suggesting the importance of each of these predictor skills in influencing reading acquisition in beginning readers. It was further found that specifically targeting the development of these precursor skills in formal literacy instruction made a contribution to improving achievements in reading. Interestingly, authors started their evaluation with highlighting that they only focused on cognitive factors that influence reading development, rather than exploring motivational or self-perception factors and their impact on literacy development. While authors regarded these factors as potential important contributors, they suggested cognitive factors to be more “plausible causes of reading development” (Kirby et al., 2008, p. 103). In their systematic meta-analytic review Melby-Lervåg and colleagues specifically explored the relationships between children’s phonological skills – including phonemic awareness, rime awareness and verbal short-term memory – and their word reading skills (Melby-Lervåg, Halaas Lyster, & Hulme, 2012). Results suggested that phonemic awareness was the strongest correlate of individual differences in word reading ability in children from an unselected sample. This is particularly interesting, as relationships remained strong, even after verbal short-term memory and rime awareness was controlled for. Based on these findings, suggesting phonemic awareness as a key predictor of individual differences in reading development, authors suggested a possible causal relationship between phonemic skills and reading (Melby-Lervåg et al., 2012).

The finding that phonological awareness was a strong precursor skill for word reading was confirmed by results from Storch and Whitehurst's (2002) study: Findings based on 626 children showed that their reading abilities at primary school level were mainly determined by their knowledge of print, as well as their phonological awareness skills at the beginning of formal education. In addition, a study conducted by Oakhill and Cain (2012) with 102 participants found converging evidence, suggesting that phonemic awareness predicted children’s later performance on a word reading accuracy assessment. In addition, the study identified performance on vocabulary and verbal IQ assessments as significant precursors for comprehension skills in slightly older children.

Naming speed, phonological awareness, and orthographic knowledge were also considered as predictors of reading by Manis and colleagues’ study on 85 children, with phonological skills in particularly being reported to have a strong contribution to their abilities in nonword decoding (Manis, Doi, & Bhadha, 2000). A study conducted by Shapiro and colleagues (2013) yielded similar results specifically for nonword decoding: Authors looked at the relationships between decoding and traditional predictor skills by individually exploring predictors for decoding nonwords versus familiar words in 392 4- to 5- year olds (Shapiro et al., 2013). Results revealed that while phonemic awareness, alongside early print knowledge (knowledge of letters and digits), phonological short-term memory and RAN (rapid automatised naming) were direct predictors of nonword reading, early print knowledge was the only direct predictor for familiar word reading.

Apart from phonological awareness, children's letter-sound knowledge just before entering school has repeatedly been shown to be one of the most reliable predictors of reading acquisition in alphabetic writing systems. In his review, Foulin (2005) explored different studies reporting converging evidence for letter-name knowledge as a good predictor of reading, to better understand the role letter names play in the process of reading development. One of the key meta-analyses of prediction studies discussed in this context was conducted by Scarborough (1998), who identified letter-name knowledge as the strongest single predictor of reading in the first year of schooling.

Findings highlighting the wider relevance of established precursor skills in the English language context for other alphabetic languages were yielded by a study conducted by Caravolas and colleagues. When investigating shared patterns in predictor skills of early literacy in different alphabetic orthographies (N = 735), results revealed that repeatedly shown predictors of reading in studies targeting English speaking children, such as phonemic awareness, letter-sound knowledge, RAN, verbal memory span were also reliable precursor skills in three different European languages (Spanish, Slovak, Czech) (Caravolas et al., 2012).

While studies discussed above suggested that phonological skills and letter-sound knowledge in English speaking children were key predictor skills of word reading especially at the beginning of formal schooling, vocabulary, alongside grammar and listening comprehension skills have been shown to be precursors of reading for higher-level and text related skills (Melby-Lervåg et al., 2012; Oakhill & Cain, 2012; Storch & Whitehurst, 2002). In the following section, large-scale longitudinal studies looking at individual differences in children's literacy development will be explored. This will facilitate further insight about the role and importance of four early predictors of word-level literacy skills in English speaking children – phonological awareness, letter-sound knowledge, receptive vocabulary, and phonological short-term memory – as they formed part of the assessment battery adopted in the main study of this thesis.

1.3.1 Phonological awareness

Phonological awareness (PA), defined as the ability to reflect and manipulate phonological units within a word, has repeatedly been shown to be a strong independent predictor of early reading and spelling skills across different languages (Caravolas et al., 2012; Goodman, Libenson, & Wade-Woolley, 2010; Lerner & Lonigan, 2016; Muter et al., 2004).

A discussion of how children develop phonological skills in a broader sense was provided by Snowling and Hulme (1994). In their article, authors reviewed the gradual development of phonological processing skills specifically in relation to their impact on short-term memory and PA. It was concluded that the development of PA was reciprocally linked with the development of reading, as the latter also initiated the refinement of the former (Snowling & Hulme, 1994). Anthony and Francis (2005) provided a more specific review of PA development in children, summarising findings of multidisciplinary and cross-cultural research studies. Based on their findings, authors stated that the development of PA seemed to run through stages, similar across different languages and that certain aspects of spoken and written language had an impact on the development and levels of PA observed in typically developing children (Anthony & Francis, 2005). Duncan and colleagues (2006) further highlighted that an individual's native language and literacy impacted the development of PA. When comparing young English native speakers with young French native speakers prior to school entry in two experiments (n = 123, n = 155), cross-linguistic differences were found in the processing of syllables, with French speakers outperforming English speakers in a syllable manipulation task (Duncan, Cole, Seymour, & Magnan, 2006). Authors concluded that this difference might have been based on the linguistic characteristics of participants' native language, with French being a 'syllable-timed' language, in comparison to English being 'stress-timed'.

PA is high in complexity and can be considered according to at least two dimensions: the size of linguistic unit that can be identified – syllables, onset-rhymes, phonemes –, and the levels of explicitness, reaching from identification to conscious manipulation, including segmentation and blending (Stackhouse & Wells, 1997). Further, Kenner and colleagues describe PA as consisting of five separate components that all have a unique contribution to the early stages of reading acquisition: sentence awareness, word awareness, syllabication, rhyming, and phonemic awareness – the latter defined as the ability to segment words into its individual sound units (Kenner, Patton Terry, Friehling, & Namy, 2017). In comparison to the other four skills, phonemic awareness has consistently been found to be the strongest predictor of reading achievement for both, typically developing children (Anthony & Lonigan, 2004; Muter, Hulme, Snowling, & Taylor, 1997; Wackerle-Hollman, Schmitt, Bradfield, Rodriguez, & McConnell, 2015) and children with reading disabilities (Metsala, 1999; Scarborough, 1989). This unique contribution of phonemic awareness to children's reading skills was also highlighted in the meta-systematic review conducted by Melby-Lervåg et al. (2012). In addition, existing theories of PA development have argued that phonemic awareness develops not before a child is exposed to formal reading instruction (Anthony, Lonigan, Driscoll, Phillips, & Burgess, 2003; Castles & Coltheart, 2004; Goswami, 1990). This fact was therefore suggested as another difference to the above mentioned remaining components of PA, which are measurable in children at preschool stage (Aidinis & Nunes, 2001; Carroll, Snowling, Hulme, & Stevenson, 2003). However, these results have been contested by studies conducted in different languages (e.g. Hulme, Caravolas, Málková, & Brigstocke, 2005; Kenner et al., 2017; Van Bon & Van Leeuwe, 2003), showing that phonemic skills do develop to a certain level before children are exposed to formal literacy instruction. Recent findings from Kenner and colleagues' (2017) study on 50 children for instance suggested that phonemic awareness capacities emerge in children as young as 2.5 years of age.

The majority of studies now seem to recognise and emphasise the reciprocal links between children's performance on phonemic awareness assessments and their word reading skills, and the greater importance of phoneme sensitivity as opposed to onset-rime sensitivity (e.g. Burgess & Lonigan, 1998; Hulme, Snowling, Caravolas, & Carroll, 2005; Melby-Lervåg et al., 2012; Muter et al., 2004). However, the controversy in this area is ongoing, as there are still others who have been advocates for rime awareness, as opposed to phonemic awareness being the foundational skill for learning to read, with the latter only being the product of reading acquisition (Ziegler & Goswami, 2005). In addition, there is also a third view supported by another group of researchers (Anthony & Francis, 2005; Anthony & Lonigan, 2004) who believe that phonological skills are best considered as a unified and single ability that can be identified in different skills a child acquires in a period stretching from before starting formal education to the first years in school.

In summary, while there is still a debate regarding the onset of phonemic awareness in young children, as well as opposing views regarding the role of phonemic awareness or rime awareness in children's literacy acquisition, there is also overarching agreement on the importance of mastering phonological awareness, as the ability to recognise, identify and manipulate phonological units within a word, for successful literacy acquisition across a range of languages (e.g. Ziegler & Goswami, 2005). Further, there is consensus of a reciprocal relationship between literacy and phonological awareness, with the act of reading acquisition changing the way children process language (Castles & Coltheart, 2004; Wagner, Torgesen, & Rashotte, 1994).

Given the outlined complex nature of PA, it is not surprising that it has been assessed in different ways in the past. Broadly speaking, a distinction can be made between explicit and implicit PA assessments (Melby-Lervåg et al., 2012): Explicit assessments, either referred to as phonological sensitivity or PA assessments, specifically explore PA skills. Implicit phonological processing tasks on the other hand, such as RAN assessments, explore phonological processing mechanisms indirectly, as they need to be applied for succeeding in the specific task. However, using these implicit tasks could be seen as problematic based on findings from a recent study providing evidence for the independence of PA and RAN in influencing literacy acquisition (van der Stappen & van Reybroeck, 2018). Explicit PA assessments aim to assess whether the child is able to reflect upon and manipulate the speech sounds in individual words (Gombert, 1992). Therefore, this mode of explicitly testing PA is grounded on the prevalent hierarchical developmental model, arguing for PA to undergo a process that gradually enables the child to first distinguish between large sound units, such as words or syllables, to secondly differentiate between intermediate word units like onsets and rimes, and to finally discriminate individual phonemes of a word (Treiman & Zukowski 1991). A range of explicit PA assessments has been adopted, varying regarding the size of the phonological unit that needs to be manipulated and the judgement participants need to make. As a result, these assessments vary in level of difficulty, with assessments that require the manipulation of phonemes and speech sounds being harder to complete than syllable tasks or tests relying on forced-choice judgements (McBride-Chang, 2004).

These differences in terms of task-specific demands in PA assessments adopted in a range of studies have been discussed as possible reasons why reported results often differ from each other (e.g. Caravolas, 2004; Stackhouse & Wells, 1997). While the majority of explicit PA assessments used have either tested rime awareness or phonemic awareness, many empirical studies and reviews have combined both measures of PA (Bus & IJzendoorn, 1999; Ehri et al., 2001; Stuart & Coltheart, 1988; Swanson, Trainin, Necoechea, & Hammill, 2003). In a recent study by Hayward and colleagues (2017) conducted with 215 participants, authors criticised the fact that currently only total scores achieved are considered for determining a child's PA skills. They subsequently argued for incorporating error classifications into the score in future, as it would not only enhance the understanding of a child's PA but would also improve the effectiveness of instructions provided (Hayward et al., 2017). While the main study of this thesis also yielded total scores, by adopting a combined phonemic awareness assessment for exploring sound isolation and sound deletion skills in children based on the *York Assessment of Reading Comprehension (YARC)* (Hulme et al., 2009), it is felt that Hayward and colleagues' conclusions draw attention to the need for reconsidering traditional PA assessment scoring procedures.

As mentioned earlier, there is widespread agreement among researchers, teachers, and policy makers in the English speaking context that the adoption of a teaching approach centred on PA was most effective in supporting children in their reading acquisition (Rose, 2006). This approach typically includes activities to encourage PA, which are then used to help children in mastering phoneme-grapheme correspondences. Extensive research demonstrating the close relationship between children's phonological skills and word reading acquisition has been provided by the National Early Literacy Panel (2008) and by Wagner and Torgesen (1987). Converging evidence was found by a meta-analytic study conducted by Bus and IJzendoorn (1999): Authors concluded that PA training was effective, as it did not only improve children's PA skills, but also their reading skills. Authors further revealed that differences between a group receiving PA intervention and a control group was Cohen's $d = .70$, suggesting that there was a strong to medium effect of PA on reading skills. In addition, PA skills in children receiving an intervention, accounted for around 12% of the variance in tested children's reading skills (Bus & IJzendoorn, 1999).

A further meta-analytic study conducted by Ehri and colleagues (2001) reviewed 52 studies regarding the effect of phonemic awareness instruction on children's literacy acquisition. Results suggested that instruction on phonemic awareness was not only supporting children to acquire phonemic awareness skills, but also correlated moderately with children's literacy skills in reading and spelling. Further, phonemic awareness instruction had a significant and moderate effect on children's word reading and reading comprehension (Ehri et al., 2001). The importance of implementing effective PA interventions for improving decoding abilities of young children and especially of those from low SES backgrounds, has again been highlighted by a recent UK cohort study on data from 13,680 participants (Russell, Ukoumunne, Ryder, Golding, & Norwich, 2018). However, while the positive effect of PA training on children's reading has been uncontested, Bus and IJzendoorn (1999) reviewing different literacy interventions added that a combination with letter training resulted in the intervention being more effective than the phonological training on its own. These results suggested that while PA was an important skill for reading, targeting it in interventions alone, was not sufficient for ensuring success in early reading tasks.

PA provides children with foundational skills needed to create links between phonological representations of spoken language and the orthographic representations of written language (Ziegler & Goswami, 2005) and a number of longitudinal studies investigated relationships between children's performance on PA assessments and literacy outcome skills. A meta-analysis conducted by NELP (National Early Literacy Panel, 2008), revealed that PA in children between the ages of 0-5 showed moderate significant correlations with their later skills in word reading, reading comprehension and spelling ($.40 \leq r \geq .44$), suggesting consistency in the relationships between the predictor skill and the literacy outcome measure. However, concerning this matter, Muter and colleagues (2004) emphasised that relationships between phonemic awareness and literacy outcomes were subject to variability as they depended on which literacy skill was considered as the outcome variable. Converging evidence to suggest that children's phonemic awareness skills had a direct impact on their performance regarding word-level reading, was further provided by Vellutino and colleagues: In their study on 468 children authors argued for phonemic awareness only being indirectly related to comprehension through its effect on word reading (Vellutino et al., 2007).

In a study conducted by Oakhill and Cain (2012) with 102 children, findings suggested that PA skills predicted word reading accuracy. However, at the same time authors emphasised that no direct relationship was found between PA and comprehension, which went in line with results from studies investigating the development of word reading (Bryant, MacLean, Bradley, & Crossland, 1990; Muter et al., 1997; Torgesen, Wagner, & Rashotte, 1994). Melby-Lervåg and colleagues' (2012) meta-analysis on 155 correlational studies with independent samples looking at phonemic awareness, rime awareness and reading yielded the following results: There was a significant and strong mean correlation between phonemic awareness and decoding (r = .57), and a medium mean correlation between rime awareness and decoding (r = .43). When investigating the amount of independent variance in reading ability with Cholesky factoring analyses, results further revealed that phonemic awareness, rime awareness, and verbal short-term memory together explained 37% (43.2%, when corrected for reliability) of the variance in reading skills, and that phonemic awareness explained 14.4% (16.1%) of additional variance, when rime awareness and verbal short-term memory were partialed out. Since these two other components of the model explained only non-significant additional variances, Melby-Lervåg and colleagues (2012) made the conclusion that phonemic awareness was the only independent predictor of reading within the tested models. Swanson and colleagues (2003) reached similar correlational results in their meta-analysis published nine years earlier, reporting significant and moderate correlations between real word reading and PA (r = .48). However, while findings of both meta-analyses are comparable, the conclusions drawn by Swanson and colleagues stand out, as authors conclude that the importance of the contribution of PA alongside RAN for children's reading performance has been overstated (Swanson et al., 2003).

1.3.2 Letter knowledge

Learning the letters of the alphabet is a major milestone in alphabetic literacy acquisition (Adams, 1990; Whitehurst, & Lonigan, 1998) and consists of recognising the different identities of each letter, such as its forms in lower- and uppercase, its letter name, as well as its corresponding sound(s) (Foulin, 2005). The skill connected to the latter is referred to as letter-sound knowledge (LSK) and has been acknolwedged as a necessary skill for understanding the alphabetic principle of a language, i.e. letters representing speech sounds and therefore the phonemes of a language (Byrne, 1998; Stuart & Coltheart, 1988). The contribution of letter name knowledge (LNK) to early literacy on the other hand is suggested to lie in improving children's visual word recognition (Mason, 1980; McGee, Lomax, & Head, 1988). Together, LNK and LSK have consistently been proven to be the best predictors of children's later reading and spelling skills (Hammill, 2004; Scarborough, 1998; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). When exploring the body of research available in this area, it becomes apparent that some studies focus on LNK and its impact on literacy acquisition, while others explicitly discuss relationships between LSK and emergent reading skills. In addition, there are two diverging approaches regarding the facilitation of LSK and LNK when teaching early literacy: While advocates of the alphabetic theory argue for LNK helping children in the acquisition of LSK, which subsequently helps children in decoding words (e.g. Adams, 1990), others argue for only focusing on LSK in English language early reading instruction, as LNK would be more of a hindrance than a help, with letter names often differing from the acrophonic principle (Feitelson, 1988). Finally, it has also been suggested that LNK and LSK don't follow the same developmental paths and also predict reading in different ways (Lerner & Lonigan, 2016; McBride-Chang, 1999). A possible explanation of this hypothesis can be found in cultural differences between the US and the UK: While literacy instruction in the UK has traditionally put an emphasis on teaching LSK, the focus in the US context has been more on teaching LNK (Caravolas, Hulme, & Snowling, 2001; Piasta, Purpura, & Wagner, 2010). These differences in instructional practices may therefore also have had an impact on the predictive power of LNK or LSK on later reading.

While LNK and LSK have therefore often been discussed separately in the past – see Lonigan (2005) for further discussion of the reasons for considering them individually–, they have both consistently been identified as strong predictors of early literacy and have often been shown to have stronger predicitve power compared to PA or oral language (Burgess & Lonigan, 1998; McBride-Chang, 1999; Wagner et al., 1994). In addition, Caravolas and colleagues (2001) (N = 153), as well as McBride-Chang (1999) (N = 91) emphasised their close relation by reporting a moderate to strong correlation of .43 - .80 between the concurrent measures of LSK and LNK at different points in time. As a result, many studies have considered and assessed both skills together in a combined letter knowledge (LK) measure, aiming to gather more complete information on what a child knows about letters (Bond & Dykstra, 1967; Bruck, Genesee, & Caravolas, 1997; Duncan & Seymour, 2000; Foulin, 2005; Gallagher, Frith, &

Snowling, 2000; Muter et al., 2004, 1997; Seymour et al., 2003). Adopting a composite measure is especially beneficial when conducting a study with preschoolers, as children from this age group are often either familiar with the name or the sound of a letter (Foulin, 2005). The following discussion of the literature will jointly consider studies looking at LNK or LSK separately, as well as the composite LK in relation to early reading acquisition.

When comparing the characteristics of LNK and LSK as precursors of early literacy, study findings revealed that their predictive strength is of limited duration: Foulin (2005) suggested that while LNK may be a stronger predictor compared to LSK until a child enters school, the latter may be more predictive of reading achievement after children have reached ceiling in LNK. This went in line with results provided by Schatschneider and colleagues (2004) who conducted a longitudinal study with 384 children: While the variance in reading accuracy, reading fluency, and comprehension assessed at the end of Grade 1 and 2 was explained by LSK and LNK measured at the beginning of kindergarten (equivalent to Reception in the UK), ceiling effects were reached by the end of kindergarten, making them no longer useful as predictors. This finding was further confirmed by Seymour and colleagues, who reported that LSK reached ceiling in a normative group of 30 English speaking children within the first year of formal education (Seymour et al., 2003). However, when taking Caravolas' (2004) review and Ellefson and colleagues' (2009) study findings based on 182 children into account, this is not universally true, as the development of LK is also effected by cultural and educational practices.

While some have questioned the necessity of LK, and particularly LNK for the acquisition of reading and spelling (Groff, 1984; McGuinness, 2004), a number of longitudinal studies and meta-analyses have argued for LK being a prerequisite for later literacy development and have grounded their hypothesis on reported high correlations between LK and later decoding skills. In a meta-analytic study by Scarborough (1998), kindergarten children's LK knowledge before entering school was found to be the strongest predictor of word reading in the first year of schooling. These findings were further confirmed by the NELP meta-study conducted a decade later, in which moderate to large average correlations were reported between LK and decoding (r = .50), spelling (r = .54), as well as reading comprehension (r = .48) (National Early Literacy Panel, 2008). Similar findings were yielded by Muter and colleagues (2004) who explored traditional predictors of reading and emergent literacy in 90 UK children from Reception to the start of Year 2. Results showed that LK in 4- to 5- year old children at the beginning of formal schooling was significantly and strongly (r = .71) correlated with children's reading skills assessed a year later (Muter et al., 2004). Further, results of the study revealed that LK as an important predictor of early reading was partly independent of effects of PA and phonolgical processing (Muter et al., 2004). Their findings also went in line with results by Schatschneider and colleagues' (2004) study conducted with 945 children of the same age group in the US. Results revealed that both, LSK (r = .50) and LNK (r = .43) corrrelated significantly and moderately with decoding. Further, LK alongside PA and naming speed were good predictors for different reading outcomes, as they – in contrast to vocabulary, oral language or perceptual skills – accounted for significant and unique variance across reading outcomes (Schatschneider et al., 2004). Repeatedly provided evidence that LSK and PA were reliable predictors of reading acquisition was further validated by Hulme and colleagues (2012): Their mediation study concluded that there was a causal influence of LSK alongside PA on the development of children's skills in early literacy (Hulme, Bowyer-Crane, Carroll, Duff, & Snowling, 2012).

In their meta-analytic study investigating the learning and instruction of LK, Piasta and Wagner (2010) underlined the importance of alphabet knowledge as a key skill for early literacy, with preschools in the US considering the facilitation of its development as one of their primary objectives. The necessity of providing effective LK instruction for children has been confirmed by study results suggesting that children identified with poor knowledge of letter names and sounds before entering school, were more likely to struggle with learning to read in the first years of formal education, and subsequently were higher at risk of developing a reading disability (e.g. Gallagher, Frith, & Snowling, 2000; Torppa, Poikkeus, Laakso, Eklund, & Lyytinen, 2006). Torgesen (2002) agreed with these findings and further pointed out that children having difficulties with reading acquisition due to less LK knowledge at the beginning of schooling, showed increasing gaps in vocabulary, spelling, reading fluency, and comprehension when compared to their more able peers later on in their school career. When investigating the effectiveness of different LK interventions, Piasta and Wagner's (2010) review yielded interesting results: School-based LK instruction showed larger effects on LK knowledge than home-based instruction, as did small-group instruction in comparison to individual tutoring sessions. These results seemed to further support the implementation of intensive LK instruction in early learning settings and were confirmed by a recent study involving 120 children, showing the effectiveness of a classroom-based and teacher-delivered LK instruction, alongside PA instruction for 3- to 5- year olds (Kelly, Leitão, Smith-Lock, & Heritage, 2017). However, Piasta and Wagner’s study also revealed that while these interventions were effective in terms of increasing children’s LK knowledge, there was only little evidence that they would also have an impact on the development of other literacy skills such as PA, spelling or reading (Piasta & Wagner, 2010).

While LK has therefore consistently been found to be a strong predictor of early reading in correlational studies, advanced skills in LK following an intervention has generally not been found to be followed by improvements in literacy skills (Adams, 1990; Hulme et al., 2012; Piasta & Wagner, 2010). Based on this observation the following two hypotheses have been made: Either LK is mediated by other skills, or it serves as a proxy for influential factors impacting early literacy, such as informal reading instruction at home, exposure to book-reading, interest in learning to read (Adams, 1990; Bowey, 2005), general cognitive ability (Bowey, 1994), or skills in visual-verbal learning (Foulin, 2005). However, while the circumstances of the relationships between LK and literacy acquisition await further investigation, having knowledge of letters and their function in an alphabetic writing system is key for gaining assured knowledge of the alphabetic principle (Bowey, 2005). The assessment battery of the main study reported in this thesis adopted a LSK assessment for testing children at the first time point, when they started formal schooling.

1.3.2.1 The relationship between PA and LK

When reviewing the literature, it became clear that in preschool-age children, PA and LK seemed to be in a close and reciprocal relationship (Burgess & Lonigan, 1998). Bowey (2005) pointed out that understanding the principle of an alphabetic language was inextricably linked with the understanding of how letters represented the sounds of a language (phonemic awareness). As already mentioned above, some considered LK to be closely connected with the development of PA and especially so with the development of sensitivity towards phonemes (Bowey, 1994; Johnston, Anderson, & Holligan, 1996), as opposed to the larger sound units – onsets, rimes, syllables (Maclean, Bryant, & Bradley, 1987). This goes in line with Castles & Coltheart (2004) who suggested that PA at a phoneme level may only develop as a consequence of learning LK. Vice versa, effects of PA on LK development and especially for letter names highly corresponding to their sounds, have additionally been reported (Kim, Petscher, Foorman, & Zhou, 2010). An explanation of the close connection between PA and LK, once both of them are developed was provided in a paper by Byrne and Fielding-Barnsley (1989), reporting on the results of 5 experiments, with 11-30 participants each: Based on their results, authors suggested that only children who had LK and phonemic awareness showed an overall understanding of the alphabetic principle. However, they concluded that while both skills were necessary to acquire an understanding of this key principle, they alone were not sufficient (Byrne & Fielding-Barnsley, 1989).

The apparent reciprocal relationship between PA and LK was reported by a number of studies: Findings by Muter et al. (1997) suggested that LK together with phonemic awareness accounted for 60-70% of the variance in reading and spelling in the first year of schooling (N = 38). Similar, albeit weaker results were reported in their subsequent study with 90 children: Here, LK and phonemic awareness accounted for 52% of the variance in a word recognition task (Muter et al., 2004). Burgess & Lonigan (1998) tracked the development of literacy skills in 97 5- to 6- year olds over a one year period. Regression analyses revealed that not only PA was a significant and unique predictor of growth in LK, but that conversely the same was true for LK predicting growth in PA, when age and oral language abilities was controlled for. These findings were further confirmed by mediation analyses conducted by Hulme and colleagues' (2012): Study results showed that the improvement of 152 British children who had completed a reading and phonology intervention on a word reading task were fully explained by increases in LK and PA. These results provided strong evidence for the causal role of both LK and PA in the development of children's literacy (Hulme et al., 2012).

Intervention studies exploring the causality within this bidirectional approach yielded mixed results: A study by Castles and colleagues showed that 76 children receiving a phonemic awareness intervention made better progress in a subsequent LSK training than their peers in the control group (Castles, Coltheart, Wilson, Valpied, & Wedgwood, 2009). Contrasting results were found in other studies where a LK intervention did not have an effect on children's PA skills (Lonigan, Purpura, Wilson, Walker, & Clancy-Menchetti, 2013; Piasta et al., 2010; Piasta & Wagner, 2010). A further study on 324 children suggested that a successful acquisition of PA did not directly translate into better performance on LK assessments (Lonigan et al., 2013). While findings of these studies therefore proposed an interdependence between PA and LK, studies did not examine bidirectional relationships within the same time frame and same sample. However, this was looked at by a later study conducted by Lerner and Lonigan (2016) with 358 4- to 5- year olds: When investigating the links between LK and PA in connection with different linguistic units (words, syllables, phonemes) authors identified significant bidirectional relationships. Within one year, the growth of either PA or LK was uniquely predicted by the initial skill level of the other (Lerner & Lonigan, 2016). Further, study findings suggested that the influence of the initial skill level in PA and LK on growth in the other was independent of the general growth in each of the predictors over a year.

Overall, while there has been some discussion around the nature of the relationship between PA and LK, and especially so between phonemic awareness and LK in alphabetic orthographies, there has been widespread agreement that early reading development depends on both, children's PA and LK (Hulme et al., 2012). Thus, Bowey (2005) advocated for considering PA and LK as co-determinants of literacy skills, rather than trying to determine which of those was more essential for the acquisition of reading.

1.3.3 Vocabulary

The influence of early oral language skills on later reading performance has been suggested by previous studies (Cooper, Roth, Speece, & Schatschneider, 2002; Olofsson & Niedersøe, 1999; Scarborough, 1990, 1998), with the majority (Biemiller & Boote, 2006; Bowey, 1995; Bryant et al., 1990; Caravolas et al., 2001; National Reading Panel, 2000; Wagner et al., 1994) mainly focusing on the relationships between expressive and receptive vocabulary and early reading achievement, including both word recognition and comprehension.

Sizeable studies and statistical analyses have shown a relationship between children's vocabulary knowledge, defined as consisting of semantic and phonological representations (Levelt, Roelofs, & Meyer, 1999), and reading accuracy. The exact nature of this relationship however, has been subject of discussion (Dickinson, McCabe, Anastasopoulos, Peisner-Feinberg, & Poe, 2003). One study exploring the links between vocabulary and literacy development was provided by Wise and colleagues: Study results based on 279 participants showed that vocabulary knowledge was uniquely related to pre-reading skills and that expressive vocabulary (r = .19) was significantly and independently related to children's word identification skills (Wise, Sevcik, Morris, Lovett, & Wolf, 2007). Supportive evidence of these findings were provided by an earlier study conducted by Bowey (1995): In her study, receptive vocabulary in 116 kindergarten children who were yet unable to read, predicted 20-27% of variance in their reading skills at the end of Grade 1. These findings suggested that advanced phonological and semantic representations of a word could be beneficial for literacy development. The stance of seeing vocabulary as directly related to reading has also been taken by Share (1995): Based on his self-teaching hypothesis, the author argued that vocabulary knowledge, and therefore stored phonological representations of words, helped children in the process of decoding these familiar words.

The lexical restructuring theory (Metsala & Walley, 1998) also suggests a relationship between vocabulary and reading but advocates for the impact of vocabulary on children's reading development being mediated by phonology: According to this theoretical account, children therefore start with representing words holistically in terms of their phonology until it becomes ineffective once they need to distinguish between a growing number of increasingly similar words. As a result, a more systematic strategy is needed for the distinction of phonologically closely related words, leading to children progressing onto recognising words in increasingly smaller units – first syllables, then phonemes – in the process of adding new words into their lexicon. Growing vocabulary knowledge helps the child to further develop their phonological skills, which in turn has a positive impact on children's word reading development (e.g. Goodrich & Lonigan, 2015; Metsala & Walley, 1998; Walley, Metsala, & Garlock, 2003). In short, reading is influenced by vocabulary knowledge through its key role in the development of PA. Supportive evidence of the indirect relationship between reading accuracy and vocabulary, and therefore the significant relationships between oral language skills (i.e. vocabulary) and code-related skills (i.e. PA) in preschool as well as in the first years of formal education has been found in a number of studies (Burgess & Lonigan, 1998; Lonigan, Burgess, Anthony, & Barker, 1998; Storch & Whitehurst, 2002; Vellutino, Scanlon, Small, & Tanzman, 1991). One further example was provided by a study conducted by Sénéchal and colleagues: Their findings revealed that 4% of the variance in PA skills of Canadian English speaking children in Grade 1 were uniquely predicted by their vocabulary skills assessed in kindergarten, even after alphabet knowledge, invented spelling, listening comprehension, and parent literacy levels were controlled (Sénéchal, Ouellette, & Rodney, 2006).

However, given the characteristics of English as an inconsistent orthography, entailing many irregular words, decoding may not only be supported by vocabulary, but also by semantic knowledge, providing additional contextual support, as highlighted by the connectionist triangle model of reading (Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996). All in all, when reviewing available evidence, it can be concluded that while positive relationships between vocabulary knowledge and broader measures of reading accuracy have been suggested by some studies (Dickinson et al., 2003; Duff, Reen, Plunkett, & Nation, 2015; Lee, 2011; Sénéchal & LeFevre, 2002), and for irregular word reading more particularly (Nation & Snowling, 2004; Ricketts, Nation, & Bishop, 2007), others have failed to find evidence of a direct relationship between vocabulary and decoding (Metsala, 1997; Muter et al., 2004)

In comparison to the disagreement in the results regarding the links between vocabulary and decoding, studies exploring the relationship between children's vocabulary skills and reading comprehension have yielded coherent results, identifying vocabulary as a significant and strong predictor of reading comprehension development in the first years of formal schooling (Bast & Reitsma, 1998; de Jong & van der Leij, 2002; Torgesen et al., 1997). Evidence suggested that longitudinal relationships can be found between school-aged children's comprehension and previously assessed vocabulary skills, even when the latter was measured very early on in a child's life. Muter and colleagues conducted their study with 90 participants in the UK and found that vocabulary skills measured when children were on average 4;9 of age, predicted reading comprehension in the first two years of schooling, with PA, LK, and word recognition being controlled (Muter et al., 2004). A recent study conducted by Duff and colleagues on 300 children yielded similar results: Authors applied structural equation modelling to explore the predictive power of parental reports of children's vocabulary skills at 16-24 months on their reading accuracy and reading comprehension at the age of 4;5-9;5 years, controlling for effects of age (Duff et al., 2015). Even though vocabulary was measured at such a young age, findings revealed that infant vocabulary knowledge accounted for 11% of variance in reading accuracy and 18% of variance in reading comprehension.

Authors suggested that these results provided good evidence for vocabulary being a plausible causal influence of later reading accuracy and comprehension. Findings from the study were further more distinct but still comparable with results from a large-scale study (N = 1,073) conducted by Lee (2011), with vocabulary production at the age of 24-months explaining 5% of the average variance in reading accuracy and 7% of the average variance in reading comprehension when attending school.

Following a hypothesis brought forward by the SVR, it is further likely that the influence of vocabulary, alongside other oral language skills, on children's reading is increasing alongside their reading proficiency, as they get more and more confronted with linguistically complex texts (de Jong & van der Leij, 2002; Muter et al., 2004; Oakhill & Cain, 2012; Roth, Speece, & Cooper, 2002; Storch & Whitehurst, 2002). In addition, while the research studies reviewed so far have suggested a linear relationship between vocabulary and reading, the possibility of a reciprocal causal relationship between reading development and vocabulary knowledge emerging within more advanced readers has been discussed (e.g. de Jong & van der Leij, 2002), with text serving as an important source to increase one's vocabulary knowledge (Nagy & Scott, 2000). Supporting evidence of a bidirectional relationship between vocabulary and reading was found in a study conducted on 74 French speaking children by Seigneuric and Ehrlich (2005): Findings revealed that vocabulary measured in 7- year olds at Grade 1, not only predicted their performance on a comprehension task when they were two years older, but also suggested that reading comprehension assessed in Grade 1 explained 15% of the variance in children's performance on the vocabulary measure in Grade 3 (Seigneuric & Ehrlich, 2005). However, the predictive role of vocabulary on reading has also been contested: On the one hand, findings from two studies (N = 504, N = 1,585) reported by Eldredge, Quinn, and Butterfield (1990) suggested that the impact of reading comprehension on vocabulary growth was bigger than the influence of vocabulary knowledge on reading comprehension. On the other hand, evidence was found that global measures of comprehension, such as listening comprehension, have a unique predictive power over and above vocabulary when considering reading comprehension (e.g. de Jong & van der Leij, 2002).

In summary, the development of reading skills on the word level, and especially of reading comprehensions skills is influenced by vocabulary knowledge. There is further a reciprocal relationship between reading comprehension and vocabulary, as reading contributes to vocabulary growth in children on a more advanced reading level. For the main study discussed in this thesis, it was decided to capture children's vocabulary skills by adopting the *British Picture Vocabulary Scale (BPVS)* (Dunn, Dunn, Styles, & Sewell, 2009) as a widely-used and reliable receptive vocabulary measure.

1.3.3.1 The relationships between PA, LK, and vocabulary

The discussion provided about traditional predictors PA, LK, and vocabulary so far, included references to different theoretical approaches in instances when their connections were outlined. To reach a better understanding of these complex relationships, this section will briefly summarise the key concepts of available theoretical accounts considering the links between PA, LK, and vocabulary in relation to an individual's phonological development in a structured manner. When reviewing available theories they show disagreement regarding how both, growth in vocabulary and LK, impact the development of phonological representations of words, which is closely linked to children's knowledge of phonological elements. The key similarities and differences between these diverging theoretical accounts will be outlined below:

Proponents of the accessibility account argue that children from a very young age have the ability to store phonological representations, i.e. words, in great phonological detail and therefore in an adult-like way (e.g. Bailey & Plunkett, 2002; Ballem & Plunkett, 2005; Swingley, 2009). At the same time, children are only able to access the detailed sound structure of words, and therefore successfully complete advanced PA phoneme deletion assessments, once they have acquired essentially needed meta-cognitive skills and LK (Liberman, Shankweiler, & Liberman, 1989; Rozin & Gleitman, 1977). Hence, LK is considered to be a prerequisite for PA on the phoneme level, as orthographic knowledge is needed to access smaller sound elements within words (ibid). In contrast to this, the emergent account builds on the hypothesis that children initially do not store phonological representations in the same detail as adults do, but rather have to go through a process that gradually enables them to have more detailed representations of words (Ainsworth, Welbourne, & Hesketh, 2016; Carroll & Myers, 2011; Metsala & Walley, 1998). Within this emergent view, three different accounts can be identified:

First, the lexical restructuring model (LRM) as proposed by Metsala and colleagues, argues for vocabulary growth being responsible for stimulating the development of PA, and therefore the ability to segmenting words in increasing detail (Metsala, 1997;

Metsala & Walley, 1998). LRM further argues that children are able to distinguish phonemes automatically through advances in oral language skills, leading to LK not being considered separately, as it is not thought to have an impact on phonological representations or PA on a phoneme level (Metsala & Walley, 1998). Second, Ventura and colleagues (Ventura, Kolinsky, Fernandes, Querido, & Morais, 2007) investigating illiterate adults, and Carroll (2004) considering literacy development in children, have extended the LRM. While authors have shared the view that phonemes at a representational level can only emerge through the development in oral language skills, they further emphasised the need for children to acquire LK in order to deliberately target phonemic segments. This account therefore advocates a unique relation between LK and PA. Finally, a third emergent account is proposed by Ziegler and Goswami (2005) and referred to as psycholinguistic grain size theory. While this theory agrees with the LRM in that children's vocabulary growth enables the process of segmenting stored words, this restructuring is not happening gradually from large to small representational components, but rather in the sense that representations are augmented with phonological detail at both large and small 'grain sizes' (i.e. syllables, onset-rime, nucleus-coda, phoneme, phone). It is therefore argued that representations of words undergo changes in terms of redundancy and specificity. In addition, psycholinguistic grain size theory argues for PA at a phoneme level only to emerge through explicit LK instruction, as study results showed that children acquire the ability to count phonemes soon after they are exposed to formal literacy instruction (Ziegler & Goswami, 2005).

Overall, while there is not a universally shared understanding of the nature of the relationships between PA, LK and vocabulary, the above discussed theoretical approaches further highlight the close and multi-faceted connection between the discussed precursor skills. The following section will consider the fourth and final predictor skill, included in the main study of this thesis.

1.3.4 Short-term memory

Short-term memory (STM) enables an individual to store information passively and temporarily in memory (Oakhill & Cain, 2008). According to Baddeley and Hitch's (1974) model of working memory, information is differently stored in memory depending on its modality, with visual information being stored in the *visuo-spatial sketchpad*, and language in spoken form being stored in the *phonological loop.* In this chapter the emphasis will be on the latter, as it is concerned with phonological STM and therefore with the storage of spoken linguistic information. On the one hand, phonological STM is suggested to influence the development of reading directly, as the ability to repeat a novel phonological form is a key prerequisite for incorporating this representation into the lexical knowledge and hence fundamental for learning new words (Gathercole, 2006; Melby-Lervåg et al., 2012). On the other hand, phonological STM is suggested to influence literacy development indirectly through contributing to other predictors such as PA and LK (Gathercole, Tiffany, Briscoe, & Thorn, 2005).

Nonword repetition (NWR) as a serial recall measure similar to RAN, is commonly utilised to test children's phonological STM skills by scoring the accuracy of repeating an unfamiliar sequence of phonological elements – i.e. non-existent words (Gathercole, Willis, Baddeley, & Emslie, 1994). A number of studies have reported a close relationship between children's performance on NWR tasks and their language development, and more specifically highlighted links between NWR and vocabulary growth in young children (e.g. Gathercole, Willis, Emslie, & Baddeley, 1992). They further gave evidence that children who fail to perform well on NWR tasks were also often struggling to learn new words (Gathercole & Baddeley, 1990), had language impairments (Graf Estes, Evans, & Else-Quest, 2007), or were identified as poor readers (Catts, Adlof, Hogan, & Weismer, 2005). While the association between language development and NWR has therefore been uncontested, different theoretical stances can be found discussing their relationship (see Nation & Hulme, 2011, for an overview).

Especially children in the early years are not only used to hear and repeat unfamiliar words in their day to day life, they also seem to have remarkable capacity, as well as a natural desire to add these new words into their lexicon (Carey, 1978; Rice, 1990). Gathercole and colleagues (1994) concluded that this was the reason why children from the age of two had little trouble understanding a NWR task, making it particularly suitable for studies investigating young children. There also is big variation in children's skill to repeat multisyllabic nonwords during childhood, further making it one of the most effective precursors to look at when assessing children's language learning ability (Gathercole, 2006). However, while NWR could be seen as an easy and straight-forward task, it is not trivial and requires performance which is influenced by a number of factors, including an individual's temporary phonological storage capacity (Gathercole, 2006), elements related to the nonword properties, such as articulatory factors, like co-articulation and complexity (Archibald, Gathercole, & Joanisse, 2009), and speech motor skills (Sasisekaran, Smith, Sadagopan, & Weber-Fox, 2010).

The majority of studies looking at the development of phonological STM and its relationship to reading have mainly considered children with reading difficulties, such as Down syndrome, language impairment, or autism (e.g. Archibald & Joanisse, 2009; Catts et al., 2005; Laws & Gunn, 2002; Williams, Botting, & Boucher, 2008). The contribution of phonological STM in predicting literacy skills in typically developing children has been subject of debate. The majority of conducted studies have shared the assumption that skills assessed with a NWR task were contributing to the development of reading (Wagner & Torgesen, 1987). Gathercole and colleagues reported significant correlations between word reading and NWR in 118 children between the ages of 5 to 7, leading authors to suggest a causal relation between phonological memory and reading development (Gathercole et al., 1992). Similar findings were reported in a study conducted by Gathercole and colleagues (2005) with younger children: 926 4- year olds' performance on the NWR task significantly correlated with their early reading skills assessed a year later. However, no significant concurrent correlation was found between literacy and NWR in a study exploring 111 children at the age of 5 (Gathercole, 1995). A third study yielded reverse results, reporting a significant concurrent relationship between a phonological memory measure including a NWR task and literacy in 83 7- year old children, but no significant longitudinal correlation between phonological memory measured at the age of 7 and literacy skills assessed a year later (Gathercole & Pickering, 2000). More recent studies also reporting on phonological STM yielded the following results: A meta-analytic study conducted by the National Early Literacy Panel (2008) suggested only weak to moderate correlations for STM assessed before or during kindergarten, and decoding (r = .26), as well as reading comprehension (r = .39). Caravolas et al.'s (2012) study explored the predictive power of phonological STM on reading and found STM not to be a unique predictor of reading. In addition, findings of a small-scale study conducted on 44 French-speaking natives aged 5 to 6 (Nithart et al., 2011) suggested that while in very young children phonological STM was at first almost congruent with PA, they quickly seemed to develop separately as children got older and played different roles in reading acquisition. Their findings further revealed that phonological STM assessments with a NWR task were especially relevant for decoding and word recognition.

Finally, while the studies discussed so far considered NWR and its impact on reading development, Nation and Hulme (2011) provided evidence that there was not a linear connection between these two elements, but that their relationship was rather reciprocal, with reading development influencing children's performance on a NWR task. In more detail, their study findings based on 215 participants suggested that although no unique relationship was found between NWR and learning to read during the first year of schooling, reading skills at the age of 6 predicted the growth in performance on the NWR task when assessed one year later (Nation & Hulme, 2011).

While the nature of the relationship between phonological STM and learning to read awaits further investigation, currently available evidence suggests that young children's performance on NWR tasks is closely linked with their emerging literacy skills, as phonological STM helps them to hold and process information during decoding and recognising words. When finally considering phonological STM in relation to the three formerly discussed predictor skills, it seems that STM is closely related to vocabulary and primarily supports the development of PA and LK.

1.4 Summary

Research studies discussed above have focused on investigating four cognitive and linguistic skills and their relationships to the development of early literacy. All four traditional precursor skills discussed here have shown to be predictors for literacy skills at the beginning of formal education, proving the suitability for incorporating these measures into the assessment battery of the main study. When reviewing the relationship between the predictor skills and reading it seems that PA, as well as LK are primarily and directly related to the development of reading accuracy. Their contribution to children's comprehension on the other hand seems to be indirect, as they support the development of lower-level literacy skills. Following the SVR, vocabulary, as an oral language measure, has most influence on comprehension skills, but also influences single word reading skills. Finally, NWR as a measure of phonological STM is closely linked to vocabulary growth, supports the development of PA and LK and is suggested to be particularly important for decoding, alongside word recognition.

Chapter 2 – Visual attention and reading acquisition

2.1 Introduction

Based on the review of literature on emergent literacy skills in the previous chapter, it is evident that psychologists and educationalists have intensively studied print reading over the past decades, leading to a significant body of research and a high level of understanding of the cognitive processes needed for and involved in skilled reading. While the impact of well-established precursor skills on literacy acquisition is uncontested, it is argued that as the amount of reading across different digital formats both in schools and at home has experienced a steady increase over the past years, it is necessary to (i) expand our knowledge of the skills and processes involved in digital reading, and to (ii) understand how reading digital text impacts cognitive functioning. When considering children's reading acquisition more specifically, there is therefore the need to further explore potential digitally-relevant precursor skills of reading. To this day, it is yet unknown to what extent the modality and therefore whether text is presented digitally or on paper, as well as the resulting size, spacing and line length of text impacts reading achievement. As a result, the effect of text presentation on reading acquisition has not been considered in discussions around effective teaching methods for early literacy either.

A well-functioning visual system and particularly an individual's visual attention span has recently been recognised as particularly important for reading performance (Franceschini et al., 2012). It could therefore be suggested that the increasingly rapid move away from standardised typographic formats of printed books (Picton, 2014), makes individual variation in visual attention skills likely to be an important moderator of reading performance. This chapter will therefore provide a theoretical justification for the present work's aim to investigate visual attention as a potential digitally-relevant precursor skill of reading and thus its relation to reading and reading development in the light of children's increased exposure to text presented in different modalities.

Since attention can be described as a term widely used in everyday and scientific contexts alike, this chapter will first investigate the specific understanding of visual attention (VA), working as a foundation of the present study: A short characterisation will therefore be given on VA and VA development, revealing its close links to the parallel cognitive process of memory. After providing justification for using Bundesen's (1990, 1998) Theory of Visual Attention (TVA) as theoretical basis of this study, TVA and the related VA assessment will be explained in more detail. In the subsequent section, the links between VA and reading will be discussed, followed by a review of studies that have applied TVA in different ways to explore the relationship between individuals' VA and their reading abilities. The following section will focus on the emergence of digital technology and its impact on children's reading development to emphasise the potential importance of VA when reading on a screen. The final section of the literature review will consider how children's exposure and engagement with digital devices in the early years has an impact on children's emergent literacy skills. The aims and research questions of the present study will be presented at the end of the chapter.

2.2 Visual attention

Attention can be viewed as a set of selection processes, which guide received perceptual information. The main task of these processes is to avoid the overload of the limited human cognitive system by restricting the amount of external stimuli that are being submitted to further processing (Anderson, 2004; Carrasco, 2014; Driver, 2001; Goldberg & Wurtz, 2013; Kandel, 2013; Nobre & Mesulam, 2014). Attention plays a vital role in all aspects of everyday functioning, such as interacting with others, meeting basic needs, or learning new information. The term itself is rather broad, incorporating a range of operations from basic lower-level orienting in the direction of a sensory stimulus to more higher-level processes. The latter further encompass different categories, including focused attention, selective attention, sustained attention, divided attention, or attention shifting (Driver, 2001; Lezak, Howieson, & Loring, 2004; Wager, Jonides, & Reading, 2004). Broadbent (1958) and Mullane, Lawrence, Corkum, Klein, & McLaughlin (2016) point out that the individual needs to acquire a sufficient level of sustained attention in order for successful learning processes consisting of effective identification, memory and learning to take place. Further, since both attention and working memory are characterised by limited capacity, they are in close collaboration and guide each other reciprocally: While an individual's decision on what attention should be drawn to is guided by memories of past experiences, attention regulates which experiences are encoded into memory (Chun & Turk-Browne, 2007).

The concept of VA as a selecting process was mentioned as early as 300BC, when Greek philosopher Aristotle claimed that it would be impossible for humans to perceive two objects by one simultaneous act (Beare, 2007). Although we tend to believe that we are processing all details when looking at an object or watching a scene, human visual systems are only able to focus on a small central area within the visual field, caused by over representation of central vision in the cortex (Horton & Hoyt, 1991). Following Corbetta (1998), selective VA can therefore be understood as the mechanism that allows individuals to select important stimuli for further processing while at the same time ignoring other visual inputs. Therefore, VA can been conceptualised as a subtype of attention concerned with the selection processes in human visual perception (Zhang & Lin, 2013).

Research has differentiated between overt and covert VA. While overt VA is relying on the eye fixation on certain stimuli, covert attention includes neural adjustments for paying attention to something without the movement of the eyes (Wu & Remington, 2003). The latter phenomenon was first described by Von Helmholtz in the 19th century, who made the following statement, ‘I found myself able to choose in advance which part of the dark field off the side of the constantly fixated pinhole I wanted to perceive by indirect vision’ (Von Helmholtz 1896, as cited in Itti et al., 2005, p. XXV). This mechanism can for instance be observed when we become aware of motion taking place in the peripheral areas of our vision while being focused on something else. On the other hand, some actions, such as scanning a text, can only be performed by overt attention and therefore quick eye movements (Findlay & Gilchrist, 2001), so-called *saccades* (Cassin & Solomon, 1990). However, while both processes are different in nature, covert and overt attention often work in close collaboration: While covert attention makes it possible for an individual to perceive a specific area of interest, the following overt saccades enable acquisition of further information (Deubel & Schneider, 1996).

Another binary concept similar to covert and overt attention that has been discussed in the literature is the assumption of a pre-attention and an attention stage (Hoffman, 1975; Neisser, 1967): The pre-attention stage is understood as automatic, very high in speed, and as having no capacity limitation. Here, the entire visual field of information is being pre-processed in parallel to segment visual information into clusters and to subsequently form separate objects. Some distinct features such as colour, shape, and size (Wolfe, 1998), as well as motion (e.g. Bartram, Ware, & Calvert, 2003; Franconeri & Simons, 2003), increase the probability of a certain pre-attentive target reaching conscious attention. Therefore the subsequent active attention stage is only reached once the visual field has been analysed, leading to focused attention processing objects in serial (Duncan, 1984).

Many studies have further looked into what exactly causes VA to target an element in the visual field and have identified three different units triggering attention: spatial locations, certain features, such as colour or motion, and specific objects. Whereas neurobiological and psychophysical studies have taken a stand for VA being mainly location or space based (Bisley & Goldberg, 2003; Posner, 1980; Yantis et al., 2002), others have argued for it being feature-based (Giesbrecht, et al., 2003; Treisman & Gelade, 1980), or object-based (Ben-Shahar et al., 2007; Driver & Baylis, 1998; Duncan, 1984). Yet another approach based on findings from psychological (Awh & Pashler, 2000; Pylyshyn, 2003) and neurobiological (McMains & Somers, 2004) studies have provided converging evidence that attention can be simultaneously driven by many different factors, as opposed to one.

Finally, VA has long been viewed in the context of a top-down versus bottom-up theoretical dichotomy (Corbetta & Shulman, 2002; Egeth & Yantis, 1997; Pashler, Johnston, & Ruthruff, 2001; Wolfe, 1998) highlighting the difference between automatic and voluntary control of VA. However, more recent work by Awh and colleagues (2012) highlighted the insufficiency of this characterisation, as it fails to explain instances in which neither current goals (top-down), nor physical salience (bottom-up) of a symbol cause strong selection biases. As a result, authors argue for a more comprehensive framework to categorise attentional control that integrates three distinct categories of selection bias viewing VA as subject to a complex interplay between current goals, selection history and physical salience (Awh et al., 2012).

Overall, VA, broadly understood as a selecting mechanism to identify important stimuli in the visual field for further processing while at the same time ignoring other visual inputs, has been considered by different theoretical approaches. While these briefly discussed and largely binary concepts do not necessarily fit together or complement each other, they all explore conditions on which VA selection takes place.

2.2.1 Visual attention development

Research on the development of VA has investigated the maturation of different VA processes as well as their impact on individuals' learning and memory development (e.g. Markant & Amso, 2013; Ross-Sheehy, Oakes, & Luck, 2011; Shimi, Nobre, Astle, & Scerif, 2014). However, these developmental research studies are closely linked with research looking at attentional development in a broader sense in typically and atypically developing children, with Attention Network Theory (Posner & Petersen, 1990) being taken as a reference model by the majority of these studies (e.g. Huang-Pollock, Kratz et al., 2011; Mezzacappa, 2004; Mullane, Corkum, Klein, McLaughlin, & Lawrence, 2011; Nigg, & Halperin, 2006; Rueda et al., 2004; Sobeh & Spijkers, 2012; Weatherholt et al., 2006). The essence of Posner's theory is to characterise attention as consisting of three neural networks: alerting, orienting and executive networks. According to this widely shared theoretical account, different aspects of attentional networks are acquired at different speed. Whereas the development of some of them begins very early, reaching maturation before a child starts school, others develop in a more protracted manner, reaching maturation in middle (7 to 9 years of age) or late (10 to 12 years of age) childhood (Casey, Giedd, & Thomas, 2000; Posner & Rothbart, 2007; Ridderinkhof, van der Molen, Band, & Bashore, 1997; Rueda et al., 2004; Simonds, Kieras, Rueda, & Rothbart, 2007; Van der Molen, 2000). While this conceptualisation is therefore quite different from the VA approaches discussed in the previous section, making it in some ways hard to integrate these diverging theoretical stances, VA can be understood as a subtype of orienting, with orienting also involving other sensory attentions, such as auditory, or tactile.

Alerting, characterised as one's ability to reach and maintain an alert state (Posner & Rothbart, 2007), is suggested to take some time to develop, reaching a mature level not before the end of middle childhood (Mullane et al., 2016). Orienting on the other hand, also incorporating the ability to move towards a particular stimulus in the visual field, i.e. VA, seems to develop earlier, and is almost fully mature before children are 6 or 7 years of age (Wainwright & Bryson, 2002). It can further be described as being among the first active and coordinated exploration systems that develop in the early stages of life after birth (Amso & Scerif, 2015). Having said that, some specific aspects of VA orienting, such as the deployment of spatial attention, defined as the ability to direct attention to a certain location within the visual field, do not complete maturation before the end of late childhood (Iarocci, Enns, Randolph, & Burack, 2009). The third neural network in Posner's theory, the executive network, is closely connected with one's *voluntary* control of attention and has the key role to manage and resolve conflicts triggered by a simultaneous activation of correct and incorrect responses (Posner & DiGirolamo, 1998). Studies into the development of attention networks argue that infants as young as 6-7 months of age may already have acquired some fundamental elements of executive attention (Berger, Tzur, & Posner, 2006; Sheese, Rothbart, Posner, White, & Fraundorf, 2008). However, given that the prefrontal cortex of the brain executes these higher order processes of directing an individual towards focusing on long term goals (Posner & Rothbart, 2007), the executive network only reaches maturation in adolescence (Band, van der Molen, Overtoom, & Verbaten, 2000; Casey et al., 2000; Mullane et al., 2016). Finally, top-down executive function of VA – the ability of allocating attention voluntarily towards items in a goal-driven manner – develops into late adolescence and adulthood (Crone, 2009; Hwang, Velanova, & Luna, 2010). Crone, and colleagues (2006), using neuroimaging, highlighted that children between 8-12 years of age have poorer attention-related top-down frontoparietal modulation of visual regions. Based on this model, information coming in via VA could specifically be processed by the executive network to facilitate reading, for instance by enabling children to attend to print, in order to allow decoding and meaning making.

VA as a subtype of attention orienting has a strong impact on learning (Markant & Amso, 2013; Ross-Sheehy, Oakes, & Luck, 2011; Shimi et al., 2014), enabling the individual to focus on one specific area in the visual field while ignoring other previously attended locations (Golomb, Chun, & Mazer, 2008; Hollingworth, Williams, & Henderson, 2001). Consequently, these attention mechanisms play a vital role in encoding visual short term memory (VSTM), a memory system that stores visual information for a short period of time to enable further cognitive processing (Ross-Sheehy et al., 2011). Subsequently, an individual's VSTM abilities facilitate the integration of information gained from saccadic eye movements (Hollingworth, Richard, & Luck, 2008). Although VSTM capacities are rather limited in early infancy (Kaldy & Leslie, 2005; Ross-Sheehy, Oakes, & Luck, 2003) – with storage capacity being restricted to as little as one item of information at a given time – studies (Butcher, Kalverboer, & Geuze, 2000; M. H. Johnson & Tucker, 1996) have provided evidence that attention orienting can be found in infants as young as 3 months of age, in cases when external cues[1] are provided (Ross-Sheehy et al., 2011).

While the studies discussed above have been key in providing a foundational understanding of VA development in children, their theoretical foundation on Posner's ANT and therefore a framework of attention as a whole (Posner, Petersen, 1990), is considered as limitation that should not be ignored. Given the existence of more elaborated models of VA specifically, it is therefore argued that our understanding of VA development could be more fine-grained. Today, understanding the development of VA is probably more important than ever, with children's learning involving increasingly complex visual environments, especially when digital and non-linear elements are involved, with the latter including complex, hyperlinked text, as opposed to more linear print-based formats.

2.3 Bundesen's Theory of Visual Attention

A particularly prominent VA model is Bundesen's Theory of Visual Attention (TVA) (Bundesen, 1990, 1998). TVA is a mathematical model that defines VA as unifying the processes of attentional selection – choosing relevant information for further processing, and visual recognition – the ability to visually identify an item, which are engaged in a parallel processing 'race'. That is, caused by the limited storage capacity of VSTM, objects in the visual field are simultaneously recognized and selected, and compete against each other for representation in the VSTM store (Bundesen, 1990). TVA therefore offers an alternative interpretation to other theories considering these two processes as happening serially (Posner, & Rothbart, 2007) and separately, either viewing attentional selection as a requirement for recognition (Broadbent, 1958), or claiming recognition precedes selection (Deutsch & Deutsch, 1963).

In order to quantitatively investigate an individual's VA based on Bundesen's TVA, two experimental tasks need to be performed: a whole report (WR) task and a partial report (PR) task, designed to produce data that can be used to estimate five attentional

[1] These external cues guide attention to a stimulus location, before it is set to appear at that point.

parameters of the individual performing the task (Duncan et al., 1999). The parameters computed by TVA are: storage capacity of VSTM, visual processing speed, efficiency of attentional control, spatial bias of attention and visual perception threshold (Bundesen, 1990). Given that the TVA-based assessment method provides a specific measurement of five different cognitive abilities, has shown good reliability in previous studies, and can be adapted depending on the research interest and target group, Habekost (2015) concluded that TVA could be considered as a suitable theoretical foundation for an in-depth investigation of VA.

2.3.1 TVA-based visual attention assessment

2.3.1.1 The quantitative TVA model

According to TVA (Bundesen & Habekost, 2008), a visual object is stored in an individual's consciousness through encoding of this object's certain features, such as shape, colour or size, into the VSTM store. However, this VSTM store only has a very limited capacity (referred to as parameter K): Whereas healthy young adults can typically store 3-4 objects, K can vary from person to person. Subsequently, in order to reach conscious cognition, objects in the visual field are competing against each other during the encoding process. The main assumption of TVA is that whereas all objects in the visual field are processed independently and in parallel, these individual processes are not equal in speed, as for instance an object's position in the visual field or salience might make these processes faster or slower. So in instances when VSTM storage has not already reached its capacity, this process rate of an object determines its chances of successful encoding. An individual's VSTM processing speed (referred to as parameter C) is thus defined as the sum of processing rates for all objects in the visual field. Based on each object's individual processing rate, the share of the overall processing capacity that has been assigned to this object can be extrapolated. Since the calculation of different objects' attentional weights is incorporated into the TVA model, a comparison between each of the objects' attentional weights makes it possible to compute two further parameters: The first one is efficiency of top-down attentional control (referred to as parameter α), which defines the attentional weight that is put on a target versus a distractor object. The second one defines an individual's spatial attentional bias (referred to as parameter ω_{index}) by comparing the attentional weight that is given to objects according to their position in the visual field (e.g. top vs bottom or left vs right).

Finally, TVA model's fifth and last parameter t_0 stands for the time point at which objects start to have a higher than zero chance to be encoded into VSTM (Bundesen & Habekost, 2008).

Provided that specific conditions are given during the experiment, the TVA model as a mathematical model can give exact predictions of an individuals' attentional performance, seen as the sum of the above described parameters (Habekost, 2015).

2.3.1.2 Assessment Method

The method of TVA testing was initially designed by Duncan and colleagues (1999), who investigated patients' attention after suffering from a stroke. Since the late 1990s their experimental design has been widely used and has acted as a theoretical foundation for VA studies in different areas of research; it has hence been established as the standard way for TVA-based assessment (Bundesen & Habekost, 2008, 2014; Habekost, 2015). In order to compute the five parameters of attention as defined by TVA, an individual is tested on two different experimental tasks: WR and PR. However, not all studies based on TVA use both tasks – as further discussed in the subsequent section 2.4.1 –, but rather specific versions of the WR or PR task, depending on the studies' aims.

The WR can generally be described as a task where one or more simple visual objects (usually letters) are displayed on a screen for very short time periods (typically < 200 ms). The stimuli are then either followed by pattern masks, in order to avoid visual afterimage, or are alternatively followed by a blank screen. In case the latter option is chosen, the exposure duration is prolonged by an estimated constant (generally referred to as μ), therefore making the task easier for participants. In the experimental condition, the participant is asked to name as many stimuli as they can identify on a screen, without guessing. In order to ensure that participants are familiarised with the task, actual testing is preceded by a short practice test. Habekost (2015) argues that provided a participant is tested on a sufficient number of tasks and with different exposure times, the performance on the WR can be depicted in a curve, computed on basis of the collected data. This depiction shows a steady increase in the number of correctly reported stimuli with an increase in exposure duration, until VSTM capacity (K), i.e. the maximum number of stimuli that can be stored in one's VSTM, is reached (see Habekost, 2015, for a more in-depth description).

In comparison to the WR, the PR consists of two different stimuli types – targets and distractors – distinguishable through cues such as different colours. Subsequently, participants are asked to only report target stimuli while ignoring distractors. Individuals' performance on the task only displaying targets is then compared to the performance on tasks including both targets and distractors, which enables computation of the efficiency of top-down attentional control α. α represents the ratio of attentional weight that is given to a target or a distractor. (Bundesen & Habekost, 2008)

For the original TVA-based assessment introduced by Duncan and colleagues (1999), Kyllingsbæk (2006) developed a software program, designed to analyse WR and PR data, which was widely adopted by studies using TVA. Five years later, Dyrholm and colleagues (2011) made improvements on the software program, that enabled an increased precision in estimating the individual parameters, especially regarding a more robust fitting of the storage capacity parameter K.[2]

2.3.2 The benefits of using TVA- instead of an ANT-based assessment

Following Habekost (2015), a TVA-based assessment has many strengths, one key aspect being that the assessment tool is based on a general theory and model of VA, which results in the computed parameters representing distinct aspects of an individual's attentional function. TVA can be compared to another key attention test, based on a theoretical account discussed earlier in this section: the ANT test, developed by Fan and colleagues (2002) and grounded on Posner's Attention Network Theory (ANT), a framework of attention as a whole, defining it as an entity consisting of three independent neural networks (executive, orienting, alerting) (Posner & Petersen, 1990).

The key difference between both models (TVA & ANT) is their understanding of attentional processes: Whereas Posner characterises attention as a serial process comparable with a spotlight moving across the visual field (Posner & Rothbart, 2007), studies based on TVA provide evidence that lead to a contrasting hypothesis of stimuli being processed in parallel. Since the decision was made to ground the investigation of VA in young emerging readers conducted in this thesis on Bundesen's TVA, the

[2] More details on the TVA software package for analysing TVA data, as well as the reliability of the tests and other psychometric properties can be found in: Dyrholm and colleagues (2011), Habekost, Petersen, & Vangkilde (2014), Kyllingsbæk (2006).

following reasons led to the rejection of adopting Posner's ANT test (Fan, et al., 2002) for the purpose of this study:

First, Bundesen's TVA (Bundesen, 1990; 1998) was favoured over Posner's ANT because TVA explicitly focuses on VA parameters, whereas ANT provides a tool for a more comprehensive investigation across different attentional functions. This goes in line with Habekost, Petersen, & Vangkilde (2014) who claimed that TVA providing three parameters of VSTM capacity made the test especially suitable for testing individual's abilities in activities that require visual processing load, such as reading.

In addition, the fundamental differences between ANT and TVA in defining attention as either serial (ANT) or parallel (TVA) processes resulted in the development of two different tests to assess individuals' attention abilities. In comparison to the above described WR and PR tasks of TVA-based assessment, the ANT test (Fan et al., 2002) combines two different tasks: A flanker task (Erkisen & Eriksen, 1974) requires participant to block out conflicting irrelevant information and selectively attend to relevant stimuli. The spatial cueing task (Posner, 1980), on the other hand, looks at the ability of the participant to perform an attentional shift. Despite ANT assessments' wide application in over 60 studies (Habekost, Petersen, & Vangkilde, 2014), its test-retest reliability (Fan et al., 2002), as well as its internal reliability of scores gained within one test session has been questioned (Macleod et al., 2010). In addition, studies have found – albeit small – correlations between alerting and orienting (Lehtonen, 2008), as well as alerting and executive network scores (Fossella et al., 2002), raising questions about the independence of attention networks, a key element of ANT (Macleod et al., 2010). Habekost, Petersen, & Vangkilde (2014) directly compared TVA and ANT assessments and confirmed low internal and retest reliability scores of ANT tests, in contrast to TVA-based assessments' high internal reliability.

In addition to suggested shortcomings in ANT test regarding the reliability of the measures tested, TVA shows a clear advantage in terms of controlling for confounding factors: Whereas the ANT test asks participants to give responses by pushing buttons on a keyboard, TVA testing provides a range of five different attentional measures, that are not influenced by an individual's motor processes or speed of verbal response. Considering that the current research study targeted young children being 4-5 years of age, this fact was hoped to provide data that specifically targets VA.

Another advantage in the practical application of TVA-based assessment are that both tasks (WR and PR) are rather simple, not difficult to explain and require a relatively basic verbal response from the participant. In addition, the fact that all five parameters can be determined by the application of two straightforward tests increases the user friendliness of the tasks. Further, the possibility of adjusting TVA-based assessments according to the specific participant group, as well as different theoretical interests, makes it attractive for application in practice. Finally, a TVA-based assessment can be considered as a highly specific test with high overall reliability, as the correlation between parameters is rather low (apart from K and C), supporting suggestions that the five different parameters are measured separately (Habekost, 2015).

2.3.3 Variations of adapted TVA-based assessments

As already mentioned above, the 'original' TVA test design was initially designed by Duncan and colleagues (1999) and has been widely applied by subsequent studies grounded on Bundesen's TVA. Apart from providing estimations of all five parameters of VA as defined by TVA it mainly stands out due to its assessment procedure length. In search of best possible estimations, participants tested on the original assessment design perform between 252 to 672 trials across 12 different trial types on the WR, with variations including different display positions and exposure times (Duncan et al., 1999). The same logic applies to the PR: Here participants are tested on 512-672 trials across 16 different display types (Duncan et al., 1999).

The broad application of TVA-based attention assessments in a range of studies, led to Duncan and colleagues' (1999) experimental design being altered to either take account of the specific needs of a study's participant group, or to focus on investigating a specific hypothesis related to VA. Variants of TVA-based assessment includes exchanging letter stimuli with digits (Starrfelt, Habekost, & Leff, 2009), short words (Habekost et al., 2014), or faces (Peers et al., 2005), changing the way of displaying symbols – e.g. Habekost & Rostrup (2007), who displayed symbols in a circle as opposed to the usual square or line – or displaying just one stimulus to focus on visual processing speed (Peers et al., 2005). In addition, a CombiTVA was recently developed by Vangkilde, Bundesen, & Coull (2011) and introduced as a second paradigm for TVA-based assessment. This combined VA assessment has been applied in more recent studies (e.g. Dyrholm, Kyllingsbæk, Espeseth, & Bundesen, 2011; Habekost, Petersen,

& Vangkilde, 2014; McAvinue et al., 2012) and mixes WR and PR trials within one assessment.

In the field of reading research the majority of studies adopting a TVA-based assessment have made use of a simplified version to investigate children's VA skills in relation to their reading abilities or literacy development (Bosse & Valdois, 2009; Bosse et al., 2007; Prado, Dubois, & Valdois, 2007; Valdois et al., 2003). The simplified WR adopted in these studies can be described as a VA span task and consists of only 20 random five-letter strings (based on 10 consonants) displayed in the centre of the screen with a fixed exposure duration of 200 ms. In line with these alterations, the PR as a simplified target detection task comprises of 50 five-letter strings displayed for 200 ms, identical to those used for the WR. In addition, participants are asked to report one letter within the string, cued with a vertical bar. Compared to the original PR, this is rather different, as letters are presented in different positions across the screen there, with colour being used as a cue. However, it is important to note that as a consequence of these simplifications, there is no estimation of the five different parameters of VA based on TVA (Bundesen, 1990). Instead, a score based on the percentage of letters accurately reported on average in the WR, as well as the percentage of accurately reported targets in the PR is calculated.

Following an evaluation of these studies, the decision was made to also adopt a simplified TVA-based assessment for investigating VA skills of 4- to 5- year olds in this research project. However, after a close examination of the characteristics of the simplified test versions used in the studies listed above, it was felt that a slightly more in-depth version of the assessment could be created, providing more information, yet being suitable for the target age group. It was therefore decided to design a new simplified TVA-based assessment for the purpose of this study, with its development being described in more detail in the following chapter (Chapter 3).

2.4 Visual attention and reading development

As outlined above, Bundesen's VA model has acted as the theoretical foundation for many studies across different areas of research (Bundesen & Habekost, 2008, 2014; Habekost, 2015). Most of those conducted so far have been clinical studies aiming to investigate attentional deficits in the neurological and psychiatric field, such as: age related neurodegenerative diseases, neglect and simultanagnosia, neuropsychiatric or neuropaediatric disorders, or reading disturbances following a stroke (alexia) or caused by a developmental language disorder (dyslexia) (see Habekost, 2015, for a review on clinical TVA-based studies). Given this research project's focus on emerging readers, this section will focus on studies that investigated the links between VA and reading development, including studies on attentional deficits in relation to dyslexia, as well as normative studies on typically developing children and young adults.

Researchers who have employed Bundesen's TVA in their studies exploring reading development or reading abilities of different target groups, have found a correlation between an individual's VA and reading skills. Study results suggested that effective and successful reading can only be accomplished if an individual has sufficient attention, and within that VA skills, enabling them to focus on the content of a text, which in turn results in better reading performance through practice (Chen & Huang, 2014; Stern & Shalev, 2013). More specifically, successful reading, characterised as an effortful as well as volitional activity, depends on a range of attentional aspects: At first, individuals need to have the basic skill to orient themselves to visual text before guiding their attention towards new information. Whereas we tend to believe that our eyes are smoothly and steadily moving along the lines of a text while reading, quite the opposite is the case, with our eyes oscillating between engaging in short and quick movements, so-called *saccades* (Cassin & Solomon, 1990), and fixating a specific area of the text, so-called fixations (Reichle, Rayner, & Pollatsek, 2003). The majority of information is being processed in these short time spans (200-250 ms) in which the eyes remain stationary (Erdmann & Dodge, 1898; Huey, 1908). During the short saccadic eye movements (20-50 ms) on the other hand, only very little visual information is being processed (Ishida & Ikeda, 1989; Wolverton & Zola, 1983). Perceptual span (Rayner, 1998) or VA span (Bosse & Valdois, 2009; Bosse et al., 2007) refers to the sum of orthographic elements (such as letters, letter clusters, or syllables) which can be simultaneously processed within one single fixation. Research has consistently shown a close relationship between this span and the development of reading ability: In languages with left-to-right writing systems for instance, improvements in readings have been associated with accompanying increases in the amount of information processed regarding the number and nature of letters to the right of fixation (see Häikiö, Bertram, Hyönä, & Niemi, 2009; Rayner, 1998, 2008).

Such findings suggest that the act of learning to read itself may contribute towards the refinement of the VA skills so integral to the act of reading. However, in terms of other aspects of attention needed for successful reading e.g. orienting or sustaining attention, the development of these skills is subject to broader maturational influences, which are still in the process of being fully understood. For example, the maturation of the prefrontal cortex, a process that extends into adolescence, enables young people to increasingly exert cognitive control over their attention (Casey et al., 2000), enabling them to develop strategies for reaching future goals, instead of focusing on immediate gratification (Posner & Rothbart, 2007). These processes, also referred to as executive processes, are not only key for ensuring well-functioning memory skills and learning, but also for the successful acquisition of academic skills (Checa, Rodriguez-Bailon, & Rueda, 2008; Posner & Rothbart, 2007; Rueda, Posner, & Rothbart, 2005).

VA hypothesis representatives argue that reading ability is determined by VA span, regardless of an individual's phonological skills in both typically developing children (Bosse & Valdois, 2009; Valdois et al., 2003; Valdois, Bosse, & Tainturier, 2004; van den Boer, de Jong, & Haentjens-van Meeteren, 2013), and children with dyslexia (e.g. Bosse et al., 2007). The VA hypothesis has its roots in the multiple-trace memory model (Ans, Carbonnel, & Valdois, 1998; Valdois et al, 2004), and is defined as entailing two successive reading processes: In a first step, the reader tries to process words as one entity in a so called *global procedure*. Only when this step fails, the *analytical procedure* is called into action, which identifies word's orthographic units by transferring related phonological outputs into short-term memory (van den Boer et al, 2015). VA span is therefore not only considered to be a unique predictor of spelling skills and orthographic knowledge, but is also regarded as having the ability to predict word reading fluency in beginning and advanced readers (van den Boer et al., 2015; Bosse et al., 2007; Valdois et al., 2003; 2004).

TVA-based studies investigating the links between VA abilities and reading development or reading impairments (developmental dyslexia[3] and acquired alexia[4]) respectively, have mainly focused on an individual's basic visual efficiency of stimuli

[3] Dyslexia is characterised as a developmental learning difficulty affecting an individual's ability of word reading and spelling (Rose, 2009).
[4] TVA-studies that have further investigated the syndrome of acquired alexia and its impacts on an individual's reading ability are for instance Habekost and colleagues (2014), Starrfelt and colleagues (2010; 2009), and Duncan and colleagues (2003).

processing (usually letters), which is represented by the parameters of VSTM capacity (K) and visual processing speed (C). While some of them have applied the original, full TVA-based assessment as developed by Duncan and colleagues (1999), the majority adopted a simplified version of the assessment and have been conducted in the area of developmental dyslexia research, looking at the relationships between impairments in visual processes and reading development.

So far, three studies investigating the links between VA and reading in individuals with developmental dyslexia have applied the original TVA-based assessment. Dubois and colleagues (2010) explored the relationship between dyslexia and VA skills in their small-scale study on two dyslexic boys aged 9. The research yielded interesting results, finding deficits in VSTM storage capacity (K) in both participants, as well as deficits in visual processing speed (C) in one of them (Dubois et al., 2010). These initial results were supported by a comparatively larger study conducted by Bogon and colleagues (2014), who investigated a group of twelve 10-year old children with dyslexia. Study results not only revealed that participants had lower K and C on the whole, but also that K correlated with children's reading performance (Bogon et al., 2014). These two studies of dyslexic young individuals seem to suggest that some of those children experiencing difficulties in literacy acquisition also have deficiencies in VSTM storage capacity and visual processing speed. Finally, Stenneken and colleagues' (2011) conducted a study on 23 young dyslexic adults in higher education. Their study results revealed that highly functioning adults with dyslexia seem to only have remaining deficits in VA speed, but not in VSTM capacity (Stenneken et al., 2011). Overall, these studies suggested that VA processing speed and VSTM capacity appear implicated in developmental dyslexia. However, it needs to be considered that none of the three studies discussed above included a control group, raising questions regarding how children's deficits in K and C were determined. As a result, mixed findings as to the relative role of each of these parameters, were potentially due to lack of control groups, alongside small sample sizes, or variations in participants' ages.

In comparison, four studies considering dyslexic and/ or normative groups of children (Bosse & Valdois, 2009; Bosse et al., 2007; Prado, Dubois, & Valdois, 2007; Valdois et al., 2003) used the adapted and simplified version of the WR and PR of TVA-based assessment as outlined in Section 2.3.3 to accommodate for the relatively young age of their participants. Rather than providing K and C, the simplified assessment comprised of a VA span task, yielding the percentage of letters accurately reported on average in the WR, supplemented by a target detection task, yielding the percentage of accurately reported targets in the PR.

In the small-scale study conducted by Valdois and colleagues (2003) which compared the reading abilities of two French dyslexic teenagers aged 13 and 14, the simplified TVA-based assessment was conducted for the first time. The results showed that whereas one participant mainly seemed to have phonological deficits but otherwise good VA skills, the second participant struggled to process letter strings, while having no phonological disorder. This study revealed that phonological and VA deficits can potentially occur independently in cases of developmental dyslexia (Valdois et al., 2003). Similar conclusions were drawn by Bosse and colleagues (2007): Their study comprising of two experiments, one conducted with 133 French native speakers, and another one conducted with 52 British native speakers, included dyslexic and non-dyslexic students between the age of 9 to 16. Study results in both groups supported the visual span hypothesis, suggesting that VA was a predictor of reading skills, alongside phonological skills. In addition, the study on the English native speakers revealed that the correlation between VA span and reading performance remained significant even after controlling IQ, vocabulary and single letter identification skills, verbal fluency, and phonemic awareness. In line with Valdois and colleagues (2003), the study thus revealed that dyslexic students had either deficits in phonological skills or in their VA skills, which supported the idea of seeing developmental dyslexia as multi-factorial. Both studies could therefore be seen as key studies of the VA span deficit hypothesis.

Prado and colleagues' (2007) investigated 28 10- to 11-year old French students, comparing 14 dyslexic participants with an identified VA span reduction with 14 typically developing readers. Dyslexic and non-dyslexic students were tested on their VA span and compared regarding their performance on a visual search task – requiring to count the number of ‘R’s occurring in a four line long text displayed on a screen (by means of an eye tracker) – and their text reading abilities. Results suggested that a child’s VA span could be directly related to the number of letters that were simultaneously processed in reading. Finally, a large scale cross-sectional study of typically developing children was conducted by Bosse & Valdois (2009): 417 French students in Grade 1 (6- to 7- year olds), 3 (8- to 9- year olds), and 5 (10- to 11- year olds) were tested to explore the relationship between an individual’s VA span and reading development in relation to years of formal reading instruction. The result of this study revealed that VA span was a predictor for decoding and significantly influenced irregular word reading. Furthermore, authors concluded that an individual's VA span impacted on reading performance from the start of literacy instruction, interpreted as an indicator for having a long-term influence on an individual's acquisition of orthographic knowledge (Bosse & Valdois, 2009).

Apart from these four studies, two additional studies conducted by van den Boer and colleagues (2013; 2015) made yet another small change to the simplified TVA-based assessment. In their first study (van den Boer et al., 2013), the authors specifically looked at the impact of VA on the length effect, defined as a prolonged reading latency correlating with increase in word length. Adopting the WR of the simplified TVA-based assessment, i.e. VA span task, as reported by Valdois and colleagues (2003), authors tested the ability of 184 children in Grade 2 (7- to 8- year olds) to report a string of 3-5 letters correctly from left to right. Consequently, a slightly more advanced score calculation was also performed. Researchers not only looked into proportions of correctly identified letters, but also at the order of reported letters, arguing that the 'correct' (i.e. left to right) report of letters was essential in reading (van den Boer et al., 2013). Results of this study suggested that children's ability to read words of an increased length was predicted by their VA span and phonological awareness (van den Boer et al., 2013). In the second, more recent study (van den Boer et al., 2015), the same adapted version of the simplified TVA-based assessment was employed. Van den Boer and colleagues looked into whether the predictive character of VA span on reading performance independent from phonological awareness – as being promoted in the four previously conducted studies in the UK and France (Bosse & Valdois, 2009; Bosse et al., 2007; Prado et al., 2007; Valdois et al., 2003) – also holds true for Dutch, an orthographically more transparent language. In two sub-studies, a total of 453 students between 8 and 11 years of age participated in the study. Based on the analysis that looked at proportions of correctly identified letters and at the order of reported letters, study results showed that VA span independently contributed to reading fluency and spelling performance in an orthographically transparent language in both beginners and more experienced readers, independent of rapid naming and phonological awareness (van den Boer et al., 2015). Authors further argued that the found relationship between VA span and reading/spelling could be explained through the development and application of orthographic knowledge. At the same time, performance on a VA task adopting letters as target symbols might also reflect someone's ability to mutually activate phonology when encountering orthography and vice versa.

Finally, one study (Lobier et al., 2013) was identified that integrated both elements of the original TVA-based assessment (Duncan et al., 1999), with the simplified VA span test (Valdois et al., 2003). Lobier and colleagues (2013) investigated the relationship between VA span and reading speed in 49 typically developing 8- to 9-year old children. As well as conducting a VA span assessment (e.g. Bosse & Valdois, 2009; Valdois et al., 2003), participants were also tested on a WR task, in which 3 or 6 letters were displayed in a circle. Students performed a total number of 150 trials, divided into 3 blocks that were carried out between other experimental tasks. Study findings suggested that VA span influenced the effect of visual processing speed on reading speed, concluding that a limited VA capacity could constrain reading speed in elementary school children (Lobier et al., 2013). Lobier and colleagues' (2013) study could therefore be seen as an alternative possibility to use TVA-based assessment with young participants by adjusting the assessment procedure according to the needs of the target group, without fully refraining from a more in-depth analysis based on TVA parameters.

In summary, the seven above discussed studies provide essential contributions for the VA span deficit hypothesis in young children and adolescents. VA span was not only considered as a unique predictor of spelling skills and orthographic knowledge but was also seen as having the ability to predict word reading fluency in beginning and advanced readers (Bosse et al., 2007; Bosse & Valdois, 2009; Prado et al., 2007; Valdois et al., 2003; van den Boer et al., 2013; van den Boer et al., 2015). In addition, van den Boer and colleagues (2015) stated that an individual's performance on a VA span task using letters as targets could also give evidence about someone's ability to mutually activate phonology at the same time as encountering orthography and vice versa.

The studies above were conducted by advocates of the VA span deficit hypothesis, which pointed out the possibility of an individual's VA span as potentially important predictor of reading performance (Franceschini et al., 2012). With an increasingly rapid move away from standardised typographic formats of printed books (Picton, 2014), it is argued that individual variation in VA skills might be an increasingly important moderator of reading performance. Equally, no study to date has attempted to look at possible links between children's VA span at school entry and their exposure to digital devices prior to school entry. In the following section, the role of VA as a potential digitally-relevant precursor skill of reading will be further highlighted within the discussion of how reading on screen changes demands on attention.

2.5 Reading on screen is changing the demands on (visual) attention

The emergence of digital technology, such as computers, tablets, or smartphones has not only had an impact on our day-to-day lives but has also changed the way we engage with written information, as digital devices have made it possible to change the way text is displayed according to one's individual preferences and needs. With new digital device features being frequently introduced onto the market – one example being enhanced electronic books (e-books), entailing interactive features, such as games, narration and other embedded media –, researchers, teachers and parents are increasingly interested in finding answers on how digital technologies are influencing an individual's ability to engage with written text. A survey conducted by Hayler (2011) yielded interesting results, reporting that the way text is presented had an impact on adults' level of engagement with the text content, with convinced e-book users claiming that they would still prefer print in instances when they wanted to engage in sustainable reading. While these reported levels of engagement might be caused by complex motivational factors, converging research evidence from cognitive science (e.g. Koriat, Ackerman, Adiv, Lockl, & Schneider, 2014; Kornmann et al., 2016; Montani, Facoetti, & Zorzi, 2014), as well as typography (Dyson, 2004) suggested that an individual's cognitive profile might also influence preferences to read across different modalities of text presentation. In addition, new technologies have transformed teaching and learning in educational institutions, with many primary and secondary schools in the UK and elsewhere adopting tablet technology for classroom instruction. Considering preliminary findings about the impact of digital technology on adults' engagement with written content, questions arise regarding the impact of new technologies on children's literacy acquisition. While this area is still largely awaiting research, the purpose of this section will be to consider how digital reading in a more general sense and in comparison to print reading is changing the executive function demands of text processing, specifically focusing on attention.

While it is not claimed here that other more linguistic reading processes associated with e.g. word recognition and syntactic parsing do not differ in any way in print and digital reading, it is contended that digital reading makes particular, increased demands on executive processes. The term ‘digital reading’ can refer to any engagement with a large range of text formats including books, newspapers, magazines, websites, blogs, and forums. Some of these formats are ‘fixed’ in the sense that the reader can make only minor, if any, adjustments to them in terms of appearance, for instance via sizing. In fixed formats, readers typically progress through the text and engage with content in an order determined by the author. In contrast, less ‘fixed’ formats such as websites may contain hyperlinks which enable readers to engage with content according to their needs, motivations or knowledge at that particular point in time, meaning that a reader may experience the same overall content in different ways depending on their orientation and approach in a specific reading session. The flexibility inherent in hyperlinked text also means that different readers may engage with the content in different ways, rendering an overall text structure that may be more or less similar to that originally envisaged by the author. Of course, digital reading may involve engaging with more than one text or source in any reading session.

In comparison to the amount of research on traditional print-based reading, not much research on reading across different digital modalities is available today, with only a few research studies focusing on children in particular. In addition, knowledge and understanding of the development of cognitive processes related to reading, such as attention, is only emerging. However, when contrasting traditional print with digital text, two key differences can be identified that could potentially affect attention: The first difference lies in the way text is formatted and visualized. Traditional print text is characterized by a standardized way of text presentation, with publishing houses using standard page sizes, font sizes and letter-spacing parameters that have been thought to be comfortable for the majority of readers. Digital text on the other hand is presented with the use of software that enables to modify print, such as type of font, page size, spacing, and brightness (de Leeuw, 2010; Dyson, 2004; O’Brien, Mansfield, & Legge, 2005) in a variety of ways and across a range of different page formats and text window sizes (Schneps, Thomson, Sonnert, et al., 2013; Schneps, Keeffe, Heffner-Wong, &

Sonnert, 2010; Warschauer, Park, & Walker, 2011). The second difference between print and digital text lies in the presentation of the text: While text in paper books is typically presented in a linear format, digital text is often non-linear and multimodal in nature, meaning that it integrates words, images and sounds simultaneously, arousing a range of senses during the process of constructing meaning (Flewitt, 2011; Marsh, 2004, 2006). Further, these features unique to digital text, such as hyperlinks, allow the reader to interact with the text in a variety of ways, creating different reading experiences for each reader (Eshet-Alkalai, 2004).

To further investigate the impact of digital text formatting on attention, some studies have looked into the effects of modifying fonts (de Leeuw, 2010; O'Brien et al., 2005), changing page formats (Schneps et al., 2010; Schneps, Thomson, Chen, Sonnert, & Pomplun, 2013; Warschauer et al., 2011), or guiding reading dynamics in different ways (Arditi, 1999; Geiger & Lettvin, 1987). Overall, the target group of these studies has largely been individuals identified as struggling to read traditional print. A series of studies by Schneps and colleagues (Schneps, Thomson, Sonnert, et al., 2013; Schneps et al., 2010; Schneps, Thomson, Chen, et al., 2013) for instance, investigated how text displayed on different sized screens, as well as the resulting variations in line widths had an impact on the comprehension of dyslexic adolescent readers. Yielded results suggested that some participants' reading comprehension and fluency benefitted from text being displayed on the screen of smaller smart-phone sized devices, as this reduced the amount of visual text to be processed within any given moment (Schneps et al., 2010; Schneps, Thomson, Chen, et al., 2013). Converging evidence was found by eye-tracking studies (Beymer, Russell, & Orton, 2005; Paterson & Tinker, 1940) suggesting that fewer regressive saccades, defined as eye movements moving backwards along the text line, as well as shorter reading time were found in some participants who read text displayed in short lines. A possible explanation for these results was provided by Schneps and colleagues (Schneps, Thomson, Sonnert, et al., 2013; Schneps, Thomson, Chen, et al., 2013): Authors suggested that the short line width helped the reader with comprehension when fixating a word through reducing the chance that the previous word of fixation was in close proximity to the present fixation point. Thus, findings highlighted the potential of digital technologies' unprecedented opportunities to tailor text in accordance to an individual's VA profile, potentially leading to an overall improvement in literacy skills.

The above mentioned studies, as well as work by other research groups (e.g. Zorzi et al., 2012) found evidence that an increased inter-letter spacing has a positive impact on the decoding and comprehension skills of dyslexic readers. The broad availability of digital devices and thus digital text today has made it much easier to help struggling readers by adapting the spacing between letters. The advantages for struggling readers of both increased inter-letter spacing and a smaller text window can potentially be explained by the phenomenon of visual crowding (Schneps, Thomson, Chen, et al., 2013), something that can have a particularly deleterious impact for struggling readers (Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009; Moores, Cassim, & Talcott, 2011; Spinelli, De Luca, Judica, & Zoccolotti, 2002; Zorzi et al., 2012). Following Pelli and colleagues (2007), visual crowding describes the phenomena of someone experiencing difficulties in recognising individual symbols, letters or other distinct objects, in instances when they appear in a clutter. Whilst the causes of crowding for struggling readers are still being fully elucidated, psychophysical studies support the notion that crowding is intimately linked to the allocation of spatial attention, with spatial attention in the case of crowding being related to the density of visual information within a certain visual window (Petrov & Meleshkevich, 2011). With digital design features such as altered letter-spacing and altered text-window size thus allowing to accommodate for individual differences in basic attention processes, many other opportunities for supporting attention, as opposed to challenging it, may exist.

Regarding the proliferation of hypertext, the ubiquitous presence of blue, underlined words, used to signal hyperlinks, has not only implications for executive control and working memory – discussed in more detail in the review by DeStefano & LeFevre (2007) who claimed that engaging with hypertext was likely to be more demanding for working memory when compared with traditional linear reading – but also for more basic attentional implications. Eye-tracking research by Fitzsimmons (2017), for example, has shown that the mere presence of single coloured word within a written sentence will reduce the likelihood that the word is skipped (as long as the colour does not have reduced contrast, e.g. grey – with blue not appearing to reduce contrast, Gagl, 2016). When readers know that a coloured word is explicitly a hyperlink that can be clicked in order to provide more information, gaze fixation times show further attentional modulation. In an interesting follow-up study using custom-made hypertext, Fitzsimmons (2017) found that gaze fixation time was increased especially when low frequency words contained a hyperlink. Fitzsimmons interpreted this behaviour as reflecting re-evaluation of the prior content, given the potential mismatch between the presence of a hyperlink, suggesting importance, and location of the hyperlink on low frequency and thus potentially less consequential words. This example, however, also shows the close interdependence between lower level cues to information salience and higher levels of both linguistic and meta-cognitive processing.

However, and rather unsurprisingly, the flipside of these many possibilities coming along with the development of digital technologies is that they also challenge the individual to resist certain distractions, in many cases leading children's attention away from the actual text (Salmon, 2014). As well as being able to attend within the timeframe of milliseconds and seconds, reading text on digital devices increases even more the already high demands on an individual's ability to sustain their attention. One example is provided by Krcmar & Cingel's (2014) study with 70 child-parent dyads, with children being 2-5 years of age: Study findings showed that children's reading comprehension was worse in instances when e-books with interactive features were used, compared to instances when traditional print books were read out aloud. As a result, an increasing number of research has been exploring ways of how to support individuals in allocating their cognitive choices to avoid experiencing information overload or challenges in relation to cyber mobility or collaboration (McCrickard, Czerwinski, & Bartram, 2003; Roda & Thomas, 2006; Vertegaal, 2003). In addition, other studies have shown that interruptions caused by reading and working on or with digital devices do not only have a negative impact on an individual's engagement with the main task (Franke, Daniels, & McFarlane, 2002; McFarlane & Latorella, 2002; Nagata, 2003; Speier, Vessey, & Valacich, 2003), and provoke mental strain (Bailey, Konstan, & Carlis, 2001; Zijlstra, Roe, Leonora, & Krediet, 1999), but also increase the load on attention and memory (Gillie & Broadbent, 1989). Interestingly, these interruptions seem to be especially severe when users are working or reading on small devices, such as mobile phones (Nagata, 2003). As a result, some initial research has already been carried out to explore possible solutions: Roda (2010) for example emphasised the need for introducing interruption management systems. The author argued that these systems can assist the individual with making decisions about the relevance of additional information available on a currently attended topic by enabling them to individually adjust the modality and time of notifications.

Finally, apart from effects that formatting possibilities and multimodal features have on reading performance on digital devices, initial research on how the haptic dimension of holding a device impacts attention, and subsequently an individual's reading performance has been conducted by Schneps and colleagues (Schneps, Thomson, Sonnert, et al., 2013; Schneps, Thomson, Chen, et al., 2013). Based on previous studies it can be argued that holding digital reading devices, such as tablets or smartphones during usage, causes close proximity to the hand which positively impacts on an individual's attention (Reed, Grubb, & Steele, 2006). Furthermore, this haptic dimension is suggested to prevent visual perception from distracting attention, facilitating individuals attentiveness to detail and helping them to guide oculomotor tracking (Davoli & Brockmole, 2012; Davoli, Brockmole, & Goujon, 2012). Schneps, Thomson, Sonnert and colleagues' (2013) study on dyslexic adolescents produced surprising results, suggesting a correlation between VA span and holding a device in the hand: While struggling readers with low VA spans benefitted from holding a reading device in their hands, it had the opposite effect on individuals with higher VA scores, who performed poorly in this condition (Schneps, Thomson, Sonnert, et al., 2013). Further investigation is therefore needed to reach a better understanding of how the haptic dimension of holding a device in one's hands impacts attention, and subsequently an individual's decoding and comprehension.

In sum, it has become clear that the presentation of text in digital formats is altering how we attend to the written word in ways that we are only just beginning to understand. While it was highlighted in earlier sections of this chapter that someone's VA skills have an impact on their reading, it can be suggested that the relationship between these two components becomes even more relevant when digital text is involved. The range of interactive features in digital text, for instance hyperlinks, provide new external markers of text salience that are likely to create both affordances and challenges to a reader's attentional capacities. Some aspects of digital text might therefore make it harder for some readers, while others appear to have particular attentional benefits for struggling readers, for example by reducing crowding effects more easily. However, more research is needed to fully understand individual differences in how attention and technology interact. With different formats of digital layout and the non-linearity of information causing more variation on the attentional demands of reading, it might be that in turn, a person's VA span capabilities contribute more towards the variance in reading performance. The discussion above has therefore further emphasised the need to investigate VA as a potential digitally-relevant precursor skill of reading in young emerging readers – the main aim of this research study.

2.6 Children's exposure to digital devices in the early years

The emergence of digital technology has not only had an impact on the way we engage with written information as outlined in the previous section, but also brought about children being more and more exposed to digital devices before entering school (Neumann, 2014; Northrop & Killeen, 2013; Ofcom, 2014). This has been exemplified by the report of a steady increase in the use of e-books in early childhood settings, as well as home environments (Bus, Takacs, & Kegel, 2015; Korat, Shamir, & Heibal, 2013; Miller & Warschauer, 2014). Indeed, with digital technology having become an integral part of homes and educational settings, Thomson and colleagues (2018) pointed out that the question is no longer *if* a child should have access to digital devices, but rather *in what manner* and *how much*.

2.6.1 The impact of children's exposure to digital devices on emergent literacy

The fact that children are exposed to digital technology from a young age, has resulted in an interest to explore whether the use of digital devices in the early years can be beneficial or disadvantageous for the development of children's emergent literacy skills. There has been wide-shared agreement that home literacy environment, consisting of a range of different literacy related aspects, such as parental book reading, story-telling, singing songs, or the number of books at home (Johnson et al., 2008; Rodriguez & Tamis-LeMonda, 2011; Wood, 2002), has a positive impact on the development of children's early literacy and language skills (Burgess, 2011; Foy & Mann, 2003; Passenger, Stuart, & Terrell, 2000; Phillips & Lonigan, 2009; Rodriguez & Tamis-LeMonda, 2011; Wood, 2002; Wood & Terrell, 1998b, 1998a). Children exposed to a wide range of vocabulary when engaging in home literacy activities for instance have better vocabulary skills to those children who have not (Lawrence & Shipley, 1996). Further, children's experience with enriched literacy-related activities at home also has a positive impact on their literacy knowledge, as well as on their decoding skills (Farver, Xu, Lonigan, & Eppe, 2013; Niklas & Schneider, 2013). Based on the fact that today knowledge and skills needed to acquire literacy skills are gained through both, interactions with traditional print books and digital tools, like tablets or smartphones from a very young age, it is therefore argued that the definition of home literacy environment needs to be updated by also considering children's early engagement with digital text.

Adopting a sociocultural perspective, first interactions with digital and non-digital text are arguably very similar and can be described as being a mix of both, independent experiences and interactions mediated by adults (Bus et al., 2015; Neumann & Neumann, 2014). To acquire literacy knowledge these shared experiences between a child and an adult are particularly important, with the latter taking an active role to direct a child's attention to the purpose of print and to share the knowledge of the links between letters and sounds, as well as print and meaning (Sénéchal, Lefevre, Thomas, & Daley, 1998). The need for explicit adult scaffolding behaviour in the early years to promote children's literacy knowledge is further highlighted by research studies investigating shared storybook reading. These studies revealed that during shared reading children would attend to the print only if an adults explicitly drew their attention to it or if they had some prior print knowledge (Evans & Saint-Aubin, 2005; Evans, Saint-Aubin, & Landry, 2009). Children's engagement with digital text is further scaffolded technically (Yelland & Masters, 2007), since digital devices such as e-books offer features like 'read alouds', highlighting words that are read at a given moment and thus guiding the child through the text (Labbo & Kuhn, 2000). This further suggests that engagement with digital text has the potential to support children in their acquisition of early literacy skills.

When considering the range of digital technology used for literacy activities in the early years, it becomes clear that in particular portable electronic devices, such as tablets, e-readers or smartphones, have been adopted for early literacy learning, with their touch-screen user interface considered to be particularly suitable for young children (Couse & Chen, 2010; Merchant, 2015). Children's learning in the early years often happens through multisensory exploration, which becomes more and more efficient before the start of formal schooling (Scofield, Hernandez-Reif, & Keith, 2009; Thelen, 2000). Further, studies (Bara, Gentaz, & Colé, 2007; Kalenine, Pinet, & Gentaz, 2011; Möhring & Frick, 2013) found evidence that a combination of touch and visual information, so called visuo-haptic interaction, enhances children's learning over simply watching. However, while these features make e-books engaging and therefore appealing for young children, there is also the risk that they interfere with their ability to be fully immersed in the story and thus to follow the narrative (Holland, 2009; Mangen & van der Weel, 2017; Ryan, 2001, 2015). Interactive features, such as pop-up dictionaries or skill-based games are therefore often referred to as “inconsiderate features” (Labbo & Kuhn, 2000), as they have a negative impact on children’s story comprehension. Accordingly, one research study conducted by Parish-Morris and colleagues (2013) on parent-child interactions with e-books yielded mixed results. While some observations revealed positive shared e-book reading experiences that entailed dialogic reading exchanges, other observed parent-child interactions with e-books were characterised by arguments about device control, resulting in parents devoting much more time to managing a child’s behaviour and technology use (Parish-Morris, Mahajan, Hirsh-Pasek, Michnick Golinkoff, & Fuller Collins, 2013).

While there are therefore potential challenges when using e-books for literacy activities, well-designed e-books with certain properties have the potential to support children in their development of emergent literacy, for example by providing definitions for keywords, or highlighting text as the story is read (e.g. Anderson-Inman & Horney, 2007; Dalton & Proctor, 2008). Multimedia features like sound and visual animation typically entailed in e-books, are further argued to potentially compliment the story line and thus support story comprehension (Mayer, 2005), while at the same time scaffolding the development of different reading skills, vocabulary learning, and relieving executive function demands (see Bus et al., 2015). Findings from Ihmeideh (2014) strengthened this argument, suggesting that e-books and other forms of digital text promote early literacy skills, such as phonological awareness, alphabetic knowledge or vocabulary in young children. Results of studies looking at the effect of e-book interventions on children’s emergent literacy have been mixed (Takacs, Swart, & Bus, 2015). When comparing shared reading experiences with print books versus e-books, findings suggested that adults seemed to scaffold reading more in the e-book context, compared to the print book condition (Korat et al., 2013; Rvachew et al., 2017). Furthermore, results from Rvachew and colleagues' (2017) study revealed that while children’s post-reading comprehension and story retell skills were equivalent in the e-book and print book condition, children in the e-book cohort had significantly better emergent literacy performance post intervention than those in the print book cohort.

However, while converging evidence was found by Korat and colleagues (2013), as well as Lauricella and colleagues (2014), authors pointed out that there was no difference between print and digital books in the sense that engagement with both supported children's emergent literacy. This finding is further related to Levy's (2009) study illustrating a transfer of knowledge between digital and non-digital text, when exploring how children use their phonological decoding strategies to read print, as well as on screen. Based on her study, the author concluded that there was a need to provide children with a range of opportunities to engage with digital technology, in order for them to be supported in developing different strategies of making meaning of digital and non-digital text (Levy, 2009).

Finally, studies looking into possible reasons for the positive or negative impact of digital devices on early literacy skills suggested that this is determined by children's age and skill level, alongside the quality of technology they engage with (Lewin, 2000; Littleton, Wood, & Chera, 2006; Plak, Merkelbach, Kegel, van IJzendoorn, & Bus, 2016; Russo-Johnson, Troseth, Duncan, & Mesghina, 2017; Smeets & Bus, 2012). Thus, rather than discussing the benefits of either print or digital text presentation for children's reading, Zipke (2017) argued for the need to focus on the specific elements and features of a digital book to understand their effects on young children's reading experience and to encourage literacy learning.

Overall, children's engagement with digital devices, such as tablets in the early years has been suggested to have a potential positive effect on their emergent literacy skills, including their knowledge of print concepts, letters and words (McManis & Gunnewig, 2012). Further, the biggest advantage and potential of digital technology, such as e-books for supporting literacy skills in young children has been suggested to lie in their flexible and malleable nature (Barzillai, Thomson, & Mangen, 2018). However, the positive contribution of digital devices to the development of phonological awareness, letter-sound knowledge, or word recognition in early childhood crucially depends on the design and quality of digital text and its adequate use (Bus et al., 2015; Labbo & Kuhn, 2000), on children being encouraged to actively engage with print (Rvachew et al., 2017), as well as on the reading experience being led and instructed by an adult (Neumann & Neumann, 2014). Finally, it is also dependent on an individual's skill level, as the use of e-books offers both, promise and risk to readers with different characteristics, which also provides new opportunities to individualize learning

(Barzillai et al., 2018). While evidence has therefore been found suggesting potentially beneficial effects of digital device use on traditional predictor skills of reading, this study wanted to specifically look into the impact of digital device use in the early years on children's VA skills, explored here as a potential digitally-relevant predictor skill of reading.

2.6.2 Parental reports and children's self-reports on digital exposure in early childhood

When reviewing available literature about young children's exposure and interaction with digital devices in the early years, three different approaches to investigate this topic could be identified. First, there have been small to medium sized (quasi-) experimental studies looking at particular scenarios, for instance how children interacted with technological toys and resources in home settings (McPake, Plowman, & Stephen, 2013; Stephen, Stevenson, & Adey, 2013), what effects viewing certain programs had on preschool children's behaviours (Coyne et al., 2017), or how children engaged with technology-enhanced books in comparison to more traditional print presentations (see Bus et al., 2015, for a review). Second, small-scale qualitative research studies targeting parents of preschoolers have been conducted to explore children's screen-viewing behaviour across different devices (Bentley, Turner, & Jago, 2016), or to investigate how parents mediate children's digital device use at home (e.g. Zaman, Nouwen, Vanattenhoven, de Ferrerre, & Looy, 2016). Third, small to large national and international quantitative surveys have been exploring children's engagement with digital technology through parental reports (Kostyrka-Allchorne, Cooper, & Simpson, 2017; Kucirkova & Littleton, 2016; Lauricella, Wartella, & Rideout, 2015; Palaiologou, 2016), as well as through combining both, parental and children's self-reports (e.g. Ofcom, 2014; Scholastic, 2014, 2016). The study here, aiming to collect data from a sizable sample of families, as opposed to a small subgroup, used a survey method for data collection. Given this decision, findings from previous survey data will be discussed in more detail below.

The Ofcom report (2014) explored children's media use, understanding and attitudes in a general sense and drew on 9 previously conducted large-scale UK surveys with more than 680 participants in each study. The report targeted parents, as well as children and young people aged 5-15, with a subgroup of parents also being specifically interviewed about the media use of 3- to 4- year olds. When specifically focusing on the youngest age group included in the study from 2014, media consumption indicated that 3- to 4- year olds spent more time watching television (roughly 14 hours per week) than engaging in other media related activities, such as being on the internet, gaming, or listening to the radio (Ofcom, 2014). Converging evidence showing that children's media use in the early years was dominated by watching TV or DVDs was found by a US large scale study with 2,300 parents of 0- to 8- year olds (Lauricella et al., 2015), by a multinational European study involving 540 families (Palaiologou, 2016), as well as by a recent smaller UK survey of 90 parents of 3- to 6- year olds (Kostyrka-Allchorne et al., 2017). However, while authors from the UK study also reported that children would currently enjoy watching TV the most in comparison to engaging with other digital devices, they also drew attention to the fact that there might be a change in young children's consumption patterns in future, with tablets having become equally preferred as more conventional DVDs (Kostyrka-Allchorne et al., 2017). Lauricella and colleagues' (2015) US based study further investigated links between children's exposure to digital devices and parental digital device use and attitudes. The results showed that children whose parents who spent more time watching TV or using a tablet and had more positive attitudes towards the impact of media, spent much more time watching TV or using tablets in comparison to children whose parents who reported less media use and were more concerned about the impact of media (Lauricella et al., 2015). Interestingly however, this observation was not true for parent-child dyads with children under the age of 2. Here no significant relationship between parent attitudes and children's tablet use was found (Lauricella et al., 2015).

The Scholastic surveys specifically investigated children's attitudes and behaviours regarding reading books for fun, including e-books, and have been carried out in the US biannually since 2010 with more than 2,500 (2014: N = 2,558; 2016: N = 2,718) adults and children participating in each study. In particular, parents of children aged 0-17, as well as 6- to 17- year olds were included in the sample. When specifically focusing on children's self-reports of children aged 6 to 8 in the two most recent Scholastic studies from 2014 and 2016, findings yielded interesting results regarding children's reading preferences. First, a steady increase in children who had read an e-book was reported by the 255 6- to 8- year olds included in the study in 2014: From 28% in 2010, to 45% in 2012, it reached considerable 65% in 2014 (Scholastic, 2014). At the same time however, 35% of all participating children aged 6 to 8 reported that they did not read e-books at all. In addition, the interest in reading e-books in children of the same age group had dropped in 2014 to 50% from 57% in 2012, with the vast majority of children (84%) reporting that they were still mostly engaging with print books as opposed to e-books. The more recent survey conducted in 2016, including 261 6- to 8- year olds, seemed to further confirm this trend with children's interest in reading e-books remaining low: 69% of participating children (in comparison to 67% in 2014) agreed with the statement to always want to read print books even if e-books were available (Scholastic, 2016).

In addition to looking into children's broader as well as more specific media use preferences, studies considering children's digital exposure in the early years also explored parental concerns. Parents involved in the study conducted by Kostyrka-Allchorne and colleagues (2017) were worried most about their children being exposed to violent content, as well as inappropriate language and behaviour when asked about potential harmful media features. In line with these results one in five (22%) parents of 3- to 4- year olds participating in the Ofcom survey in 2014, voiced concern about television content their children were exposed to, translating to a 10% increase from the previous year (Ofcom, 2014). Considering these results it is further not surprising that the vast majority of children under the age of five from parents participating in the multinational study by Palaiologou (2016) only used digital technology under parental supervision. Findings by Scholastic (2014), as well as Kucirkova and Littleton's (2016) survey including 1511 UK parents of children from 0-8 years specifically illuminated parental concerns in relation to their children's engagement with digital devices for educational purposes, such as reading: Kucirkova and Littleton's (2016) study revealed that 31% of parents surveyed reported feeling confused about how to use e-books to best support learning, with more than half of participating parents expressing the wish for access to more advice on this topic. Furthermore, parents in the study were concerned about e-books having a negative impact on children's attention and learning, as well as on their interest in print books (Kucirkova & Littleton, 2016). In line with these findings, parental views reported in the US survey Scholastic (2014) two years earlier revealed that only 9% of parents from children aged 6-8 made e-books available for their children to encourage them to read more books for fun. In addition, more than half of these parents (63%) stated that they preferred their child to engage with print books rather than e-books when reading for fun.

While reported concerns of parents in relation to children's digital device use could be considered as slightly overstated, they arguably not only underscore a common belief of young children in the process of learning literacy and language skills being especially vulnerable to the impact of digital media (Barzillai et al., 2018), but also shine the light on the new position of digital text in debates on how children spend their time. When televisions became widely available for the first time, it caused considerable fear with many people arguing for the seemingly more positive activities, such as reading, social interaction or physical activity, soon to be displaced by watching television (Deszcz-Tryhubczak & Huysmans, 2018). Today, reading having now partly developed into a screen-based activity has thus moved into much larger and emotional debates about 'screen time', potentially adding to reported confusion and concerns by parents. However, some progress can be observed: The American Academy of Paediatrics (AAP) has recently updated its recommendations around screen time, from the notable, but restrictive '2 x 2' rule – no screen time for children younger than two and not more than two hours per day for older children – to more nuanced guidelines, taking into account the multiple ways in which children use screens, for instance for learning, active play or social interactions (American Academy of Pediatrics Council on Communications and Media, 2016). The upgraded statement now advises against children under the age of 18 months using digital devices, with the exception of video chatting. Guidelines for older children recommend parents to limit screen time and especially so around meal times and before bedtime. While advice given on the amount of time children should engage with digital devices is therefore explicitly made, recommendations regarding media content choices are limited: With only little relevant evidence available, AAP broadly suggests to select 'high-quality' rather than 'fast-paced' programmes and to avoid distracting and violent content. More information on how to evaluate available programmes however, is not provided. Whereas some guidance on what good resources are and where to find them has been made available, for instance by the literacy app guide produced by Natalia Kucirkova and the UK National Literacy Trust (http://literacyapps.literacytrust.org.uk), much more research is needed to provide parents adequate advice with specific recommendations regarding children's digital device use.

Overall, some studies have been looking into children's digital device use in the early years, with most of them relying on parental reports. Despite possible limitations of the parent questionnaire approach, for instance around reliability of reporting or potential under-reporting of things parents perceive as "bad" practice, previous precedence led to believe that adopting this form of measurement could elicit reliable data and so was used for investigating children's digital exposure before school entry at the first time point of this research project. Given that this research project wanted to investigate potentially persistent associations between visual attention and digital exposure, it was important to capture digital behaviours in quite a broad sense, as any engagement with digital devices might have an impact on visual attention. However, since this research project focused on children's emerging literacy, it was decided to include specific questions about engagement with books into the parent questionnaire, in many instances contrasting digital device use with the use of print (see section 4.3.3 for further details on the questionnaire of the main study). Finally, with the US based Scholastic (2014, 2016) surveys including self-reports from children aged 6 or older, the decision was made to also include participating children's reports on their engagement with digital devices at the second time point, when children had a mean age of 5 and a half years.

2.7 Summary

The discussion of the literature in this chapter focused on visual attention (VA) and its role as a potential digitally-relevant precursor skill of reading in young emerging readers. In the first sections of this chapter, VA was introduced as a key concept of this study, followed by an exploration of how VA is linked to reading. It was further demonstrated that the relationship between these two components becomes even more relevant when digital text is involved, as engagement with these increasingly complex visual environments, including digital and non-linear elements, alters how children attend to the written word and thus has an impact on their VA span capabilities. Subsequently, an argument was made for the need to investigate the links between VA and literacy skills in a normative group of emerging readers and therefore VA as a potential digitally-relevant precursor skill of reading. In the final section, exploring children's exposure to digital devices in the early years first highlighted the need to gain a better understanding of the impact children's use of digital devices has on their emergent literacy. This was followed by a discussion of some studies that have explored children's digital exposure through parental reports and children's self-reports to provide a theoretical foundation for one aim of this study – to investigate possible links between children's engagement with digital devices and their VA skills.

2.8 The current study

The longitudinal main study presented in this thesis focused on the need to update our understanding of reading development in the light of young children's increased exposure to digital text on different sized devices in the early years and the impact this is likely to have on their reading performance after one year of schooling. As outlined in the literature review, VA span has recently been recognized as a potentially important predictor of reading performance (Franceschini et al., 2012). Following Valdois and colleagues (2004), an individual's VA span is particularly relevant for reading processes, as it determines the maximal string of characters that can be simultaneously processed within a single fixation. With an increasingly rapid move away from standardized typographic formats of printed books (Picton, 2014), it is argued that individual variation in VA skills is likely to be an important moderator of reading performance.

This study's main aim was to explore longitudinal relationships between children's exposure to digital devices, VA development and traditional predictors of reading and their impact on single word reading after one year of schooling in a large cohort of Reception year children in the UK. In more detail, the primary aim of this study was to explore VA as a potential digitally-relevant literacy predictor skill by assessing children on their VA, alongside other pre-existing measures of academic readiness and cognitive skills, including phonological awareness, letter-sound knowledge, receptive vocabulary knowledge, and short-term memory at two time points – at school entry and after one year of schooling. A secondary aim of this project was to gather information on Reception year children's experiences with digital devices, and therefore on the length of time, as well as on the frequency a child has been exposed to different formats of digital texts (e.g. tablets, laptops, e-books, smartphones) prior to school entry and after one year of schooling. This was carried out in order to investigate whether there is a relationship between a beginning reader's VA profile and their use and exposure to digital devices.

2.8.1 Hypotheses

Based on the reviewed literature, the following hypotheses guided this study:

When considering the relationships between traditional predictor measures, it was first expected that both phonological awareness (PA) measures (sound isolation and sound deletion) would be strongly and significantly correlated with each other at both time points, confirming the strong and significant relationship between similar measures of PA as suggested by Lonigan et al. (1998) and Wagner et al. (1997). Second, strong and significant correlations between PA and letter-sound knowledge (LSK) were predicted at school entry highlighting a close relationship between the understanding of the principle of an alphabetic language and the awareness of the sounds that can be mapped to letters during children's literacy development (Bowey, 2005; Burgess & Lonigan, 1998; Lerner & Lonigan, 2016). In addition, strong and significant correlations between PA and receptive vocabulary were expected, providing evidence for claims that language skills are strongly related to PA skills (Sénéchal et al., 2006; Storch & Whitehurst, 2002), for instance by playing a key role in the development of PA in children (Metsala & Walley, 1998). In line with these predictions, significant concurrent relationships between both PA measures and short-term memory (STM) were expected at both time points, as phonological STM is being argued to influence literacy development indirectly through supporting the development of PA (Gathercole, Tiffany, Briscoe, & Thorn, 2005). Concurrent relationships between LSK and STM at school entry were also predicted to be significant, given the ongoing debate regarding the relationship between LSK and STM (de Jong & Olson, 2004). Finally, a close relationship between receptive vocabulary and STM for children at school entry and after one year of schooling was predicted, as suggested by Gathercole et al. (1992).

Based on VA span having recently been recognized as a potentially important predictor of reading performance (Franceschini et al., 2012), associations between VA and pre-existing measures of academic readiness and cognitive skills were predicted for this study. While it was not possible to outline specific predictions based on previously conducted studies, the investigation was driven by the following expectations: VA measures at school entry were thought to either be stronger correlated with the non-verbal ability (NVIQ) measure or with the language-based measures (PA, receptive vocabulary, STM), given that verbal responses were required in the VA tasks. In addition, relationships between receptive vocabulary and the VA whole report measure were considered to be stronger than the relationships between receptive vocabulary and the VA partial report measure, given that vocabulary skills were less needed for the performance on the latter. Further, correlations between both VA measures, WR and PR, were thought to provide evidence to suggest that both assessments were not identical but rather capturing slightly different facets of VA performance. In line with this expectation, concurrent correlations between VA measures and the attention & executive function measure were expected to provide evidence to suggest that the VA assessment of the study was sufficiently different from other more general measures of attention and executive function. Following two separate partial correlations controlling for receptive vocabulary and NVIQ were thought to shed light on whether relationships between assessed literacy predictors and VA were mediated by broader verbal language ability or NVIQ. Finally, concurrent relationships between VA variables (WR and PR scores) and the outcome measure single word reading at t2 were thought to be comparable in strength to the longitudinal relationships between individually assessed traditional predictors at t2 and the outcome measure single word reading at t2.

The following hypotheses regarding the predictive power of assessed cognitive and linguistic literacy precursor skills were used as basis for the investigation into VA as a digitally-relevant predictor skill: Based on the expectation that strong and significant longitudinal relationships would be found between both phonological awareness (PA) measures and the literacy outcome measure, as suggested by NELP (National Early Literacy Panel, 2008) and Melby-Lervåg and colleagues (2012), PA was further expected to be a significant, unique predictor for single word reading both concurrently and longitudinally. This prediction was made based as findings from Oakhill and Cain (2012), Manis and colleagues (2000), as well as Melby-Lervåg and colleagues (2012) arguing for phonemic awareness being a key predictor of individual differences in reading development. In addition, strong and significant longitudinal relationships were predicted between LSK and the literacy outcome measure, as suggested by NELP (National Early Literacy Panel, 2008), Swanson et al. (2003), Melby-Lervåg and colleagues (2012) and Schatschneider and colleagues' (2004). As a result, LSK was also expected to be a significant and unique predictor of single word reading longitudinally as it has been suggested as one of the strongest and reliable predictors of early reading by a number of studies (e.g. Scarborough, 1998; Muter et al., 2004; Foulin, 2005; Hulme et al., 2012). In contrast, it was predicted that this study might fail to find evidence of a direct relationship between receptive vocabulary and decoding: While some studies have reported that children's early vocabulary is significantly contributing to their word reading skills (Kirby et al., 2008; Nation & Snowling, 2004; Ricketts et al., 2007), code-related skills such as PA or letter knowledge, are still argued to be stronger predictors of decoding in young readers (Storch & Whitehurst, 2002). Finally, significant longitudinal relationships between STM and single word reading was predicted, as the meta-analytic study conducted by the National Early Literacy Panel (2008), as well as two studies conducted by Gathercole and colleagues (2005, 1992) found correlations between phonological memory and reading development. However, since numerous studies suggest that STM is not a unique predictor of single word reading if measures of PA and RAN were controlled (Caravolas et al., 2012; Melby-Lervåg et al., 2012; Nation & Hulme, 2011; Ziegler, Pech-Georgel, Dufau, & Grainger, 2010) it was expected that STM might not be found as a unique predictor of single word reading in this study.

Based on these hypotheses regarding the predictive power of established literacy precursor skills on single word reading, predictions about the contribution of visual attention on single word reading, over and above traditional linguistic and cognitive predictor variables were made. First, longitudinal relationships between VA variables (WR and PR scores) at t1 and the outcome measure single word reading at t2 were expected to be comparable in strength to the longitudinal relationships between individually assessed traditional predictors at t1 and the outcome measure single word reading at t2 and thus providing positive evidence for a longitudinal relationship between VA and single word reading. Further, it was predicted that VA at the beginning of the school year might contribute to the overall variance in reading performance after one year of schooling in a multiple regression analysis. In the following, the prediction was made that VA might contribute unique variance concurrently in reading performance, over and above the variance accounted for by the potentially-similar measure of general attention and executive function. Longitudinally, it was expected that VA might contribute unique variance in reading performance, fully distinct from the contributions of other literacy precursor variables measured at the same time point in individual hierarchical regression analyses. In more detail, it was expected that VA either contributed more unique variance in comparison to language-based skills or in comparison to NVIQ. Finally, it was predicted that VA contributed additional unique variance in reading performance over and above cognitive and linguistic predictor variables in both concurrent (t2) and longitudinal (t1 – t2) multiple hierarchical models.

2.8.2 Summary of research questions

In order to test the hypotheses outlined above, the following main research questions were explored in this study:

1) What is the profile of visual attention skills in a normative group of emerging readers at school entry, as well as after the first year of schooling based on Bundesen's Theory of visual attention (Bundesen, 1990, 1998)?
    a. Is there a wide range in participants' performance with no major flooring or ceiling effects on the whole report (WR) task exploring children's VA span at both time points?
    b. Is there a wide range in participants' performance with no major flooring or ceiling effects on the partial report (PR) task exploring children's efficiency of attentional control at both time points?

2) How do visual attention skills develop in children when comparing their performance at school entry and after one year of schooling?

3) I. What is the performance and development of emerging readers on traditional linguistic and cognitive predictor variables of reading at school entry and after one year of schooling?
   II. What is the performance of emerging readers on the single word outcome measure after one year of schooling?

4) What is the relationship between emerging readers' visual attention profiles and their performance on traditional linguistic and cognitive predictor variables of reading, including
   I. phonological awareness, letter-sound knowledge, receptive vocabulary, short-term memory, non-verbal ability at school entry, as well as

II. phonological awareness, receptive vocabulary, short-term memory, attention & executive function, and the single word reading outcome after one year of schooling?

5) Is there evidence of a relationship between
    I. parental reports on children's exposure to digital devices and digital device use prior to school-entry and a child's visual attention profile at school entry?
    II. children's self-reports on digital reading and digital device use frequency and a child's visual attention profile after one year of schooling?

6) Does visual attention contribute, over and above to the prediction of single word reading alongside traditional linguistic and cognitive predictor variables in emerging readers?

Chapter 3 – The development of a visual attention assessment for children at school entry

3.1 Introduction

This chapter will present a smaller-scale study conducted prior to the main study and will describe the process of developing a visual attention (VA) assessment for children at school entry.

As outlined in the previous chapter, Bundesen's TVA has been adopted in a number of studies to assess VA of target groups with different characteristics. However, so far no study has implemented a TVA-based assessment to investigate the VA skills of young children aged 4-5, who are yet unable to read and write. Instead, studies investigating VA in young children applied either the original or a slightly modified version of a VA assessment developed by Fan and colleagues (2002), which is based on Posner's ANT (Posner & Petersen, 1990) (e.g. Mezzacappa, 2004; Mullane, Corkum, Klein, McLaughlin, & Lawrence, 2011; Mullane, Lawrence, Corkum, Klein, & McLaughlin, 2016; Rueda et al., 2004). However, it has been argued that, apart from ANT not being an explicit VA theory, the test used in these studies to investigate young children's VA skills had another limitation. That is, ANT test comprising a flanker task (Erkisen & Eriksen, 1974) and a spatial cueing task (Posner, 1980), does not directly assess an individual's VA *span* – characterised as the maximal string of characters that can be simultaneously processed within a single fixation (Valdois, Bosse, & Tainturier, 2004)–, but rather children's ability to focus on targets while disregarding distractors.

The aim of this smaller-scale study was therefore to test the suitability of an adapted and simplified version of a TVA-based assessment to investigate children's VA skills at school entry taking into account the abilities of relatively unschooled children, whose wider attention capacities are still developing. By combining a VA span task (whole report – WR) to investigate storage capacity of VSTM (K) and a target detection task (partial report – PR) to explore efficiency of attentional control (α) it was argued that a simplified TVA-based assessment could better provide data that specifically targets VA in such a young age group. A further key advantage in the practical application of TVA-based assessment, making it especially useful for testing young children, was that both tests (WR and PR) are simple in design and relatively straightforward in terms of task demands. Finally, the possibility of adjusting TVA-based assessments according to the specific participant group, as well as different theoretical interests, made it attractive for application in this study. Considering children at school entry, it seemed logical to apply a simplified and short version of the TVA-based assessment, similar to the studies discussed in the previous chapter (see Section 2.3.3). However, while these previously conducted simplified TVA-based studies inspired the development of the assessment described in this chapter, the intention was to create a tool that would allow a) the assessment of young children who are yet unable to read – by exchanging the usually used letter stimuli with simple black and white symbols –, and b) a more in-depth investigation of storage capacity of VSTM (K) and efficiency of attentional control (α).

The proposed study consisted of two smaller studies and was guided by the following research questions:

i. Is the newly-developed visual attention assessment internally reliable?
ii. Is there evidence of floor or ceiling effects in participants' performance on the whole report (WR) and partial report (PR) tasks?
iii. Does performance on the tasks improve with age?
iv. What are suitable exposure durations for the whole report (WR) task for children aged 4-5?

3.2 Background to test design

The study was designed based on the following considerations:

Concerning the number of elements to display within a string for the WR task, the most common precedent for older populations (Bogon et al., 2014; Duncan et al., 1999) was five symbols (i.e. letters) in each trial of the task. This design decision was itself based on the results of previous studies exploring the question of how many items can be stored in an individual's visual short term memory (VSTM). Whereas research on adults' capacity limits has produced more or less converging evidence around the estimate of 3-4 simple elements (Astle & Scerif, 2011; Vogel, Woodman, & Luck, 2001), studies on the development of VSTM capacity, as well as visual working memory, in infants and children across a wide age range, were more diverse (Cowan et al., 2005; 2006; Isbell, et al., 2015; Oakes et al., 2006; Riggs et al., 2006; 2011; Ross-Sheehy et al., 2003; Simmering, 2012). On the one hand, this is due to considerable variability in the amount of visual information retained by individuals of the same age (Conway et al., 2003; 2008). On the other hand, Simmering (2016) pointed out that diverse results are caused by the fact that different study designs are used to capture the limits of VSTM in children, for example, often change preference tasks are used with infants, whereas change detection tasks are used with children and adults. Ross-Sheehy and colleagues (2003) for instance used a change preference task (Luck & Vogel, 1997) with young infants (6-13 months of age). Based on the study results they concluded that VSTM seemed to develop rapidly within the first 12 months of life, when VSTM reaches adult levels of 3-4 items (Ross-Sheehy et al., 2003). However, these findings were highly contested by Cowan and colleagues (2005, 2006), and Riggs and colleagues (2006, 2011) who suggested that VSTM continued to develop until the end of later childhood. Finally Isbell and colleagues (2015), went one step further, suggesting that even 16-year old's capacity of VSTM was still lower than those of tested adults.

Based on these diverging findings and due to the fact that this study's version of the VA assessment – exchanging letters with black and white symbols of monosyllabic high frequency words – had not been tested before, it was hard to predict how many symbols needed to be displayed for 4- to 5- year olds. For Study I it was decided to use a three instead of a five symbol WR task, displaying symbols in columns on the right and the left side of the screen as presented by Bogon and colleagues (2014), who researched 9- to 10- year olds. The decision to use a three symbol WR task in Study I of this study was based on Sørensen & Kyllingsbæk's (2012) study that looked at preschool children's VSTM capacity (K). Their results suggested that preschool children's K was much lower when using a picture based task – compared to a task adopting less complex symbols such as letters or numbers – and was determined to be around 1.90 (SD = .74). However, it has to be noted, that Sørensen & Kyllingsbæk (2012) again did not use a WR paradigm (Sperling, 1960) to estimate K, but a change detection paradigm (Pashler, 1988; Phillips, 1974), when assessing children's VA skills.

Another key variable that needed to be determined in order to get a good estimation of VA span was range of exposure durations: Regarding the fixation of the maximum exposure durations for each task, the majority of TVA-based assessment studies (e.g. Bosse & Valdois, 2009; Bosse et al., 2007; Dubois et al., 2010; Lobier et al., 2013; McAvinue et al., 2012; Prado et al., 2007) set a maximum exposure duration at 200 ms. While not always discussed, this decision appears to be based on adult eye-tracking studies that examine gaze and saccade behaviour; for example, Dubois and colleagues (2010) stated that their decision to set the maximum exposure duration in their TVA-based study design at 200 ms was made in order to avoid saccades. To allow comparison with previous studies, it was decided to adapt Study I in line with the vast majority of previous studies applying TVA-based assessments (Bosse et al., 2007; Bosse & Valdois, 2009; Dubois et al., 2010; Lobier et al., 2013; McAvinue et al., 2015; Prado et al., 2007; Valdois et al., 2003; van den Boer et al., 2015) and therefore also set the maximum exposure duration at 200 ms.

3.3 Study I

3.3.1 Material and method

3.3.1.1 Participants

Forty-three Reception Year children (26 girls, 17 boys) from a two-form entry UK primary school participated in the study. The mean age of the children was 4;9 years (SD = 3.6 months). Written informed consent was sought from all children's parents/carers before the start of testing. All children attended mainstream primary education and had received approximately seven months of instruction at the time of the assessment. All subjects had normal or corrected to normal vision. The sample included 5 children with English as an Additional Language (EAL) and 7 children with Special Educational Needs (SEN), with no child being categorized as both. No one was excluded from the sample as their performance was not significantly different to the performance of their non-SEN and non-EAL peers. The majority of children had a White British ethnic background (70%), with the other participants belonging to a variety of backgrounds including Black Caribbean, White Eastern European, Chinese, and other mixed backgrounds (30%). 37.2% of all tested participants were eligible for free school meals, used as a proxy for socioeconomic status (SES).

Initially, parents of all Reception Year children from the participating primary school received information about the project and an invitation to allow their child to participate in the study. Whereas no exclusion criteria were specified by the research team, three children who were given consent by their parents were taken out of the study's sample: In one case a child's English language ability was too limited at present to follow instructions of the assessment. In two other cases teachers raised concerns about children's suitability for undertaking the assessment, given their severe degree of SEN.

3.3.1.2 Ethical considerations

Data collection for this and the main study presented in this thesis was carried out in accordance with the University of Sheffield Ethics committee guidelines (see Appendices A & B). Given the nature of the assessments, as well as the design of the studies the physical and/ or psychological harm/distress to the participants was considered to be low. However, not only because of the participants' young age, but also due to the fact that they depend on the protection of and are influenced by research gatekeepers, the children of the study were potentially considered as individuals whose competence to exercise unfettered informed consent was in doubt. Therefore, a number of actions were taken to ensure that all studies discussed in this thesis were carried out according to high ethical research standards:

Researchers were very careful in the interaction with the children during assessments in order to avoid the potential risk of them feeling the obligation to participate in the study. This could have been the case because assessments were conducted by an adult within a school setting, in which the child usually is expected to do what the teacher (i.e. an adult) asks. To counteract this perception, assessments were first explained to the children. After this they were asked if they were happy to do the assessment tasks together with the researcher. Finally, participants were given the option to withdraw from the assessment at any time, if they felt that they no longer wanted to take part in the study. In order to prevent potential performance anxiety during testing, researchers made sure that the child understood that the aim was not to get everything right, but rather to support the researcher by playing different 'games' together. In addition, supportive feedback was given to the child throughout the assessments, and rewards (stickers) were used to ensure a positive and stress-free environment during testing. Finally, the researchers' prior experience of working with children of this age group provided a good ground to ensure that participants were well taken care off during the assessment period.

3.3.1.3 Procedure

All participants were assessed individually in one 20 minute long session in a vacant classroom. In order to ensure consistency of test administration between the two researchers, both developed the administration protocol together and practiced it before the start of testing. It was also confirmed that there was no significant difference in participants' performance between the two researchers administrating the assessment (Study I: $t(41) = -.19$, $p = .85$; Study II: $t(22) = -.83$, $p = .42$).

3.3.1.4 Visual attention assessment measure

Participants were individually invited to 'play a game' on a tablet together with one of the researchers. The assessment consisted of two parts (WR and PR task) the order of administration being counterbalanced across participants. Each task contained an initial practice phase and a main test phase. The test design largely followed the design in Bogon and colleagues' (2014) study, investigating the VA profile of dyslexic children. This included the parameters of exposure duration, number of symbols displayed, as well as position and arrangement of symbols in both reports. The two visual assessment tasks lasted for about 7-8 minutes each and were split up into small blocks with a short break in between. In order to make the study accessible for the target group, letter stimuli were replaced by illustrations of familiar objects. These were displayed as black and white symbols to ensure that the objects were clear but at the same time not overly appealing. Using familiar objects followed the design precedent of Sørensen & Kyllingsbæk (2012) and allowed for more control over word length, word frequency and image discriminability compared to other types of symbol such as shapes or colours. Stimuli were presented on a Samsung Galaxy Tab 4 for Education (10.1 inch, 1280 x 800 LCD). The refresh rate was 16.21 ms and symbols were randomly chosen from the following set: car – bell – house – sun – hat – dog (Figure 3.1). Decisions on which symbols to choose were based on Snodgrass & Vanderwart's (1980) list of 260 stimuli: From this list, six symbols were chosen depicting nouns having the following criteria: high frequency (> 38 occurrences per 1 000 000, Brysbaert & New, 2009), consisting of not more than one syllable, high concept familiarity ratings (Barry, Morrison, & Ellis, 1997), and belonging to different semantic categories: transport – instrument – dwelling – celestial body – clothes – animal.

Before the start of each assessment the child was shown symbols used in the task and was asked to identify each one of them. This way researchers ensured that children were able to name the symbols independently and confidently before the beginning of the task. Each child was then asked to sit at the table and to hold the tablet with both hands, placing their thumbs on thumb markers placed on the right and left bottom corner of the tablet case. In addition, participants were instructed to make sure that the tablet stayed in the area that had been marked on the table with coloured tape (15 cm away from the desk end). Before starting the actual testing, children completed four trials in an initial practice phase together with the researcher. During this phase participants were given feedback and were reminded of the task instructions when needed. The main testing was not started before researchers were confident that the child fully understood the task.

3.3.1.4.1 Whole report task

Test administration

Following a centred black fixation cross on a white background (1000 ms) and a subsequent white screen (50 ms), 3 symbols were presented in a vertical column either to the left or to the right of the fixation cross position (Figure 3.1). Symbols were separated by 2 cm and shown at three different exposure times (100 ms – 150 ms – 200 ms). Symbol strings presented in each trial spanned 10 cm on the display screen, with the symbol sequences being unique in each trial of the study. In line with other studies (Bogon et al., 2014; Duncan et al., 1999), each symbol appeared only once on a given trial. Assuming that the tablet was held at a distance of 30 cm, the symbol string would subtend approximately 18.9°. After each trial of the WR task participants were asked to make an un-speeded verbal report of as many symbols they were able to recognise on the screen. The researcher recorded the symbols in the order they were reported. To allow data checking after the live session, a voice recorder was used to record the answers. Each child completed 42 WR trials – 7 iterations x 2 positions (left or right) x 3 exposure durations – divided into 4 blocks. After each block (consisting of 10-11 trials), the assessment was briefly paused and the child was given an achievement sticker. Upon completion the child engaged in a short physical activity (action rhyme) to allow for a break before the second half of testing.

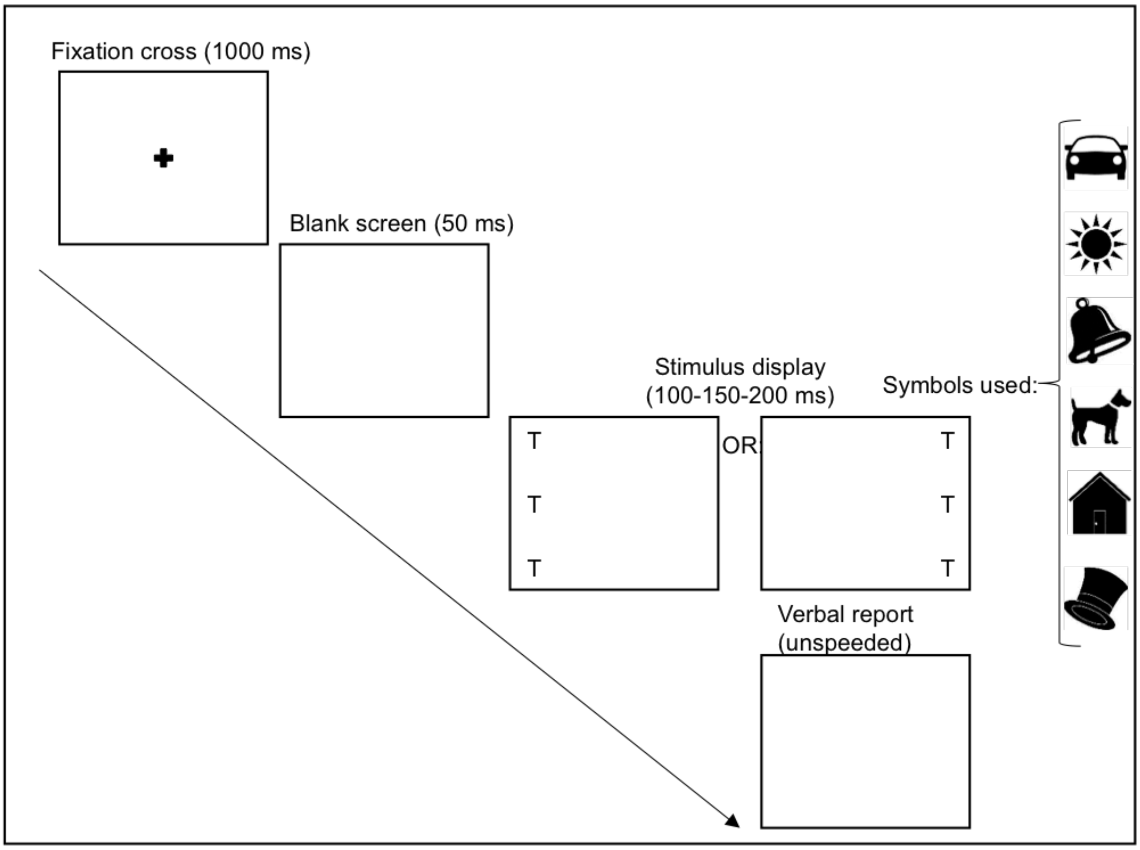

Figure 3.1 *Illustration of the whole report in Study I*

Data analysis

The WR task was used to evaluate participants' performance on how many symbols they were able to name in each trial on average, in relation to the three different exposure durations. This way possible differences between participants' visual short term memory span could be yielded, defined as the amount of visual elements which can be processed in parallel in a multi-element array during a single fixation (Bosse et al., 2007). According to TVA (Bundesen & Habekost, 2008), a visual object is stored in an individual's short term memory by encoding of this object's features into the visual short-term memory store. However, this memory store only has very limited capacity, referred to as parameter K. While this study's WR design also enables investigation of spatial bias of attention (ω), this data is not reported here, given the main aim of the study, i.e. exploring the suitability and feasibility of the test for the target group of 4- to 5-year old participants. Thus, for analysing the data of the WR in this study, the number of correctly identified symbols was totalled for each trial and a mean was computed to create a VA score (comparable to VSTM capacity K) for each participant.

However, since authors of this study argue that VSTM storage capacity K as computed by Bundesen and colleagues (Bundesen, 1998; Duncan et al., 1999) and the VA span scores (Bosse et al., 2007) – albeit not being completely identical – closely correlate with each other, links were made between this study's results and TVA-studies' results concerning VSTM storage capacity (K) when discussing the results of this study.

3.3.1.4.2 *Partial report task*

Test administration

This task started similarly to the preceding one, with an explanation of the task followed by four practice trials. At the start of each trial, a central fixation point was presented for 1000 ms followed by a blank screen for 50 ms. In each of the trials there were four array locations (upper left, lower left, upper right, lower right) arranged in a square (12x18 cm) around fixation. The array locations are 6 cm apart vertically and 9 cm horizontally. Assuming that the tablet was held at a distance of 30 cm, the rectangle containing the symbols would subtend 19.8° diagonally. In each trial, one or two symbols were displayed for 150 ms at a time and the child was instructed to report the target symbols only. The probe indicating a target was a circle, presented for 50 ms at the location where the target symbols had previously appeared (Figure 3.2). In different arrays, a target was presented either alone, in pairs, or together with a distractor (Figure 3.3). In addition, targets were presented alone in each of the four locations, while pairs of targets and pairs of targets and distractors were always presented in a row or a column (Duncan et al., 1999). Participants' unspeeded oral responses were recorded by the researcher who subsequently started the next trial. The PR task was broken into 6 blocks (10 trials each). Similar to the WR task, the whole procedure was recorded and children received sticker rewards in between, as well as by completion of the task.

Data analysis

In line with considerations regarding the main aim of the study and the resulting depth of analysis of WR data, a simplified analysis was also conducted of PR data, focusing on investigating top-down attentional control (α). This was achieved by looking at how many targets and how many distractors participants reported on average across all tasks. However, the test design adopted for this study could also be used in future studies to investigate spatial bias of attention (ω).

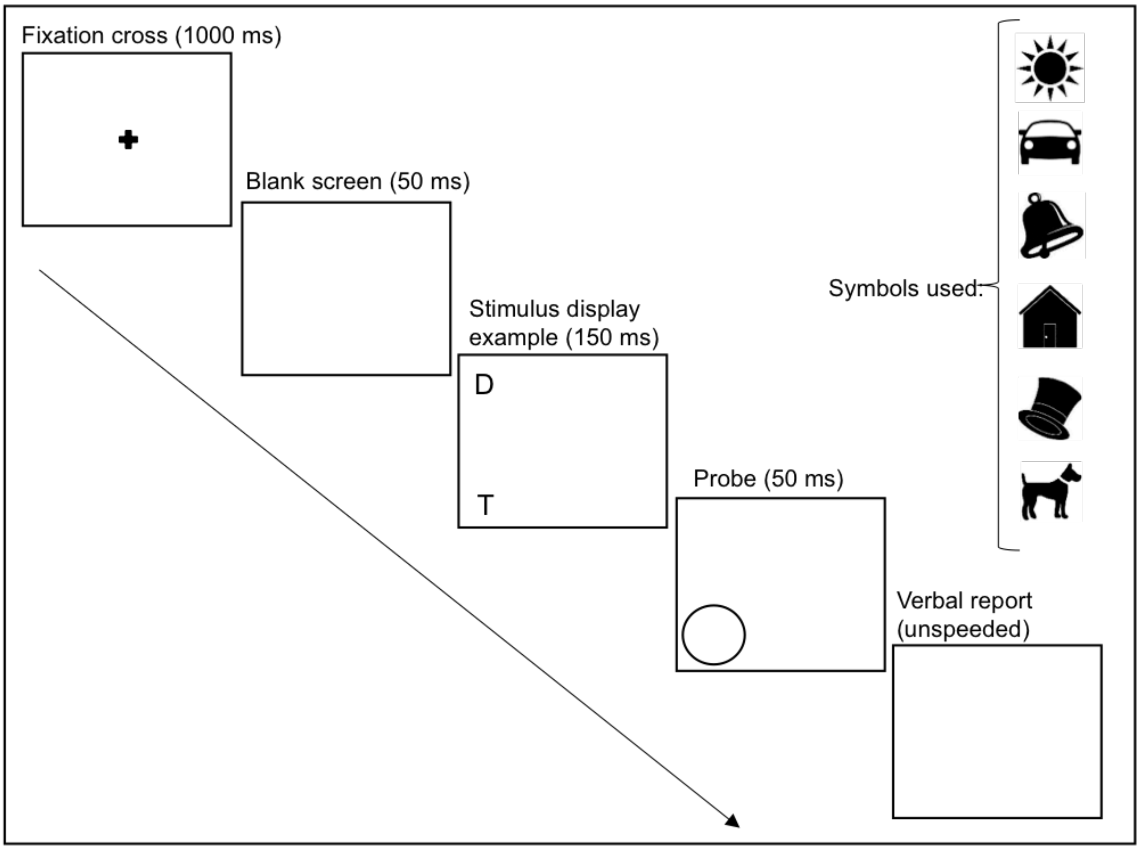

Figure 3.2 *Illustration of the partial report in Study I*

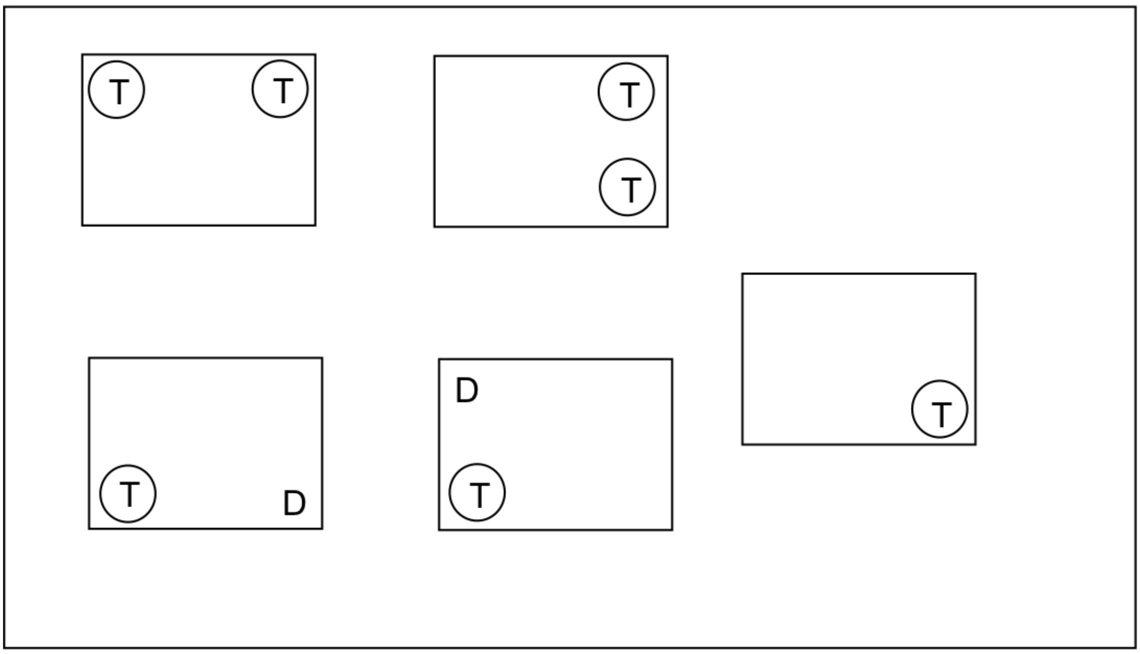

Figure 3.3 *Different stimuli displays of the partial report task with targets (T) and distractors (D)*

3.3.2 Results

3.3.2.1 Is the adapted visual attention assessment internally reliable?

Internal reliability of the adapted VA assessment was evaluated using Cronbach's alpha, a value that quantifies the extent to which all the trial items in a test measure the same construct (Cronbach, 1951). The Cronbach's alpha was $\alpha = .95$ for the WR and $\alpha = .91$ for the PR task, representing a high level of consistency.

3.3.2.2 Is there evidence of floor or ceiling effects in participants' performance on the whole report and partial report tasks?

3.3.2.2.1 Whole report results

To examine whether floor or ceiling effects could be identified, overall performance of all participants on the WR task was examined. The mean number of reported symbols in all trials by all 43 participants was 1.27 (SD = .81) with a range of 0 to 3 symbols. When looking at children's highest score across trials, i.e .their maximum performance, 17 participants (39.5%) achieved a highest score of 1, 8 participants (18.6%) a highest score of 2, and 18 participants (41.8%) a highest score of 3. No floor or ceiling effects were observed.

3.3.2.2.2 Partial report results

As illustrated in Figure 3.4, PR results also demonstrated a wide range of performance with no floor or ceiling effects. Across all PR trials performed by all 43 participants, 67.2% of the target symbols were reported correctly. Distractor symbols were reported 30.4% of the time. It was further revealed that whereas 30 participants (69.8%) showed high abilities to report targets, while disregarding distractors (participants well below the line in Figure 3.4), 13 (30.2%) participants reported targets and distractors indiscriminately and with roughly the same probability (participants close to the line in Figure 3.4). The correlation between each participant's reported targets (T) and distractors (D) in the PR was non-significant ($r = -.16; p = .32$).

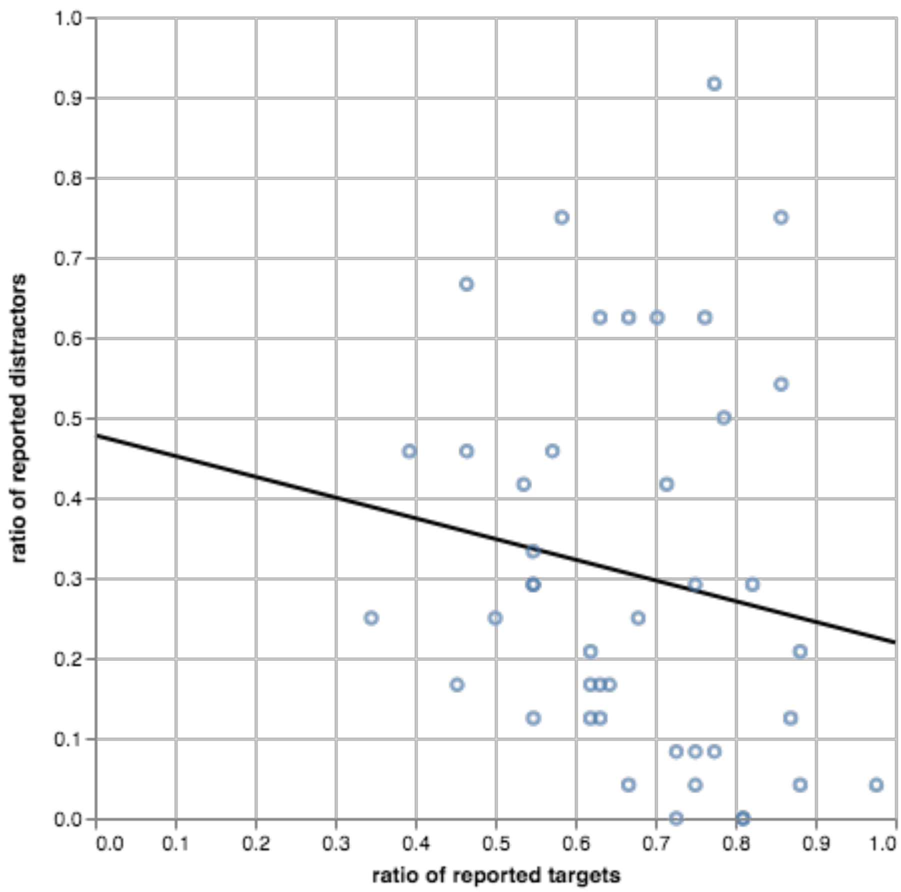

Figure 3.4 *Correlation between reported targets (T) and distractors (D) in % in Study I*

Since no major floor or ceiling effects were reached in either of the two tasks and results showed a wide range of performance between the participants, it was suggested that the newly developed VA assessment is suitable for differentiating performance between individuals of the target age group of this study. Having established the suitability of the assessment, further investigation was performed.

3.3.2.3 Does performance on the tasks improve with age?

To explore developmental effects, WR results were used specifically, to examine the correlation between numbers of reported symbols and age of participants in months. The decision to use WR as opposed to PR was a practical one, with the WR yielded a single score for each child that could more directly be correlated to their age. Figure 3.5 shows that there was a significant relationship (*r = .37; p = .016*) between the performance of participants in the WR task and their age in months. On average, the older participants were, the higher the number of symbols they were able to report. In the PR on the other hand, the relationships between correctly reported targets and age (*r*

= *.21; p = .17*), as well as reported distractors and age (*r = -.16; p = .30*) were not significant.

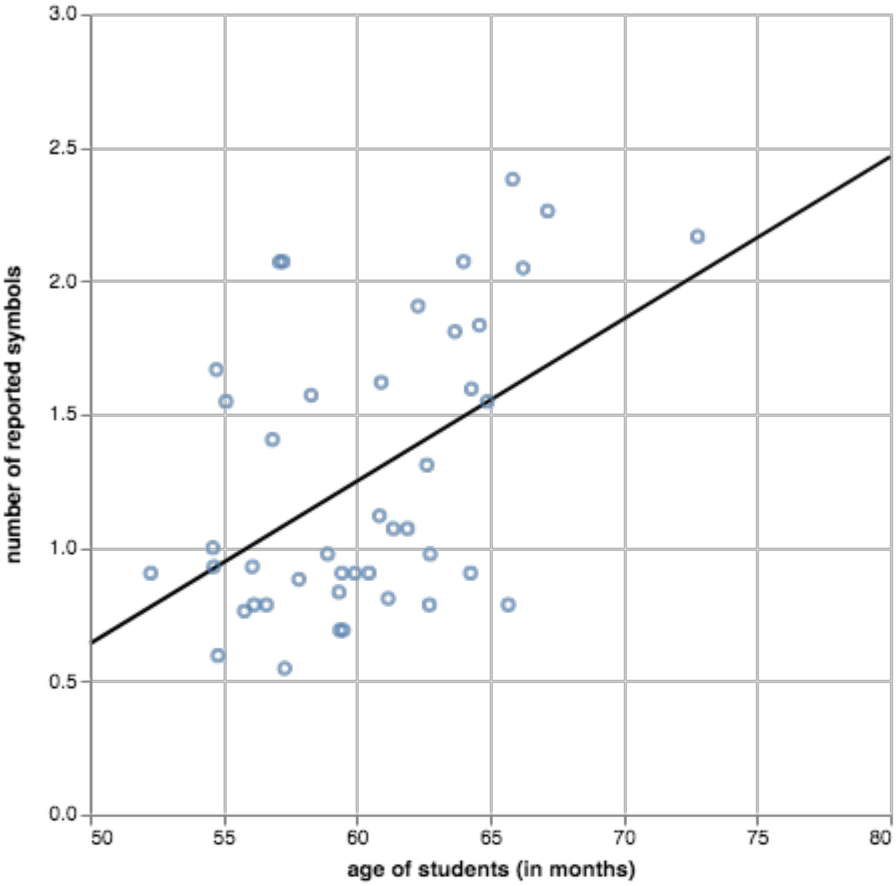

Figure 3.5 *Correlation between number of reported items and students' age in Study I*

3.3.2.4 What are suitable exposure durations for the whole report task for children aged 4-5?

Data show a slight increase of reported symbols with an increase in exposure duration, with the mean number of reported symbols at 100 ms being 1.23 (SD = .52), at 150 ms being 1.26 (SD = .55), and at 200 ms being 1.30 (SD = .58). As illustrated in Figure 3.6, there was no significant difference between the number of reported symbols per exposure duration ($F\ (3,\ 43)$ = .14, p = .87). These findings suggest that the selected exposure duration times for Study I (100 ms – 150 ms – 200 ms) only seemed to have a small impact on the symbols participants were able to report in the WR task.

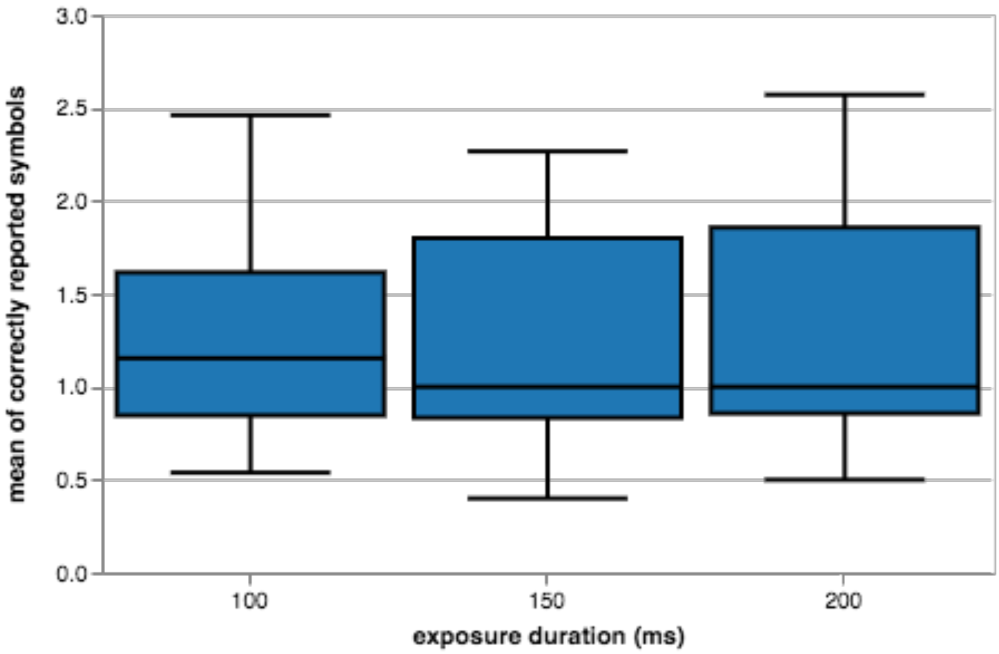

Figure 3.6 *Boxplot of number of correctly reported items and exposure durations in Study I*

3.3.2.5 Complementary observations while testing

Based on the fact that the VA assessment had been specifically designed and adapted for the target group, it was decided to not only collect data for the quantitative data analysis, but to supplement these with qualitative observations during testing: Researchers therefore paid attention to a child's behaviour and statements during testing, noting everything down of interest. Although the demands of the assessment, giving clear instructions, providing a welcoming and stimulating environment, as well as recording a child's answers only allowed the collection of very restricted qualitative data, the resulting observations raised some valuable key points, which together with the data analysis results, informed the implications for Study II:

On the first day of the study, researchers realised that emphasis needed to be put on making sure that all children fully understood the WR task. At the beginning, it seemed that a few students only focused on reporting one symbol which they saw with full certainty, instead of trying to report as many as they could spot. This challenge was overcome in the moment by encouraging children throughout the assessment to report as many symbols as possible.

Another observation was that 2 out of 43 children seemed to struggle naming symbols by referring to the same word during the trial. One participant, sometimes referred to the symbol of a dog as a “goat”, while another participant used the words “bell”, “ring” or “ding” interchangeably for the same symbol.

Regarding the WR task, a third issue arose while doing the assessment, which was noted by both researchers: More than a third of the children seemed to struggle with the fact that symbols were displayed in a column on either the left or the right side of the screen. While some of them expressed their surprise stating that they never knew where the symbols would pop up on the screen, others showed mild levels of frustration, blaming the lack of predictability of target locations for sometimes not being able to recall one or more symbols.

Finally, the main point noticed by researchers during the administration of the PR task went in line with the quantitative PR results: During testing researchers got the impression that the demands of the PR – i.e. only reporting the cued symbol(s) while ignoring the distractors – seemed to be a challenge for some children, who reported all symbols appearing on the screen, regardless of being cued or not.

3.3.3 Summary of Study I

The purpose of this first study was to test a newly developed VA assessment for children in the first year of schooling – based on Bundesen’s Theory of visual attention (TVA) (Bundesen, 1990, 1998).

Based on Study I results, the VA assessment appeared to be internally reliable, showing a high level of consistency in the WR and the PR.

When looking at the data from the WR no floor or ceiling effects were observed. The newly developed VA assessment provided a wide range of performance across all 43 participants of the study, suggesting the suitability and sensitivity of the assessment. In line with this, results of the PR data suggest that the demands of the PR task – reporting targets while ignoring distractors – could be met by the participants. The correlation between reported targets and distractors in all PR trials show that the task captured a range of performance, from participants showing high abilities to name targets while ignoring distractors, to others who had a lot more difficulty with this task.

As with other studies (e.g. Riggs et al., 2011), study results potentially show a developmental progression from the WR data analysis suggesting that age of participants had an impact on average number of reported items. In contrast to studies with older populations (Habekost, 2015), however, there was a minimal effect on performance as a function of exposure time.

As a final point, while the above results supported the overall utility of the VA assessment for the target age group, the researchers noticed that more than a third of the participants struggled with the vertical orientation of the stimuli; as per Bogon and colleagues (2014) symbols were displayed in a column on either the left or the right side of the screen in the WR. While some children expressed surprise, stating that they never knew where the symbols would pop up on the screen, others showed mild levels of frustration, blaming the lack of predictability of target locations for failed attempts to recall one or more symbols.

3.3.4 Implications for Study II

Following the results of Study I, the following changes were made to further improve the suitability of the VA assessment for the target group of the study: Firstly, since children were challenged by the display of the symbols, the revised version presented the symbols in a horizontal string at the centre of the screen. The change in displaying the symbols in a line was further based on the argument that this presentation style was more reflective of the way text is usually presented, i.e. in horizontal lines.

Secondly, the number of symbols shown in one trial was increased to four instead of three. While no overt ceiling effects were observed, given that a significant proportion of children could report all three symbols presented, trialling the use of four symbols was seen as a way to potentially capture greater between-child performance variation.

Further, to improve the sensitivity of the measure to capture performance differences as a result of varied exposure time, the exposure durations were spread out more widely: 70 ms – 100 ms – 150 ms – 200 ms – 250 ms. It was hoped that by testing five instead of three exposure times, and by increasing the overall time span from 100 ms to 180 ms, data would be more informative regarding the relationship between exposure time and number of reported symbols.

Since a bigger question remained about the impact upon validity of a reduced number of WR trials in Study I – 42 trials instead of > 150 in previously conducted TVA studies (e.g. Bogon et al., 2014) – Study II looked into effects of increasing the number of WR task trials from 42 to 100.

3.4 Study II

3.4.1 Material and method

3.4.1.1 Participants

Twenty-four Reception Year children (11 girls, 13 boys) from a one-form entry primary school in North Yorkshire participated in the study. The mean age of the children was 5;3 years (SD = 3.1 months). Written informed consent was sought from all children's parents/carers before the start of the testing and the consent procedure followed the same steps as in Study I. All children attended mainstream primary education and had received approximately ten months of instruction at the time of the assessment. All subjects had normal or corrected to normal vision. The sample included 1 SEN child and no child was excluded from the sample of this study. All 24 tested children had White British ethnic background, with one of all tested students being eligible for free school meals.

3.4.1.2 Procedure

The VA assessment was administered in 20 minutes long sessions. In line with Study I, all children were assessed individually in an empty classroom by one of the two researchers, using the same administration protocol.

3.4.1.3 Visual attention assessment measure

For the VA assessment measure in Study II the assessment procedure was nearly identical with the one in Study I. For the purpose of Study II however, participants were split into two groups of 12 participants each, with group A performing the revised version of the assessment consisting of WR and PR task, and group B performing a longer version of the revised WR task only.

Whereas the WR was changed for both groups based on the results in Study I, the same PR was used for the testing. For group A the two tasks (i.e. WR and PR) lasted for about 7-8 minutes each, were split up into small blocks and separated by a break in between. For group B the WR task lasted for 15 minutes in total, also split into blocks with in between breaks. For both groups stimuli were presented on a Samsung Galaxy Tab 4 for Education (10.1 inch 1280 x 800 LCD) and were randomly chosen from the following set: car – bell – house – sun – hat – dog – clock – pot. Based on the increased number of displayed symbols in this study, two symbols (clock, pot) were added to the list of symbols used in Study I, having been chosen according to the same characteristics as the other six (for more details see description of Study I). All other aspects of tablet positioning and practice trial administration followed the procedures outlined for Study I.

3.4.1.3.1 Whole report task

Test administration

Following a centred black fixation cross on a white background (1000 ms) and a white screen (50 ms), the silhouette of four symbols were presented in a horizontal line in the centre of the screen (Figure 3.7). Symbols were shown at five different exposure times (70 ms – 100 ms – 150 ms – 200 ms – 250 ms). With the string of symbols spanning 18 cm on the screen, symbols were separated by 3 cm each. Symbol sequences were unique in each trial of the study and, following the TVA test design (e.g. Bogon et al., 2014; Duncan et al., 1999), appeared only once on a given trial. With the tablet held at a distance of 30 cm, a symbol would subtend about 33.4°. After each trial of the WR task the child was asked to make an unspeeded verbal report of as many symbols as he/she was able to recognise on the screen. The researcher recorded the symbols in the order the participant reported them and in addition used a voice recorder throughout the sessions.

Each child of group A completed 40 WR trials – 8 iterations x 1 position (centred) x 5 exposure durations – divided into 4 blocks. After each block (consisting of 10 trials), the child received an achievement sticker. Participants of group B performed on 100 WR trials – 20 iterations x 1 position (centred) x 5 exposure durations – divided into 10 blocks of 10 trials, each shortly paused by a reward receiving activity. Whereas participants of group A engaged in a short physical exercise after completing the WR, group B engaged in physical activities after completing half of the WR trials.

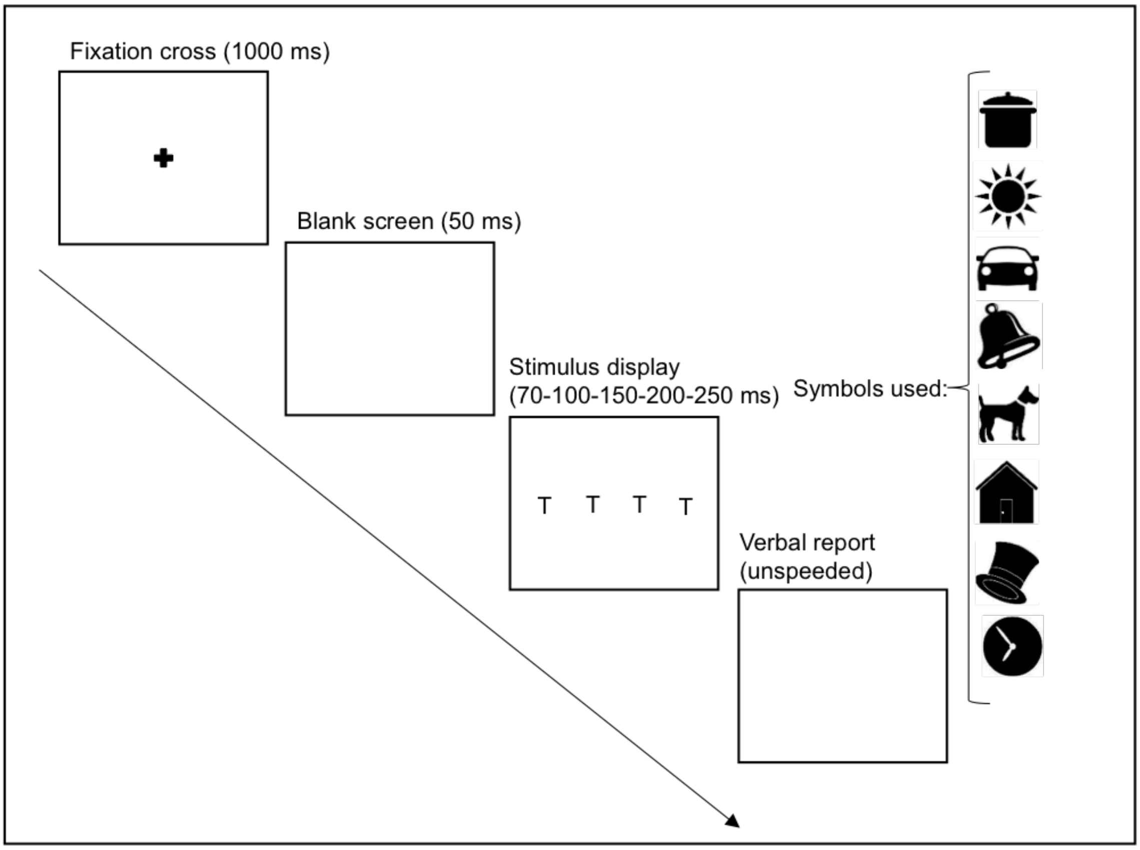

Figure 3.7 *Illustration of the whole report task in Study II*

Data analysis

In line with Study I, data from the WR was yielded to compute individuals' VA spans (comparable to VSTM capacity K) on the adapted WR task. In comparing results with those from Study I, the main focus was to investigate whether changes in the study design resulted in stronger correlation between participants' number of reported symbols and exposure durations and therefore go in line with results from other studies applying TVA (e.g. Bogon et al., 2014; Dubois et al., 2010; Duncan et al., 1999).

3.4.1.3.2 Partial report task

The conditions of the PR task remained unchanged from Study I (see Figures 3.2 and 3.3 above) and were performed by children assigned to group A.

3.4.2 Results

3.4.2.1 Is the adapted visual attention assessment internally reliable?

In line with the results in Study I, internal reliability of the adapted VA assessment was evaluated using Cronbach's alpha. The internal reliability of the VA assessment applied in Study II showed high internal reliability for the results of both groups, with α = .93 for the WR and α = .89 for the PR of group A and α = .97 for the WR of group B.

3.4.2.2 Is there evidence of floor or ceiling effects in participants' performance on the whole report and partial report tasks?

3.4.2.2.1 Whole report results

To examine whether floor or ceiling effects could be identified in participants' performance on the task in this study as well, an initial investigation looked into the overall performance of all participants (group A & B) on the WR task in Study II: The mean of number of reported symbols in all trials by all 24 participants was 1.66 (SD = .85) with a range of 0 to 4 symbols, an increase in comparison to a mean of 1.27 reported symbols per trial (SD = .81) in Study I. In line with findings in Study I, results revealed a wide range between performance of tested children, stretching from 2 participants (8.3%) reporting a maximum of 1 symbol across all WR trials, the majority of participants (17, 70.8%) reporting a maximum of 2 or 3 symbols across all trials, to 5 participants (20.8%) reporting up to 4 symbols throughout all WR trials. While results from Study I & II are not directly comparable as the display of symbols in the WR was altered between studies, it is worth noting that performance on the WR in Study II was significantly better than on the WR in Study I ($t(65) = 3.21$, $p = .002$): Whereas a significant number of participants in Study I only reported up to one symbol (39.5%) across all WR trials, nearly all participants (91.6%) in Study II reported up to 2 or more symbols across all trials (Table 3.1).

Table 3.1 *Mean, standard deviation, median and range of the number of reported symbols per trial for Study I and II*

	N	*M*	*SD*	*Mdn*	*Range*
Study I	43	1.27	.81	1	0-3
Study II	24	1.66	.85	2	0-4

3.4.2.2.2 Partial report results

As shown in Figure 3.8, there was a range in performance of all tested participants, yet generally performance was relatively strong: Across all PR trials performed by all participants, 78.7% of the target symbols were reported correctly, while distractor symbols were reported only 12.2% of the time.

Individuals' performances on the PR further showed a significant relationship (*r = -.64; p = .034*) between participants' reported targets (T) and distractors (D), supporting findings that participants tested on the PR show high abilities to report T while disregarding D (right bottom corner). No student reported an approximately equal number of T and D, which would indicate a weak ability to ignore distractors.

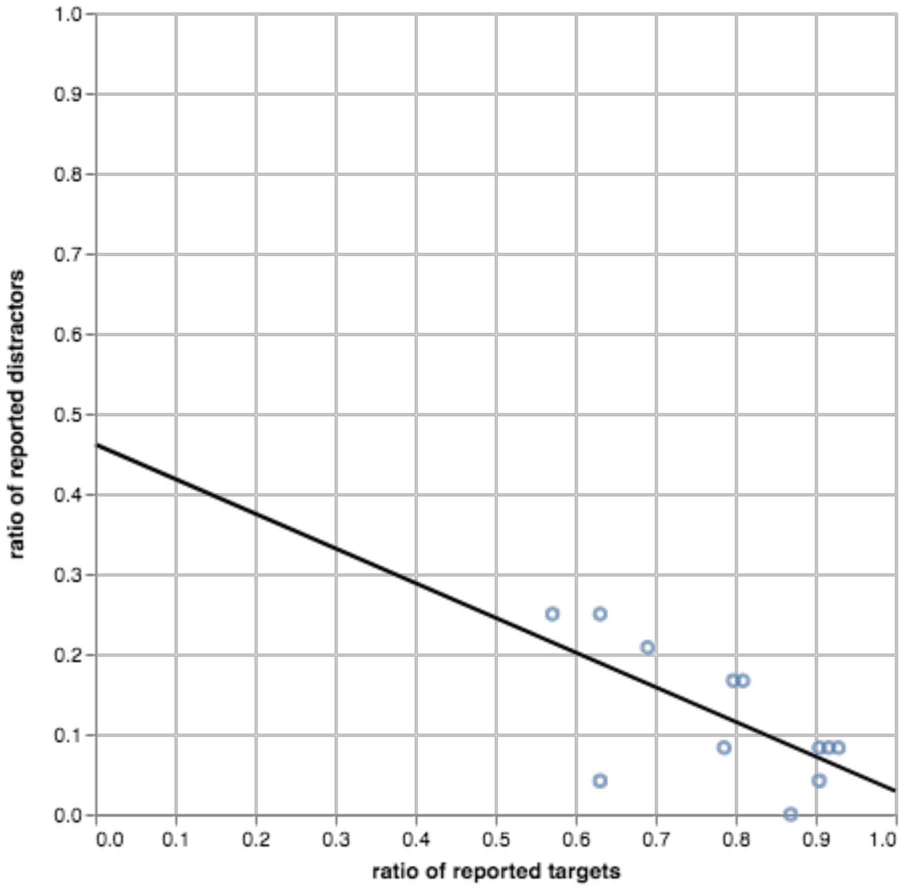

Figure 3.8 *Correlation between reported targets and distractors in % in Study II*

3.4.2.3 Does performance on the tasks improve with age?

To explore developmental effects, the relationship between number of reported symbols in the WR task and participants' age for both groups, was investigated, as can be seen in Figure 3.9. For this group (n = 24) there was no significant relationship (*r = .31; p = .14*) between the performance of participants in the WR task and their age. Similar results were yielded for performance on the PR: the relationships between correctly reported targets and age (*r = .52; p = .086*), as well as reported distractors and age (*r = -.31; p = .32*) were not significant.

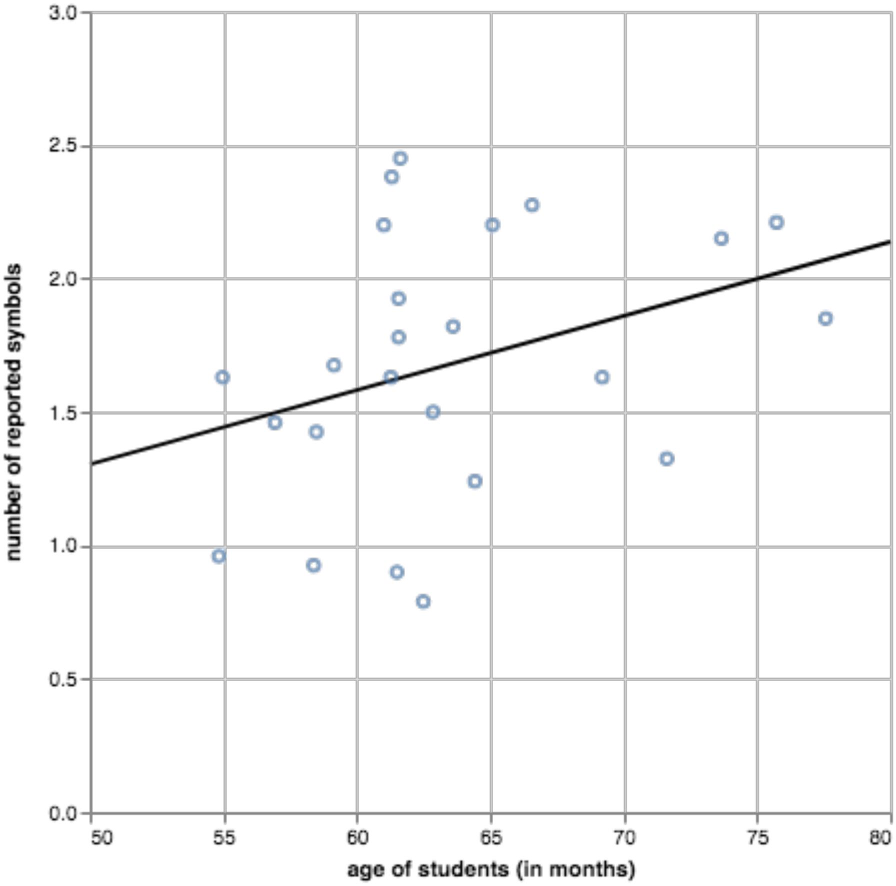

Figure 3.9 *Correlation between number of reported symbols and students' age in Study II*

3.4.2.4 What are suitable exposure durations for the whole report task for children aged 4-5?

As illustrated by Figure 3.10 WR data showed an increase of reported symbols with an increase in exposure duration, with the mean number of reported symbols at 70 ms being 1.56 (SD = .58), 100 ms being 1.61 (SD = .53), at 150 ms being 1.67 (SD = .46), at 200 ms being 1.77 (SD = .55), and at 250 ms being 1.79 (SD = .51). However, there was no significant difference between the number of reported symbols per exposure duration ($F\ (5, 24) = .85$, $p = .49$).

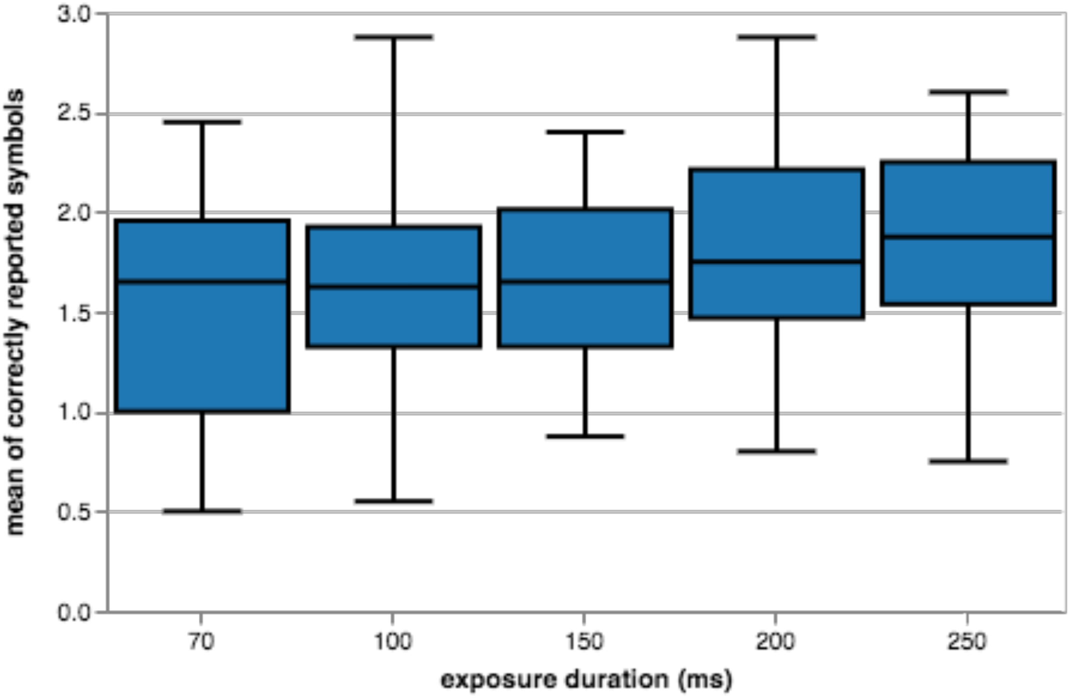

Figure 3.10 *Boxplot of number of correctly reported items and exposure durations in Study II*

3.4.2.5 How is the performance on the different versions of the whole report task in Group A and B?

To examine whether there was a difference between children's performance in the short version of the WR (participants of group A) in comparison to the long version of the WR (participants of group B) in Study II, an initial investigation looked into the overall performance of participants in both groups (Table 3.2): The mean of number of reported symbols in all trials by all 12 participants in group A was 1.72 (SD = .52) with a range of 0 to 3 symbols. In comparison to this, the mean number of reported symbols in all trials by all 12 participants in group B was slightly lower being 1.64 (SD = .48) with a range of 0-3. However, there was no significant difference between the mean number of reported symbols between the two groups ($t\ (22) = .40$, $p = .70$).

Table 3.2 *Mean, standard deviation, median and range of the number of reported symbols per trial for the whole report in Group A (40 trials) and Group B (100 trials) in Study II*

	N	*M*	*SD*	*Mdn*	*Range*
Group A	12	1.72	.52	2	0-3
Group B	12	1.64	.48	2	0-3

To reach a deeper understanding of participants' performance in the long version of the WR, a further investigation was conducted to look into participants' performance in the first half of the WR task (trials 1-50) and in the second half of the WR task (trials 51-100) (Table 3.3). While it was expected that performance would decrease in the second half of the task due to increased demands on participants' attention, the results suggested otherwise: Performance in the second half of the task was slightly better with the mean of number of reported symbols being 1.66 (SD = .53) with a range of 0-3 symbols, compared to the mean number of reported symbols in the first half being 1.62, (SD = .46, range = 0-3). However, the difference between the mean number of reported symbols in the first and the second half of the task was not significant ($t\ (22) = .20$, $p = .84$).

Table 3.3 *Mean, standard deviation, median and range of the number of reported symbols per trial for the whole report in the first half (trials 1-50) and the second half (trials 51-100) of the task in Group B of Study II*

	N	*M*	*SD*	*Mdn*	*Range*
Trials 1-50	12	1.62	.46	2	0-3
Trials 51-100	12	1.66	.53	2	0-3

3.4.2.6 Complementary observations while testing

Based on the experience that the complementary observations in Study I supported the analysis of the data, it was decided to maintain this procedure for Study II.

Similar to Study I, researchers observed that some children (6 out of 24) seemed to struggle naming symbols by referring to the same word during the trial. This time it was particularly the picture of the pot that triggered different responses: This symbol seemed to be particularly unclear for many who referred to it as a "pan" or "bin", with some of them using different words for the same symbol throughout the trials. In addition, researchers got the impression that some participants (8 out of 24) seemed to struggle naming the symbol for "clock": It was felt that they required a few moments to think of the name of the symbol before reporting it, as if it took them a little bit longer to retrieve the word from their lexical memory. In addition, changes made to symbol orientation in the WR of Study II seemed to have been effective, as children did not complain or voice frustration regarding their ability to report symbols during this round of data collection.

Finally, researchers compared data collection between group A (WR and PR) and group B (long version of the WR): Although there were no significant group differences in performance between Group A and B on the WR, the researchers got the qualitative impression that testing in group B was far more demanding for both the participant and the researcher: Whereas some children tested on the long version of the WR seemed to become tired and less engaged in the second half of testing, albeit this not being reflected in the quantitative analysis of performance in the first and the second half of the task, participants in group A seemed to stay more engaged while being tested in both versions.

3.4.3 Summary of Study II

The purpose of this second study was to test whether the amended version of the VA assessment improved its suitability and sensitivity in comparison to the first version, trialled in Study I.

Based on Study II results the adapted VA assessment appeared to be internally reliable, showing a high level of consistency in the WR and the PR. The similarly high internal reliability for both groups A and B, i.e. children who carried out 40 or 100 trials respectively, suggested that there was not a significant decrement to internal reliability for this age group in carrying out the task with a reduced number of trials.

The data from the WR showed a wide spread of performance and no evidence of floor or ceiling effects, with the addition of a further symbol to recall providing further differentiation of performance. Equally, the positive correlation between reported targets and distractors in all PR trials showed that participants tested could perform the task relatively well, yet still across a range of abilities. When comparing the performance of Reception year students on the PR across both studies, the cohort tested in June for Study II (who were a different group of children to those in Study I), performed noticeably better as a group than those tested in March for Study I, with superior ability to ignore distractors. However, these findings are more difficult to interpret, as first, results are based on different samples, and second, between Studies I and II, the children not only differed in age, but also in the amount of formal instruction they had received at school.

Regarding the relationship between number of reported symbols and age, while a positive correlation (r = .31) existed between the age of participants and average number of reported trials (WR) of a magnitude similar to Study I (*r* = .37), the correlation was not significant. This may be due to the difference in sample sizes between the two studies (Study I, n = 43; Study II, n = 24).

The investigation of the suitability of the exposure durations for children aged 4-5 explored the relationship between the number of reported items and exposure time in the WR task in Study II. Whereas five instead of three exposure times were used in Study II and the mean of reported symbols per trials (M = 1.66; SD = .85) was higher compared to Study I (M = 1.27; SD = .81), there was no significant difference in performance as a function of exposure duration in Study II. The effect of exposure duration on the number of correctly reported items therefore appears to be lower than in other studies applying TVA with older populations (8 years and older, Dubois et al., 2010; Lobier et al., 2013).

3.5 General Discussion

The primary purpose of this study was to investigate the accessibility, suitability, and sensitivity of a newly adapted version of VA assessment for children at school entry.

As observed in the discussions of Study I and II, the current assessment demonstrated good internal consistency, showed no evidence of floor or ceiling effects and thus captured a range of performance within this age group. These findings suggest that while there was a reduction of trial numbers in order to accommodate for the target age group of this study, the assessment still has enough power to demonstrate reliability. WR data revealed that the mean VA span across all tested participants lay between 1-2 items. Comparing these results to previous studies, no study has reported visual span performance on this specific age group. With slightly older children, Bosse and Valdois (2009) used a simplified TVA-based assessment with 157 6- to 7- year olds. Using a different reporting metric, the researchers looked at the percentage of trials in which all 5 letter strings were correctly reported – which was a mean of 7.3% for their sample population. Calculating a similar metric for the data here, the parallel result would be 1.04% - which is considerably lower. Part of this performance discrepancy may be due to the age difference, and the school transition period representing a time of rapid developmental change in skills relevant to formal instruction. Another factor to consider is that the processing of pictorial symbols, while circumventing the need for letter knowledge, may have a differential processing load to letters. In addition, a developmental progression was potentially observed in the WR data for Study I, suggesting that age of participants seemed to have an impact on average number of reported items. Whereas a positive relationship between an increase in the selected exposure durations and the number of symbols participants reported was observed, the effect was not significant. It will be important in future work to look more closely at the nature of errors made. For example, are children reporting items not present in a stimulus array as opposed to not reporting items that were present. This type of analysis might point to different types of developmental progression or between-individual processing biases. It will also be valuable to administer this assessment alongside a wider collection of visual processing and attention tests, to fully ascertain the accompanying validity of the measure. Another important aspect of validation will be delineating, as far as possible, the relative contribution of symbol-to-spoken word processing to task performance. Complete separation of visual and verbal processing is arguably not possible within behavioural assessment tasks, but by analysing test performance controlling for verbal ability, the relative contribution of these skills could be explored.

In the remaining part of this General Discussion, the role of age and exposure duration in relation to measuring VA in young children will be further discussed.

3.5.1 Role of exposure duration

An unexpected finding in both Study I and Study II was the lack of significant effect for exposure duration on children's performance in the WR task. In Study I, three different exposure durations were employed, of comparable length to studies with adults (100-150-200 ms), whilst in Study II the number and range of durations was extended further (70-100-150-200-250 ms).

In both studies, the mean number of reported symbols did consistently increase as exposure duration increased, thus one explanation for this result is a lack of statistical power. Having reduced the number of overall trials to make the assessment more appropriate to young children, this means that further dividing results as a function of exposure duration may have made it difficult to discern statistically significant effects in the data.

Alternatively, knowing that children process information more slowly than adults (Kail, 1991; Riggs et al., 2006), it could be suggested that studies of visual processing that have relied on adult models of gaze and saccade patterns may not be applicable to young children, especially those with minimal school experience (and thus reduced experience with processing strings of text and symbols). While small-scale studies of children's visual processing have been reported (e.g. Yang, Bucci, & Kapoula, 2002), these findings suggest the need for increased empirical research regarding childhood visual cognition in order to better understand the role of exposure duration in young children's visual processing.

3.5.2 Role of age

To investigate within sample age effects the focus was first put on the WR, where single performance scores were yielded. Regarding the observed relationship between age of participant and storage capacity, the WR results of Study I showed evidence for cross-sectionally observed developmental differences. This goes in line with other reported findings of visual short term memory capacity continuing to develop during early childhood (e.g. Riggs, et al., 2011). At the same time, no significant age effects were found in children's performance on the PR for both their ability to report targets, but also to disregard distractors.

Another opportunity to consider age effects arose indirectly in relation to the PR task used in Study I and Study II. The PR task parameters remained unchanged between Study I and II, and given the sequential order of the studies, the mean age of the children in Study I and II differed by approximately four months (mean age of 4.8 years in Study I, mean age of 5.3 years in Study II). As reported, the cohort in Study II (who were a different group of children to those in Study I) performed noticeably better, as a group, than those in Study I, with superior ability to ignore distractors. These findings are slightly more difficult to interpret than the within-in study age effects reported for the WR, as between Studies I and II, the children not only differed in age, but also in the amount of formal instruction they had received at school. The children in these studies were in their first year of schooling and acquisition of skills such as letter knowledge have been shown to have a specific and measurable effect on early cortical visual processing (e.g. Maurer, Brem, Bucher, & Brandeis, 2005), that is separable to developmental maturation per se. This study was not designed to differentiate the specific effect of formal instruction versus age on the development of VA, but it has to be noted that differing instructional environments, as well as varied international practices when reading instruction commences, may have an impact on VA development, and thus the sensitivity of assessment measures across contexts.

3.6 Conclusion

Overall, this study is the first of its kind, to the authors' knowledge, to show that measuring VA based on TVA appears feasible in such a young age group. By adopting this kind of VA assessment the role of VA in early learning, and the reciprocal relationship between children and their instructional environment may be better understood.

Based on the results of the two studies that constitute this study, the following decisions were made regarding the fixation of the VA assessment for the data collection phase of the main study commencing in September 2016.

- Reflecting on the two tested designs of the WR, it was decided to include the revised version as applied in Study II – four symbols displayed in a row in the centre of the screen – into the test battery of the main study. The second version of the test was not only thought to be more accessible to the target group, but was also considered to show a better estimation of participants' storage capacity (K).

- Resulting from participants' biases in reporting some symbols more frequent than others in the WR, it was decided to make further adjustments to the symbol pool: "Pot" was excluded from the main study as it seemed to be the least unclear symbol, with many children referring to it as a "pan" or a "bin". In addition, "bell" was taken out from the sample pool of the main assessment, as it was named least often by the participants. Finally, and after discussion within the research team, it was further decided to exchange "clock" with a different symbol. This decision was made based on the experience of researchers during data collection that seemed to suggest that many participants hesitated when naming the symbol, even though this observation was not necessarily reflected in the analysis of the data. New symbols were chosen based on the same selection criteria as the other items and were: "cake", "hand", and "ball".

- The wide range of performance on both VA assessments across all participants led to the conclusion that a comparably low number of trials still provides reliable information in regards to participants' VA skills. However, trial numbers for the main study were slightly increased and set at 60 for the WR and 72 in the PR. However, to prevent a decrease in children's performance and to counteract potential challenges to maintain attention, as observed in the longer 100 trial version of the WR in Study II, it was decided to deliver the assessment in two separate sessions, each containing half of the WR and half of the PR trials.

- The closer exploration of correlation between number of reported items and exposure time in the WR task, showed a positive relationship between an increase in the selected exposure durations and the number of symbols students reported on average. As a result, exposure durations were set at: 70-100-150-200-250 ms. The decision to go beyond the "critical" line of 200 ms was made based on studies (Riggs et al., 2006; Kail, 1991) suggesting that children process information much slower than adults and making an adjustment to exposure durations necessary.

- Finally, after comparing the options of testing children on the PR and the WR (Study I & group A in Study II), versus an extended version of the WR only (group B in Study II), it was decided to test children on the WR and the PR in the main test phase: This decision was based on two reasons: First, testing children on the PR and WR, as opposed to the WR only has the advantage to get more information on each child, by providing more parameters associated with VA by the TVA model (Bundesen, 1990, 1998). Second, the observed differences in the PR done by participants in Study I and II rose interest in further investigating to what extend the ability to distinguish between targets and distractors increases within the first year of instruction in school.

Chapter 4 – Study design, methods, & procedure

This chapter will address the details of the main study design. Within this chapter, further information will also be provided on the selection of participating schools and the participants themselves. Subsequently, all methods used to collect the data, as well as the data collection procedure will be described.

4.1 Study design

A longitudinal design was adopted to address the research questions stated in section 2.8. The project consisted of two time points (t1 and t2). Reception year children's visual attention (VA) profiles and their academic readiness and cognitive skills (including phonological awareness, letter-sound knowledge, receptive vocabulary, non-verbal ability) were investigated at the beginning of Reception (with children being 4-5 years of age) and re-assessed one year later, at the beginning of Year 1 (with children being 5-6 years of age). Data collection was carried out over a period of eight weeks at both time points. Efforts were made to maintain the same order in which testing was carried out at both time points to control time intervals between t1 and t2. Data collection was conducted by the author and with the help of a research assistant[5]. An overview of the study's time frame is given in Figure 4.1.

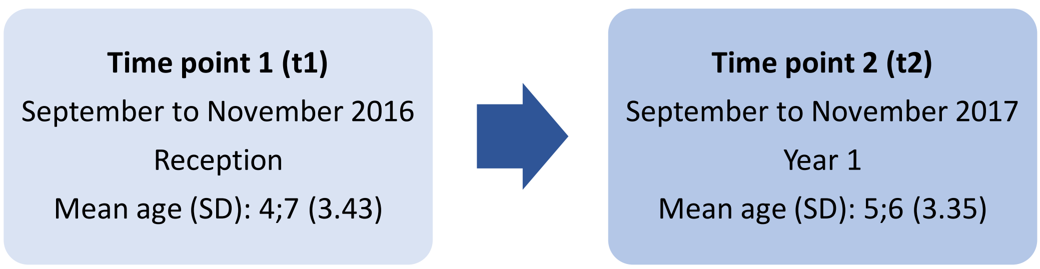

Figure 4.1 *Overview of study time frame, including participants' educational phase, mean ages and SDs*

The study received ethical approval from the Ethics Review Committee of the Department of Human Communication Sciences in line with the University of Sheffield ethics procedures (see Appendix B).

[5] Jen Neary (née Roche) assisted with data collection at t1 and Dr Chloe Bate at t2.

4.2 Participants

In total, 140 Reception Year children were involved in the study. All participants were recruited from four UK Primary schools, with two of them located in South Yorkshire (Schools A & B), one in Lincolnshire (School C) and one in the West Midlands (School D). Schools were initially contacted in spring 2016 via email/phone to provide information on the project and to invite them to participate. This was followed by a face-to-face meeting with head teachers and Reception class teachers from schools which expressed interest in the study to discuss further details of the project. In consultation with members of staff, parental information leaflets and consent forms were then sent by post to the schools at the beginning of the school year (September 2016) and distributed among parents, whose children had just started Reception.

Schools were selected based on two factors: 1) the proportion of students receiving free school meals (FSM) and 2) the proportion of students with English as an additional language (EAL) (see Table 4.1). The initial aim was to recruit schools in lower socio-economic areas, given that research first reported in the NLT (National Literacy Trust) annual reading report in 2012 (Clark, 2013) suggested that reading digitally might be more advantageous to struggling readers, typically associated with low SES. However, due to the challenges of recruitment, the sample ended up being more diverse: Participants were recruited from two schools (Schools B & C) with a lower and two schools (Schools A & D) with a higher than the national average number of children eligible for free school meals (FSM), used as an indicator of low socio-economic status. Analyses of the relationships between assessed skills, controlling for children's SES, suggested no difference in performance between children receiving FSM and children not receiving FSM for the majority of measures at t1 and for all measures at t2. The two significant comparisons at t1 where children not receiving FSM performed significantly better than children receiving FSM were:

- T1 YARC Sound deletion – $t(138) = 1.99$, $p = .049$
- T1 Partial report task – $t(138) = 2.11$, $p = .037$

Additional analyses checking whether children attending the high-SES school in the sample (School B) outperformed children from the remaining schools, showed no significant differences across all measures.

Table 4.1 *Characteristics of selected schools, including schools' proportion of the sample, EAL (=English as an additional language), and FSM (=free school meals) data*[6]

Schools	Proportion of sample	EAL	FSM (in past 6 years)
School A	20.0%	13.4%	57.6%
School B	33.6%	1.8%	12.7%
School C	29.3%	3.4%	25.6%
School D	17.1%	49.7%	60.7%
National average		**19.4%**	**26.4%**

Considerations regarding the recruitment of children being English native or non-native speakers, were based on the requirements of the VA assessment: As it requires rapid naming of symbols, good levels of English across all participants was vital to ensure the validity of the test – assessing VA rather than language skills. As a result, recruited schools' EAL proportion was lower than the national average, with the exception of School D. In this school we only recruited EAL children with preschool exposure to and good command of English. This was ensured by close collaboration with classroom teachers who offered their advice in the selection process. Finally, teachers' expertise was also incorporated in the decision making, regarding children, with special educational needs and disabilities (SEND). Children on the SEND register were therefore not excluded from the sample, but teachers were consulted towards the nature of their specific needs and whether they would impact the cognitive and linguistic demands of the assessments. As a result, it was decided to include one child with SEND at t1, as they had a motoric disability which was not felt to have impacted their performance.

Parental consent for participation in the study was received for 140 children from the four selected schools. Characteristics of the sample at time point 1 (t1) are summarised in Table 4.2.

[6] Retrieved from https://www.compare-school-performance.service.gov.uk in January 2016.

Table 4.2 *Overview of all participants taking part in t1 of the longitudinal study*

	School A	School B	School C	School D	Total
Number of participants	28	47	41	24	**140**
Mean age (SD)	4;7 years (3.26 months)	4;8 years (3.63 months)	4;8 years (3.21 months)	4;7 years (3.27 months)	**4;7 years (3.35 months)**
Gender	15 female, 13 male	25 female, 22 male	22 female, 19 male	11 female 13 male	**73 female 67 male**
Ethnicity	26 White British / British 2 other backgrounds	45 White British 2 other backgrounds	39 White British 2 other backgrounds	13 White Brit./O. White British 8 Black African 3 other backgrounds	**123 White Brit. / British / O. White British** **8 Black African** **9 other backgrounds**
FSM	9	3	1	2	**15**
EAL	2	0	1	10	**13**
SEND	0	0	1	0	**1**

At t1, the sample was fairly evenly distributed in relation to gender, comprising of 52.1% female and 47.9% male students. When looking at the ethnic background of the participants, an overwhelming proportion of students were White British, other White British or British, with 123 students (87.9%) belonging to one of these categories. Interestingly, the proportion of children eligible for free school meals (FSM) was rather low in all schools across the sample at t1, with the exception of school A, where 32.1% of tested children were registered for FSM. In line with the EAL proportion of the participating schools, the EAL proportion in the overall participant sample was very low in all schools except school D, where 41.7% of the tested students were regarded as not having English as their first language.

Unfortunately, some attrition occurred between t1 and t2. Reasons for attrition at t2 are outlined in Table 4.3. While five children had either moved school or were absent during t2 assessment, the decision was made to exclude two additional children, based on teachers' advice highlighting their increased needs in relation to their newly received SEND status during the first year of schooling. Data collected from these children at t1 were analysed and included in the results section of t1 (Section 6.1.1), but excluded from the longitudinal data analysis described in Chapter 6.

Table 4.3 *Reasons for participant attrition at t2*

Reasons for attrition	**Number of children**
Change of school	2
Long-term absence	3
Newly received SEND status	2
Total	**7**

Overall, 133 of the initially recruited 140 children were tested at both time points of this longitudinal study. When comparing the data from t1 and t2, the gender proportions in the two samples shifted by one percentage point to 51.1% female and 48.9% male participants tested at t2. The proportion of White British, other White British or British participants remained high, making up 88.7% of the sample at t2. Numbers of children eligible for free school meals (FSM) rose from 10.7% at t1 to 24.1% at t2, while the EAL proportion of the participant sample remained unchanged, with 9% of all tested children at both time points being regarded as not having English as their first language. Finally, the proportion of participants with special educational needs or disabilities (SEND), rose from one child at t1 to a total of 9 children (6.8%) at t2. The rise in the number of children classified as SEND was expected at t2, since SEND assessments were usually completed during the first year of schooling. Every child with parental consent, even if classified as SEND, was included in the sample, unless parents excluded them or teachers advised against testing.

4.3 Data collection methods

This section will first describe the adapted VA assessment: Children were tested on an adapted VA assessment based on Bundesen (1990, 1998) and tested in a pilot study and subsequently adjusted based on the results described in Chapter 3. In addition, cognitive and linguistic measures adopted in this thesis will be outlined, which comprised assessments of phonological processing skills (phonological awareness, nonword repetition – as a measure of short-term memory), a language measure (receptive vocabulary), two literacy measures (letter-sound knowledge, single word reading) and tests on children's non-verbal ability, as well as general attentional skills. Lastly, questionnaires adopted to gain further information on children's exposure to digital devices and their personal preference to read across different formats, will be discussed.

Data were collected during two sessions at each time point. An overview of tasks administered at t1 and t2 is given in Table 4.4 below.

Table 4.4 *Overview of all measures administered in the longitudinal study*

Assessments	t1	t2
Visual attention		
Whole report (WR)	X	X
Partial report (PR)	X	X
Phonological awareness		
YARC sound deletion	X	X
YARC sound isolation	X	X
Letter knowledge		
YARC letter-sound knowledge	X	
Vocabulary		
BPVS receptive vocabulary	X	X
Short-term memory		
ERB Nonword repetition	X	X
Nonverbal IQ		
WPPSI block design	X	
Word reading		
DTWRP single word reading		X
Attention & executive function		
Flanker task		X
Children's digital device use		
Parent questionnaires	X	
Student interviews		X

4.3.1 Visual attention assessment

The VA assessment used in this longitudinal study was developed by the author and is based on Bundesen's Theory of visual attention (Bundesen, 1990, 1998). A detailed description of the development and the piloting of this assessment can be found in the previous chapter (Chapter 3). Following the analysis of the pilot study results, the VA assessment included in the test battery of the longitudinal study was delivered as follows:

At the beginning of the task, participants were individually invited to 'play a game' on a tablet together with the test administrator. The assessment consisted of two parts – whole report (WR) and partial report (PR) task –, with each of them containing an initial practice phase and a main test phase. In order to keep attention demands at a reasonable level, the two tasks were further split in half, resulting in four sessions (2 WR and 2 PR sessions), lasting about 8 minutes each. Two sessions (1 WR and 1 PR task) were performed in the first assessment session of a time point (= morning session), and the remaining two in the afternoon session of the assessment. In order to make the assessment accessible for the target group, letter stimuli were replaced by the illustration of familiar objects. These were displayed as black symbols to ensure that the objects were clear but at the same time not overly appealing. Stimuli were presented on a Samsung Galaxy Tab 4 for Education (10.1 inch, 1280 x 800 LCD) and were randomly chosen from the following set: car – cake – house – sun – hat – dog – ball – hand. Decisions on which symbols to choose were based on the results of the pilot study.

Before the practice phase, the child was given a description of the task and got the chance to familiarise themselves with the symbols used in the assessment: Symbols used in the task were shown on paper and children were asked to identify each one. This way researchers ensured that children were able to name the symbols independently and confidently before completing the task. In addition, an additional reward chart (separate to the one used for indicating a child's overall progress in completing the assessment battery tasks, further described in section 5.5) was introduced with the explanation that the completion of each block of trials was rewarded with a sticker. Each child was then told to sit at the table and to hold the tablet with both hands, putting their thumbs on thumb markers placed on the right and left bottom corner of the tablet case to make sure that the tablet stayed in the area that has been marked on the table with coloured tape (15 cm away from the desk end). Before starting the actual testing, children were given time to get to know test conditions by completing four trials in an initial practice phase together with the researcher. During this phase children received feedback and were encouraged to name as many symbols as they could see. This ensured that all children were sure about the requirements of the test phase.

4.3.1.1 Whole report

Following a centred black fixation cross on a white background (1000 ms) and a subsequent white screen (50 ms), the silhouette of four symbols (from the total set of eight described above) were presented in a horizontal line in the centre of the screen (Figure 4.2). Symbols were shown at five different exposure times (70 ms – 100 ms – 150 ms – 200 ms – 250 ms). With the string of symbols spanning 18 cm on the screen, symbols were separated by 3 cm each. The symbol string presented in each trial was unique and, following the TVA test design (e.g. Bogon et al., 2014; Duncan et al., 1999), appeared only once on a given trial. Assuming that the tablet was held at a distance of 30 cm, a symbol would subtend about 33.4°. After each trial of the WR task the child was asked to make an unspeeded verbal report of as many symbols as he/she was able to recognise on the screen. Each child completed 60 WR trials – 12 iterations x 1 position (centred) x 5 exposure durations – divided into two sessions of 3 blocks (each block consisting of 10 trials). One session performed in the morning testing session and the other one performed in the afternoon of each time point.

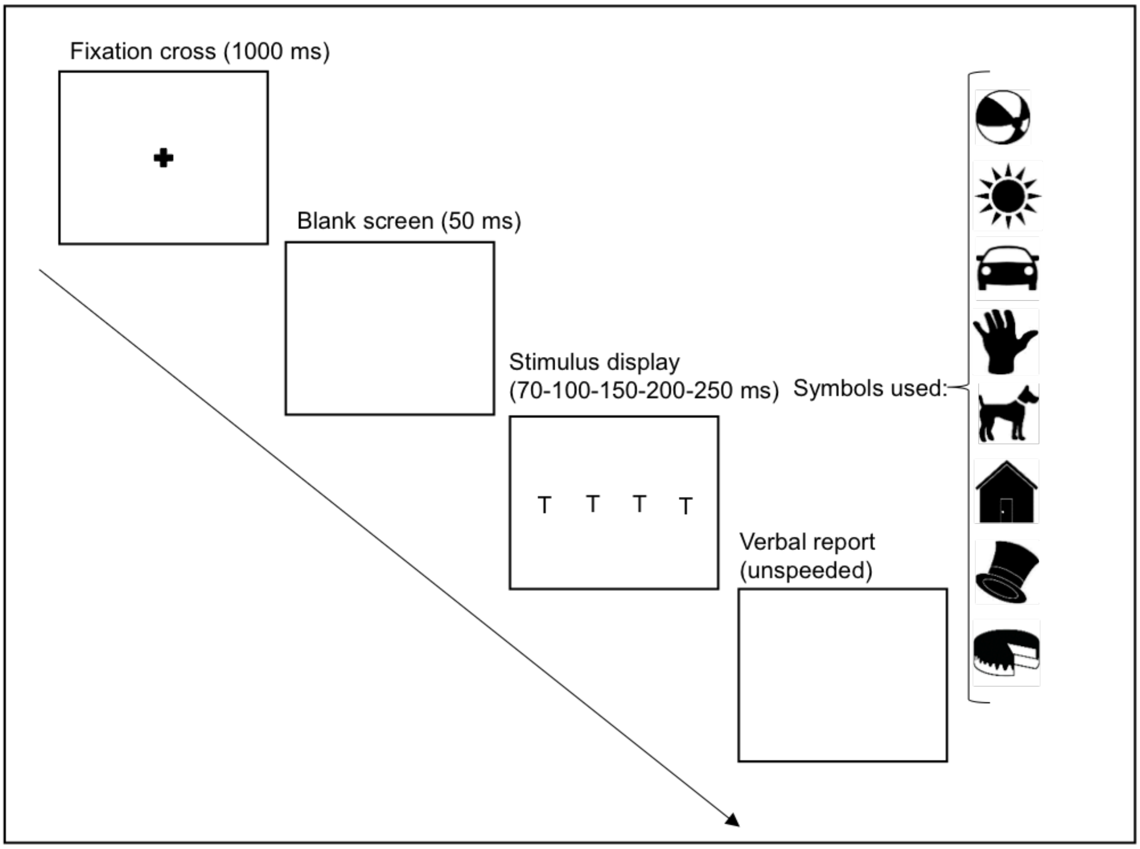

Figure 4.2 *Whole report of the longitudinal study*

The WR task was used to evaluate participants' performance in terms of how many symbols they were able to name in each task on average, in relation to the five different exposure durations. This way possible differences between students' visual short term memory span (comparable with VSTM capacity K) could be yielded, defined as the amount of visual elements which can be processed in parallel in a multi-element array during a single fixation (Bosse, Tainturier, & Valdois, 2007). For analysing the data of the WR, the number of correctly identified symbols was totalled for each trial and a mean was computed to create a WR score for each participant. Internal reliability was computed for the WR by investigating the performances of all children tested at t1. Cronbach's alpha resulted in $\alpha = .93$.

In addition, some further analysis of the WR data was conducted to gain a deeper understanding of children's performances on the task. First, and in line with analysis conducted in the pilot study (Chapter 3), the exposure time effect on task performance was looked at in more detail in order to investigate whether the selected exposure durations showed the desired increase of reported symbols with an increase in exposure duration (Duncan et al., 1999). Furthermore, children's symbol position preference was explored and therefore the distribution of correctly reported symbols according to the four different display positions on the tablet (rightmost – right – left – leftmost position). This investigation formed the basis of further analyses that looked into whether these position preferences indicated a left-to-right bias in the reports of tested children, a phenomenon that would be expected from more experienced readers in English or other languages with a left-to-right writing direction (Spalek & Hammad, 2004, 2005).

4.3.1.2 Partial report

This task started similarly to the WR, with an explanation of the task and four practice trials. At the start of each trial, a central fixation point was presented for 1000 ms followed by a blank screen for 50 ms. In each of the trials there were four array locations (upper left, lower left, upper right, lower right) arranged in a square (12x18 cm) around the fixation point. The array locations were 6 cm apart vertically and 9 cm horizontally. Assuming that the tablet was held at a distance of 30 cm, the rectangle containing the symbols would subtend approximately 19.8° diagonally. In each trial, one or two symbols, out of six symbols used in the WR – sun, car, house, hat, hand, dog – were displayed for 150 ms at a time. The probe indicating a target was a circle, presented for 50ms at the location where the target symbols had previously appeared. The child was instructed to report the target symbols only (Figure 4.3).

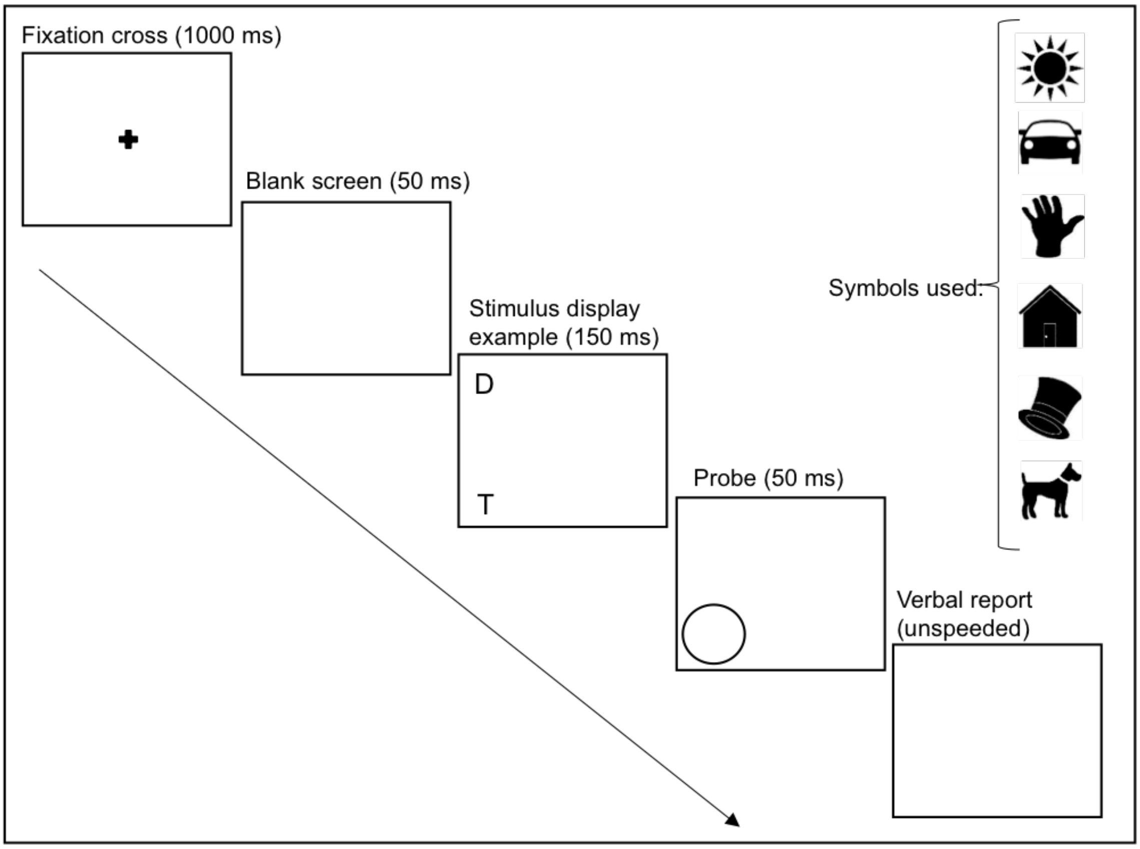

Figure 4.3 *Partial report of the longitudinal study*

In different arrays, a target was presented either alone, in pairs, or together with a distractor (Figure 4.4). In addition, targets were presented alone in each of the four locations, while pairs of targets and pairs of targets and distractors, always being two different symbols, were presented in a row or a column (Duncan et al., 1999). The PR was broken into two sessions (morning and afternoon) consisting of 36 trials (3 blocks of 10 and 1 block of 6) each, to manage attention demands.

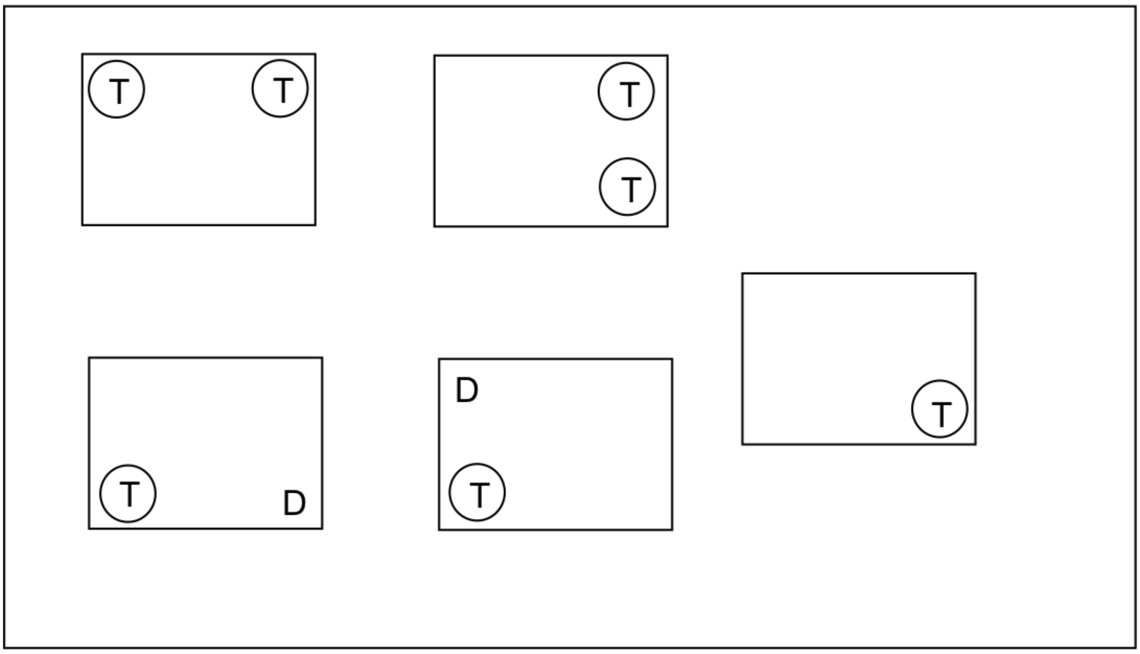

Figure 4.4 *Different stimuli displays of the partial report task in the longitudinal study with target (T) and distractor (D) symbols*

The PR was used to further investigate children's top-down attentional control (α) and thus their ability to report targets, while disregarding distractors. The task consisted of a total of 72 trials, with children being exposed to 96 targets and 24 distractors in total. In a first step, it was investigated how many targets and how many distractors each participant reported across all PR tasks. Since there were 4 times more targets than distractors in the task, each participant was awarded one point for each reported target and lost 4 points for each reported distractor. Based on the proportion of reported targets versus reported distractors, a PR score was computed for each participant reaching from a possible overall high score of +1 (report of all targets paired with no report of distractors), to an overall lowest score of -1 (report of all distractors and no reported targets). Internal reliability was computed for the PR by investigating the performances of all children tested at t1. Cronbach's alpha resulted in α = .87.

4.3.2 Cognitive, linguistic predictor & outcome measures

The tests used at either both or one of the time points to assess phonological processing skills (phonological awareness, nonword repetition – as a measure of short-term memory), a language measure (receptive vocabulary), two literacy measures (letter-sound knowledge, word reading), children's non-verbal abilities (NVIQ), as well as their general attentional skills are described below.

4.3.2.1 Phonological awareness (t1 & t2)

In order to capture children's phonological awareness (PA), and more specifically phonemic awareness skills, sound deletion and sound isolation assessments taken from the YARC – Early Reading Battery (Hulme et al., 2009) were adopted at both time points.

4.3.2.1.1 York Assessment of Reading Comprehension (YARC) – Sound deletion

This assessment was adopted to test children's ability to identify and remove sounds within spoken words, and comprised 19 real words (7 practice items and 12 assessment items). The degree of difficulty increased over the length of the task: A child was first asked to delete a syllable from a word. This was followed by the requirement to delete the final phoneme, then the initial phoneme, and finally a medial phoneme of the word. Practice items were conducted each time before a change in the position of the deletions. Pictures of the items were used during testing. The test administrator showed the picture to the child and named the item. In a next step, the child was asked to first correctly repeat the item name and then again, without either the first syllable, or the first, final or middle phoneme. Each item was rewarded with 1 point when the response was correct at the first attempt. No or incorrect were scored with 0 points. The total raw score was given out of 12 possible scores. Internal reliability of the assessment was α = .93 (Hulme et al., 2009).

1.1.1.1.1 YARC – Sound isolation

The sound isolation assessment from the YARC tested children's ability to isolate sounds within spoken words. The assessment entailed 18 nonwords (6 practice items and 12 assessment items). For the first six nonwords, participants were required to isolate the first phoneme, for the last six items the last phoneme. Each section was introduced by three practice items. To ensure good engagement with the task, pictures of aliens were used for each item as support. The test administrator introduced each nonword as the name of an alien on the picture. The participant was then asked to repeat the nonword and to either identify the first or the final phoneme of each item. Correct responses at the first attempt were awarded with 1 point, no or incorrect responses were scored with 0 points. This resulted in a total raw score out of 12 possible scores. Internal reliability for this assessment was α = .88 (Hulme et al., 2009).

4.3.2.2 YARC – Letter-sound knowledge (t1)

The Letter-sound knowledge (LSK) core assessment from the YARC Early Reading battery (Hulme et al., 2009) was used to assess children's knowledge of letter-sounds at time point 1. Each child was presented with 11 lower case letters (s, m, p, t, i, n, a, f, h, d, j), as well as 6 digraphs (ee, sh, ch, th, oo, ay) in a set order. Children were then asked to name the associated sound of each letter/digraph. Researchers encouraged children to name the sound of an item, even if they felt unsure. If children gave the letter name, they received positive feedback but were at the same time prompted to name the sound instead. Only responses with the correct sound of the letter/digraph as outlined in the YARC assessment manual were accepted as correct and awarded with 1 point, while no or incorrect responses were scored with 0 points. The maximum possible score was 17. Internal reliability for this assessment was reported as $\alpha = .95$ (Hulme et al., 2009). Since it was assumed that children's average performance would reach ceiling at the beginning of Year 1, the test was removed from the test battery at t2.

4.3.2.3 British Picture Vocabulary Scale (BPVS) – Receptive vocabulary (t1 & t2)

The British Picture Vocabulary Scale – Third edition (BPVS-III) (Dunn et al., 2009) was used to test children's receptive vocabulary knowledge. The test consisted of 14 sets, each containing 12 items, and the difficulty of the vocabulary increased with each consecutive set. Children were asked to put their finger on one of the four presented pictures that best represented the word spoken by the test administrator. The items included in the test covered a wide range of word classes and semantic categories.

A child's age at the day of testing determined the appropriate starting set, as specified by the BPVS instruction manual. Children were allowed to make up to 8 errors in order to proceed to the next set. In instances where children made more than one mistake in the starting set, the test was administered backwards until a set was reached where the child made 0-1 errors. Testing then progressed forward as usual. Each correct item was awarded with 1 point, no or incorrect responses scored 0 points. The BPVS includes norms for children from the age of 3;0 to 16;0 and was conducted at both time points. It is not possible to report a single reliability co-efficient for the BPVS due to its relatively complex administration and multiple entry/exit points. The reader is referred to the BPVS technical manual for further information (Dunn et al., 2009).

4.3.2.4 Early repetition battery (ERB) – Nonword repetition (t1 & t2)

To test children's phonological short-term memory and morphosyntactic processing abilities, the nonword repetition assessment of the preschool repetition test, part of the Early Repetition Battery (ERB) (Seeff-Gabriel, Chiat, & Roy, 2008), was used at t1 and t2. The test consists of 18 nonwords, ranging in length from one to three syllables. Both the test administrator and the child wore headphones to listen to a recording of the nonwords. A recording of the nonwords was used to ensure reliability of administration. In addition, the recording was produced by a female speaker with a standard British English accent to ensure standardised pronunciation. The children were told that they would hear some funny words that they should repeat as soon as they had heard them. The test administrator paused the recording after each word to ensure that the child was given enough time to listen and repeat the nonword. 1 point was awarded for each correctly repeated item, no or incorrect responses scored 0 points. Points on all items were summed up to yield a score, between 0-18 points. Internal reliability for this assessment was reported as $\alpha = .89$ (Seeff-Gabriel et al., 2008).

4.3.2.5 Wechsler Preschool and Primary Scale of Intelligence (WPPSI) Block Design – NVIQ (t1)

The Block Design assessment of the WPPSI (Wechsler, 2002) was used to test children's NVIQ. In this test children were first asked to recreate a block design from a model, and in later trials from an image. This activity was performed with coloured blocks within a specified time limit and children were asked to complete the task as accurately and quickly as possible. The assessment comprised 20 items. The first 12 items required the test administrator to assemble the model in front of the child first, before giving the child the same blocks to recreate the model. For item 13, the test administrator showed the child an image of the target model and again showed how to assemble the blocks in front of the child. After this, the model was taken apart and the same blocks were handed over to the child, who was asked to have a go at it themselves. For items 14-20 the child was only shown the image of the design and was asked to model it by themselves. All children started at item 6, set as the starting point for children of that age group. Children scored 2 points for each correctly assembled item, 0 scores were awarded when the model was incorrect. Internal reliability for this assessment was reported as $\alpha = .84$ (Wechsler, 2002). Since children's NVIQ is considered to be a stable characteristic (Deary, Whalley, Lemmon, Crawford, & Starr, 2000), this assessment was only administered once at t1 (beginning of Reception).

4.3.2.6 Diagnostic Test of Word Reading Processes (DTWRP) – Single word reading (t2)

The Diagnostic Test of Word Reading Processes (DTWRP) (Forum for Research in Literacy and Language, Institute of Education, 2012) was included in the assessment battery at the second time point to assess children's single word reading. The assessment consisted of three parts, administered in the following order: Nonword reading, Exception word reading, and Regular word reading. Each assessment contained 30 items that increased in difficulty. The test administrator showed a test plate for each assessment, which contained all items. Children were instructed the read as many items as possible. If children decoded the item correctly but failed to blend the sounds, they were encouraged to have another go. The assessment was stopped after five consecutive errors. Each assessment had a total of 30 points to award. 1 point was given for each correctly read or blended word, while incorrect or no responses received 0 points. Age norms for this test were reported based on a UK norming sample for children between the ages of 5;0 – 12;11, with a reliability of $\alpha = .99$ for the complete test (Forum for Research in Literacy and Language, Institute of Education, 2012).

4.3.2.7 NIH-TB Flanker Inhibitory Control and Attention Test – Attention & executive function (t2)

At t2 the attention & executive function (A & EF) measure was included in the assessment battery to investigate whether the VA assessment of the study was sufficiently different from other more general measures of attention and executive function. Children's overall attentional skills/executive function was tested using an adapted version of the Eriksen flanker task (Erkisen & Eriksen, 1974), which derived from the Attentional Network Test (Fan et al., 2002). This test, adapted by the author and following the characteristics of the NIH-TB Flanker Inhibitory Control and Attention Test (National Institutes of Health and Northwestern University, 2012), investigated children's ability to inhibit VA to irrelevant distractor stimuli. In addition, the task lasts for about 7 minutes and was designed with the OpenSesame program to be administered on a Samsung Galaxy Tab 4 for Education (10.1 inch, 1280 x 800 LCD) (the same used for the VA assessment).

After an introductory and practice phase, each trial was initiated with a blank white screen (500 ms), followed by a central yellow star as fixation point on a white background (700 ms). Subsequently, flankers (two items on the right and two on the left of the target position in the middle) were displayed in a horizontal line in the middle of the screen for 10 000 ms. Some parameters of the test were removed, including the display of a cue 'Middle' indicating the location of the target (1000 ms) followed by the display of the flankers (100 ms), located between the fixation and the test stimulus display (see Figure 4.5), as well as the voice prompt, which during piloting were felt to be unnecessary. To make the task more appealing for children, the arrows, typically used as stimuli in a flanker task, were replaced by five blue fish (with black arrows depicted within the shape to further emphasise the item direction), presented over a white background. This decision further goes in line with reports of a previous study (Berger, Jones, Rothbart, & Posner, 2000), claiming that children's work on assessment tasks is best when the task is embedded in a story and children receive clear performance feedback. Children were therefore instructed to feed the middle fish by choosing one of the two marked buttons: the keyboard button for the letter "Z" marked with a red sticker, when the fish was pointing to the left, and the "M" button marked with a yellow sticker, when the fish was pointing to the right. Responses were hence given by pressing the right or the left marked button on the keyboard which was connected with the tablet, depending on the direction of the target fish (see Figure 4.5). While children were encouraged to press the button as quickly as possible, the time limit was deliberately chosen to be 10 seconds, so that children would not be explicitly rushed by the task itself. The task consisted of two trial conditions: either all fish were pointing in the same direction (congruent trials), or the fish to the left and the right (flankers), pointed in the opposite direction from the central fish. In line with the NIH-TB cognition battery flanker task as described by Weintraub et al. (2013), the assessment consisted of 40 trials, 20 with a congruent, 20 with an incongruent condition, mixed up in a random order. In order to ensure children's engagement with the task, a short break was included half-way through the test.

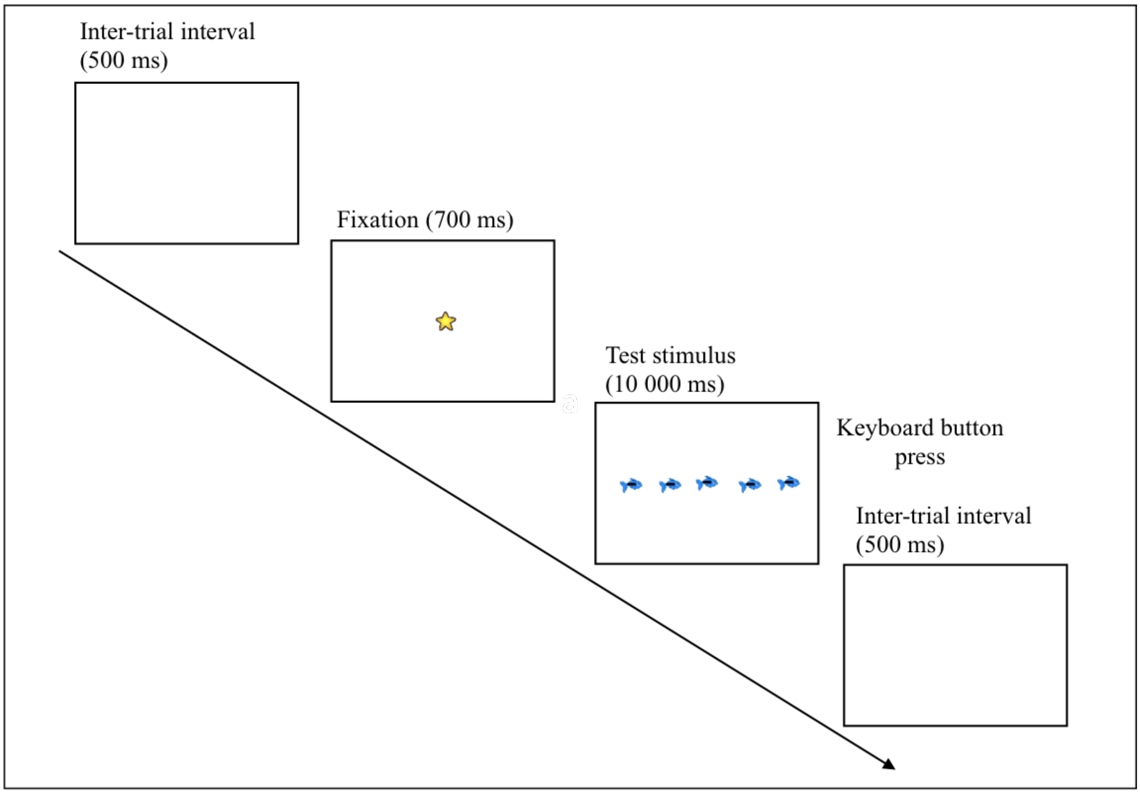

Figure 4.5 *Flanker task adopted at t2*

For each participant an accuracy score, defined as the proportion of correct responses, as well as the mean of reaction times of correctly reported responses was yielded from the data. For the accuracy score participants were therefore rewarded a score between 0-1 for each trial, while reaction time was reported in ms. The internal reliability for this test was $\alpha = .96$.

4.3.3 Questionnaires & student interviews

Parent questionnaires were initially included in the study to gather information on children's exposure to digital devices prior to school entry. This was supplemented with questionnaires given to class teachers in order to find out more about how digital device use was integrated in schools curriculum delivery. After analysing the data gathered from parent/ carer questionnaires (see chapter 6.3.1), it was felt that the questionnaires used at t1 were not sufficient to answer questions regarding children's digital device use outside of school. As a result, it was decided to include a short student interview in the assessment battery at t2, to fill the identified gaps by giving participants the opportunity to voice their opinions regarding their digital device use.

4.3.3.1 Parent/ carer questionnaires at t1

At t1, questionnaires were given to all parents/carers together with the information sheet and consent form. With 110 (78.6%) out of 140 questionnaires returned, the response rate overall was at a high level, ranging from 100% returned questionnaires in School B, to 51.2% in School C (Table 4.7).

Table 4.5 *Questionnaire return rate at t1 in each school and overall*

	School A	School B	School C	School D	Total
Returned questionnaires	23	47	21	19	**110**
Gender distribution					
F:	14	25	11	9	**60**
M:	9	22	10	10	**50**

The questionnaire was developed by Jen Neary, research assistant on the project, initially designed for a wider project that addressed a number of broader aims regarding young children's experiences with digital and non-digital text at home prior to entering school. Questions were asked to explore the range of digital literacy practices occurring at home, parents perceptions of these practices, as well as children's preferences for digital or print media.

For developing the questionnaire, a systematic search was carried out as a first step to gather information on already existing studies that investigated preschool children's home literacy environment, yielding 62 results. From these results, studies (Castles et al., 2013; DesJardin, Ambrose, & Eisenberg, 2009; Kim, Im, & Kwon, 2015; Niklas & Schneider, 2013; Phillips & Lonigan, 2009; Ricci, 2011) that collected information about preschool children's home literacy environment through parent questionnaires or parent interviews underwent extensive review. While these studies were not directly addressing children's digital device use, they provided useful information on what to include in a questionnaire. When reviewing these surveys for the purpose of investigating how to typify digital exposure, the domains covered were considerably broad, ranging from children's engagement with and exposure to books, to their television use, parental reading habits, as well as library use. Relevant questions and response options were compiled according to commonality. Subsequently, decisions were made to specifically target questions regarding the extent of children's exposure and engagement with books.

In a next step, a second literature search was carried out to specifically gather information on studies investigating preschool digital device use (Lauricella et al., 2015; Ofcom, 2014; Scholastic, 2014). Questions regarding reading on digital devices were reviewed, which mirrored those asked about reading print books in the home literacy environment studies identified in the first step of the questionnaire development process. Further, decisions were made on the categorisation of types of digital media, when to individually name different devices and when to group them together (e.g. PC and laptop). In research team meetings (attended by the developer of the questionnaire, the author of this study, and the author's supervisor) questions were reviewed and thoughtfully adapted regarding their accuracy and relevance in relation to the constraints and research questions of this project. As a result, the decision was made to incorporate digital devices into each question, in many instances contrasting it with the use of print. In a final step, it was agreed by the researchers to include two open-ended questions regarding parental views on their children's digital device use. The questionnaire was piloted and revised based on participants' feedback before reaching its final format (see full questionnaire in Appendix C).

Due to the relatedness of this questionnaire to the research interests in this study, the decision was made to administer it at t1 and to specifically investigate the answers to two index questions, which were quantifiable for the research questions addressed in this study.

4.3.3.2 Student interviews (t2)

Based on the results from the questionnaires at t1, it was decided to conduct a short interview with each participant at the end of the first assessment session at t2. Questions from the parent questionnaires adopted in t1 were carefully reviewed regarding their suitability for student interviews. As a result, questions thought to be most suitable for the target age group were identified and adapted to the specific constraints of the project. Through this interview it was sought to include participants' views regarding their exposure to books in print or digital, and their overall use for different activities on digital devices in their home environment (see list of interview questions in Appendix D). In line with the analysis of the parent questionnaires at t1, answers to two index questions were specifically investigated as they were quantifiable for the questions addressed in this thesis.

4.3.3.3 Teacher questionnaires (t1)

In order to gain a better understanding how much and for what activities digital devices were used in the classroom, each participating Reception class teacher was asked to complete a questionnaire at time point 1. The questionnaire gathered information on which technology children had access to at school, the amount of time children spent in schools using a range of digital devices, the types of activities digital devices were used for in school, and teachers' personal views on the benefits and downsides of using digital devices in a classroom. Completion of the questionnaires by teachers was voluntary. Completed questionnaires were received from 4 out of 7 Reception class teachers. However, in two instances Reception class teachers from the same school filled in the questionnaire together as they felt their practices were very similar. Overall, information on digital device use could therefore be obtained from three schools, with only the teachers from one school (School B) not completing the questionnaires. While these data were collected, the decision was made to investigate the results of these questionnaires as part of a future publication. The data are therefore not discussed within this thesis.

4.4 Procedure

In this longitudinal project (t1 & t2), children were seen individually by either the author or the research assistants of this project. All assessment sessions were conducted in a quiet room outside the classroom. Due to the length of the test battery (roughly 60min), assessments were divided into two sessions at each time point, with the same child usually being tested for ~30min in the morning and ~30min in the afternoon of the same day.

While it was therefore not possible to stick to a fixed order of the assessments in a few cases, efforts were made to follow an intended strategic order of administration of the assessment tasks at both time points (see Table 4.6).

Table 4.6 *Prototype order of assessments at t1 and t2*

t1 assessment order	t2 assessment order
Morning session	Morning session
BPVS receptive vocabulary	BPVS receptive vocabulary
Visual attention – whole report	Visual attention – whole report
Visual attention – partial report	Visual attention – partial report
ERB nonword repetition	DTWRP single word reading
YARC letter-sound knowledge	YARC sound isolation
Afternoon session	Afternoon session
Visual attention – partial report	Visual attention – partial report
Visual attention – whole report	Visual attention – whole report
YARC sound isolation	YARC sound deletion
WPPSI block design	A & EF flanker task
YARC sound deletion	ERB nonword repetition

The followed sequences contained the following certain specific design features:

- Testing sessions began with the BPVS, a measure that required only little verbal responses from the participants, to allow them to adjust to the testing situation and to familiarise themselves with the test administrator before they were required to speak.
- Tasks were put into an order that allowed for variation in task demand, in terms of level of difficulty, as well as task requirements. This was carried out to ensure that children would not get bored or frustrated in case challenging tasks were put after one another, at the end or at the very beginning of an assessment session.
- Given that the VA assessment was demanding for children's attention, the assessment was specifically placed right after the introductory measure in the morning sessions and at the beginning of the afternoon sessions.
- In line with the argument above, the Flanker task was not administered at the end of an assessment session.

To further support children's motivation to complete the different tasks, sticker charts were introduced at the beginning of the assessment. Children received a sticker for each completed task and a small prize (pencil, rubber, bookmark) upon completion of the second session at each time point.

While the test administrator recorded answers as comprehensively as possible during the assessment session on the data collection sheet, additional audio-recordings were made. These were used to check children's responses after the testing. Measures were scored by the author with the help of all test administrators involved in the study. In those instances, when children's responses were less clear, the author consulted one of the research assistants to ensure a correct interpretation of the data.

Chapter 5 – Performance and development of visual attention in children at school entry and after one year of schooling

This chapter will report findings related to children's performance and development on the visual attention (VA) assessment at school entry, as well as after one year of schooling, and addresses the first two research questions summarised in Chapter 2 and outlined in more detail below:

1) What is the profile of visual attention skills in a normative group of emerging readers at school entry, as well as after the first year of schooling based on Bundesen's Theory of visual attention (Bundesen, 1990, 1998)?
    a. Is there a wide range in participants' performance with no major flooring or ceiling effects on the whole report (WR) task exploring children's VA span at both time points?
        i. Do longer exposure durations cause an increased number of reported symbols on the WR task at both time points?
        ii. Are symbols reported differently according to position in the WR task at both time points?
        iii. Is there a left-to-right reporting bias in the symbol report of the WR task at both time points?
    b. Is there a wide range in participants' performance with no major flooring or ceiling effects on the partial report (PR) task exploring children's efficiency of attentional control at both time points?
        i. Is there a negative correlation between children's ability to report targets and their ability to report distractors?

2) How do visual attention skills develop in children when comparing their performance at school entry and after one year of schooling?
    a. Do children perform significantly better on the WR and the PR tasks after one year of schooling?

In order to answer these research questions, VA profiles of children tested at t1 and t2 will be analysed in the following ways: (i) overall task performance and development for whole report (WR) and partial report (PR), (ii) performance as a function of exposure duration (WR), (iii) performance as a function of symbol position (WR), and (iv) performance as a function of reporting direction bias (WR). The summary and discussion section completing this chapter will consider reported results in relation to relevant VA literature, as well as findings of the previously conducted smaller-scale study, concerned with the development of the VA assessment (Chapter 3). The latter was carried out to compare findings of two studies adopting the same VA assessment for young children at the beginning of their school career.

5.1 Overall task performance and development on the whole and partial report of the visual attention assessment

Children's scores on both tasks of the VA assessment – WR and PR – at t1 and t2 were considered and are outlined in Table 5.1.

Table 5.1 *Descriptives for measures of visual attention on the whole report and partial report at t1 and t2*

	N	*M*	*Mdn*	*SD*	*Range*
Whole report t1 (4)	140	1.48	1.49	.14	.47-2.68
Whole report t2 (4)	133	1.96	1.85	.46	.88-3.37
Partial report t1 (1)	140	.50	.58	.28	- .14- .99
Partial report t2 (1)	133	.72	.74	.20	- .04- .99

Note. For each measure the maximum value is listed in parentheses.

5.1.1 Whole report

Children's performance on the WR task at both time points was assessed by computing the mean of reported symbols per participant across all trials. At t1 the mean of reported symbols across all participants was 1.48 (SD = .14), while being 1.96 (SD = .46) at t2. As can be seen in Table 5.1 above and in Figures 5.1 and 5.2 below, results showed a wide range of reported symbols per trial in the WR across all participants at both time points, with no major floor or ceiling effects reached.

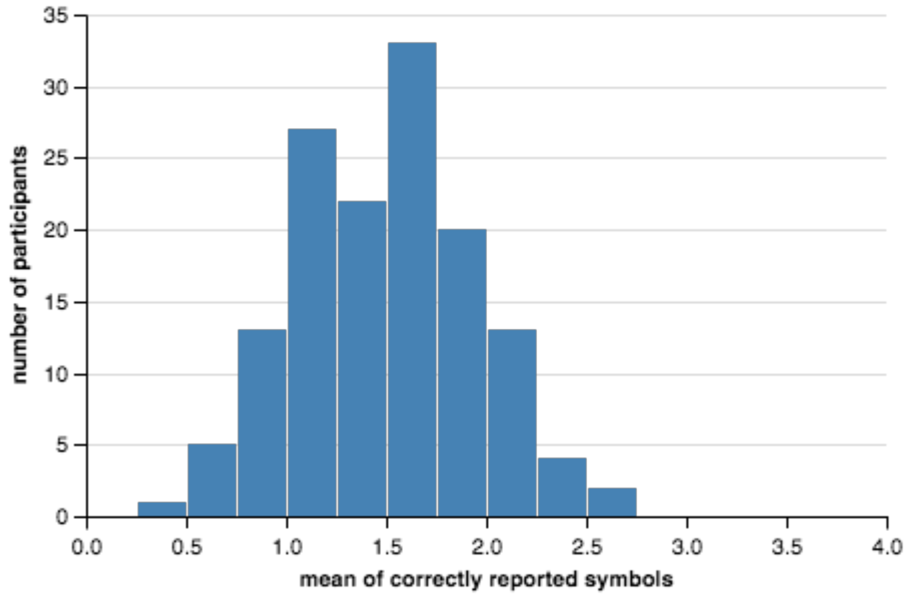

Figure 5.1 *Range of reported symbols per trial in the whole report across all children at t1*

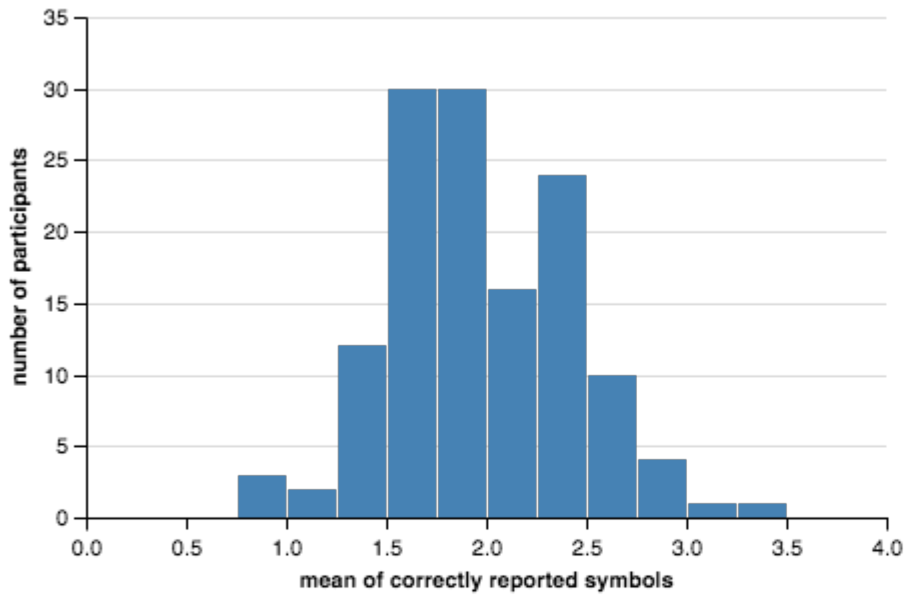

Figure 5.2 *Range of reported symbols per trial in the whole report across all children at t2*

When comparing performance across both time points, it can be seen that children's ability to report symbols on this task rose, with the mean of reported symbols across all participants increasing by .48. When considering the range of the mean of reported symbols across all participants, a further observation was that the maximum in mean of reported symbols was well above three symbols, and therefore rose by .69 compared to assessment results at the beginning of the school year. These observations suggesting that children showed better ability to report symbols after the first year of schooling was further confirmed by results of the repeated measures ANOVAs, which showed a significant increase in children's performance at t2 when compared to t1 ($F(1, 132) = 173.12, p < .001$).

5.1.2 Partial report

Children's performance on the PR was assessed by computing a PR score, which displays a child's ability to report targets while at the same time ignoring distractors. With a range of possible scores between -1 – indicating a report of all distractors and no targets – and +1 – meaning the opposite, a report of all targets and no distractors –, the PR score mean at t1 across all participants was .50 (*SD* = .28), and .72 (*SD* = .20) at t2. As can be seen in Table 5.1 above and in Figure 5.3 and 5.4 below, there is a range of performance at both time points. Children's improvement on the PR task between t1 and t2, however, appears to manifests as more of a negative skew in the t2 distribution.

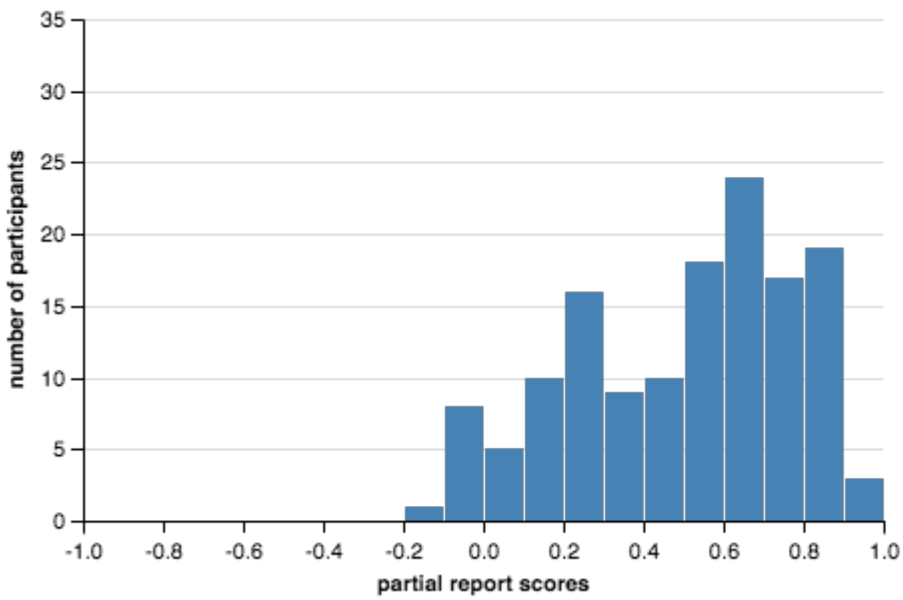

Figure 5.3 *Range of partial report scores across all children at t1*

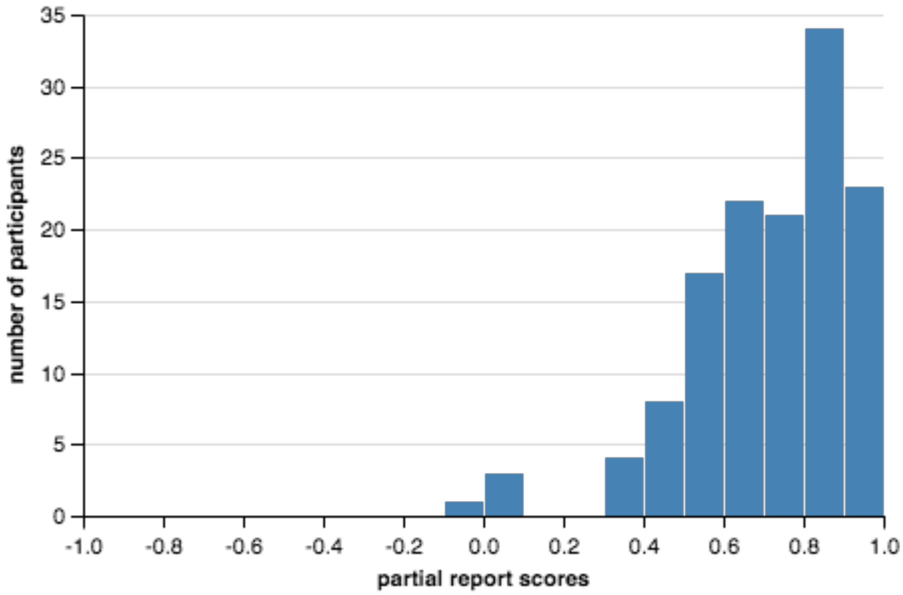

Figure 5.4 *Range of partial report scores across all children at t2*

To gain a deeper understanding of participants' skills in reporting targets related to their ability in disregarding distractors, participants' individual performance on the PR was further explored by looking at the correlation between ratio of reported distractors and ratio of correctly reported targets for each participant at both time points. In the two figures below displaying results at t1 and t2, each participant is depicted by a blue circle (Figure 5.5 and 5.6).

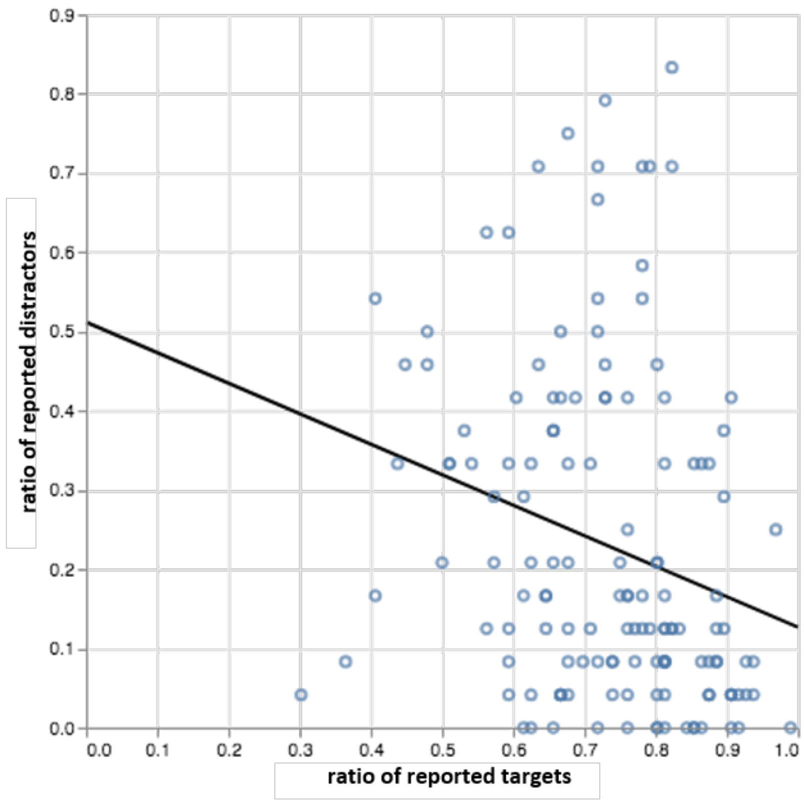

Figure 5.5 *Performance of all children on the partial report at t1*

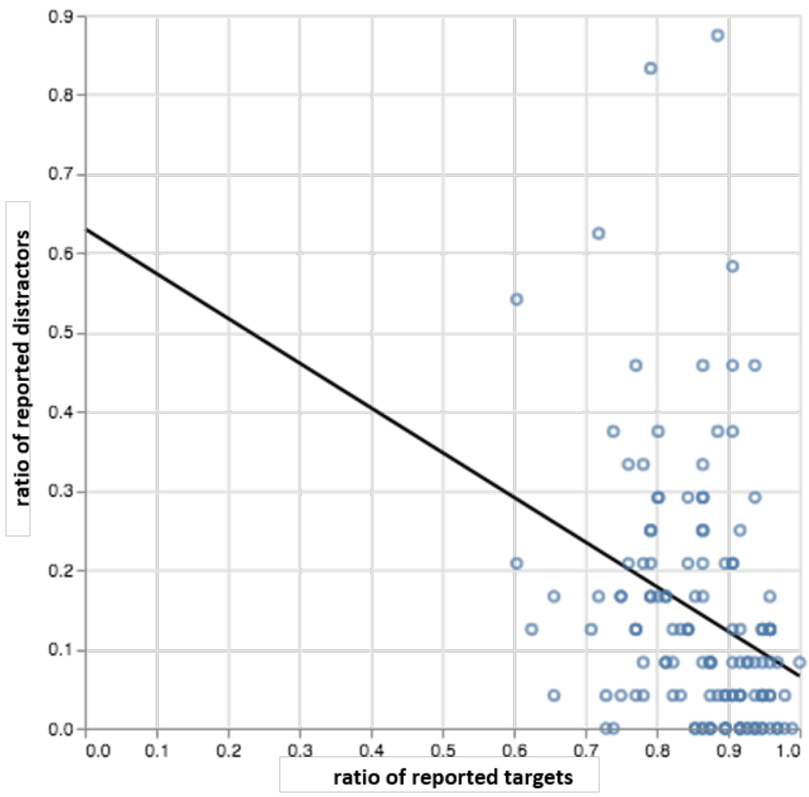

Figure 5.6 *Performance of all children on the partial report at t2*

There was a significant relationship at both time points (t1: $r = -.25$; $p < 0.01$; t2: $r = -.3$; $p < 0.01$) between children's reported targets and distractors, indicating that children's ability to report targets negatively correlated with their report of distractors. Results further showed a wide range of performance across all participants on the PR: Participants depicted at the right bottom corner of the histogram showed high abilities in reporting targets while ignoring distractors, which a ratio of 1.0 of correctly reported targets and a ratio of 0.0 of reported distractors, indicating that the task was mastered without any errors (i.e. no reported distractors). Children depicted in the upper half of the histogram on the other hand reported targets and distractors relatively equally, indicating that these children showed difficulties in mastering the task requirements, with a tendency to report all symbols they could spot during the trials.

When comparing the performance of children at both time points it can be suggested that children showed enhanced skills of reporting targets while ignoring distractors after one year of schooling, compared to when they started formal education. At t2, no child reported fewer than 60% of the targets, and only 9 children (6.8%) reported more than 40% of the distractors, suggesting that the majority of children mastered the task requirements rather well. Repeated measures ANOVAs confirmed the suggested improvement in children's ability to report targets while disregarding distractors showing a significant increase in children's performance at both test points ($F(1, 132) = 80.47$, $p < .001$).

5.1.3 Whole report performance as a function of exposure duration

In addition to investigating participants' performance and development on the WR and PR at t1 and t2, the exposure time effect on task performance was looked at in more detail in order to investigate whether exposure durations had an impact on the number of reported symbols at both time points (Figure 5.7 and 5.8).

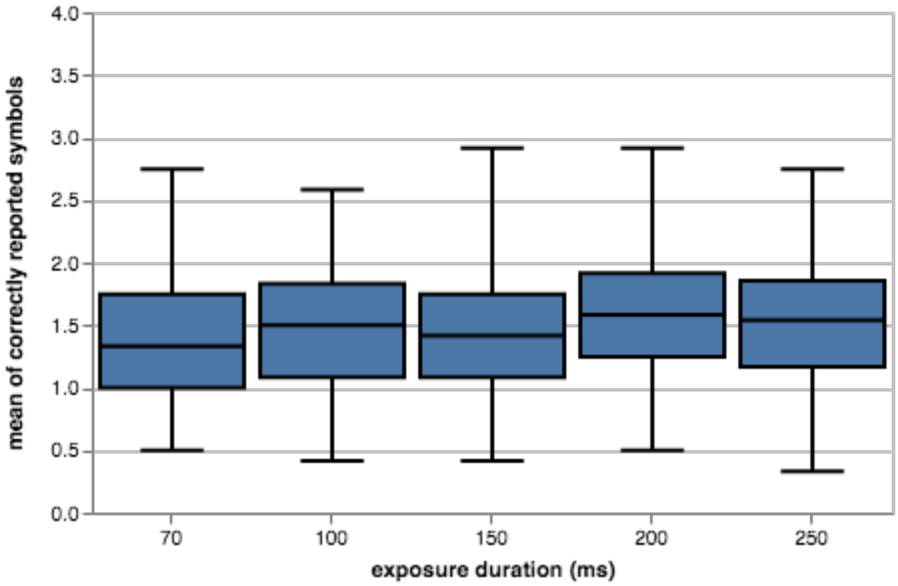

Figure 5.7 *Boxplot of number of correctly reported items and exposure durations at t1*

As can be seen in the boxplots above (Figure 5.7), the analysis of t1 showed mixed results: Overall, there was a slight increase of reported symbols with an increase in exposure duration, with the mean number of reported symbols at 70 ms being 1.39 (SD = .47) and at 250 ms being 1.53 (SD = .50). This further resulted in an overall significant difference between the number of reported symbols per exposure duration ($F(5, 140) = 2.97$, $p = .019$). However, when looking at the differences between adjacent exposure durations, a significant difference in exposure durations could only be observed between 150 ms and 200 ms ($t(138) = -2.24$, $p = .025$). Having said that, the reported significance of this difference needs to be treated with caution as it would not withstand correction for multiple comparison using Bonferroni correction ($p < .05/4 = p < .0125$).

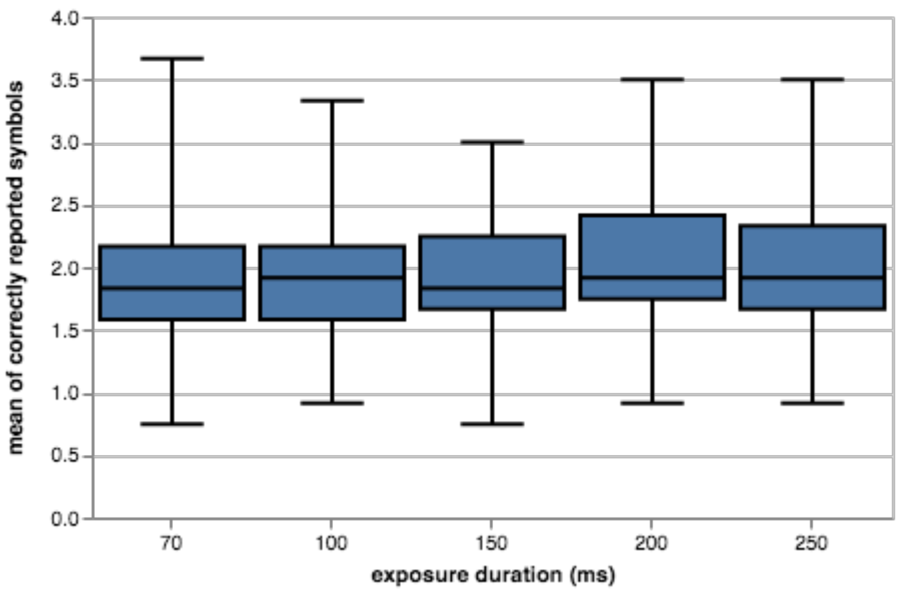

Figure 5.8 *Boxplot of number of correctly reported items and exposure durations at t2*

Findings at t2 (Figure 5.8) showed equally mixed results: There was a slight overall increase of reported symbols with an increase in exposure duration, with the mean number of reported symbols at 70 ms being 1.88 (SD = .51) and at 250 ms being 2.04 (SD = .52), resulting in a significant difference between the number of reported symbols per exposure duration (F(5, 133) = 3.36, p = .01). However, in line with results at t1, differences between adjacent exposure durations were not significant, with the exception of the difference between exposure durations 150 ms and 200 ms (t(131) = -2.18, p = .03). At the same time, this reported significance of the difference between these two time points again needs to be treated with caution as it would not withstand correction for multiple comparison using Bonferroni correction ($p < .05/4 = p < .0125$).

5.1.4 Whole report performance as a function of symbol position

In addition, children's symbol position preference and therefore the distribution of correctly reported symbols according to position was explored across both time points (Figure 5.9).

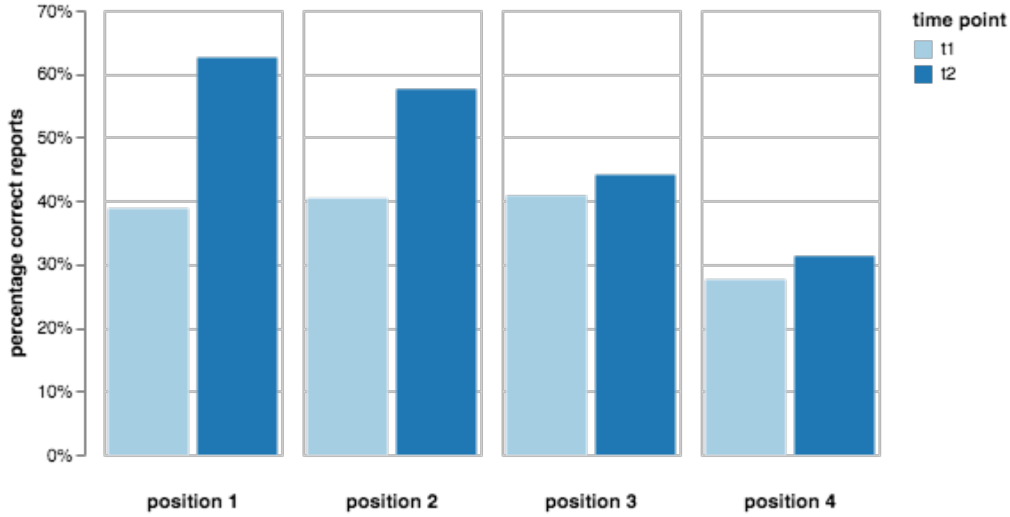

Figure 5.9 *Position preference in the whole report across all children at both t1 and t2*

Results at t1 (Figure 5.9) showed that symbols in position 2 and 3 located in the middle of the screen were reported the most and in 40.4% and 40.8% of trial reports across all participants. Symbols in position 1 were reported almost as often as position 2 & 3, in 38.8% of the trials across all participants. Symbols displayed in the rightmost position (4) on the other hand, were reported significantly less than all other positions ($p < .001$) and only in 27.6% of all trial reports.

T2 findings (Figure 5.9) showed different results: Rather than symbols in the middle of the screen, the symbols in position 1 were reported the most and in 62.6% of trial reports across all participants. This is equivalent to a 23.8% rise in reporting symbols in position 1 compared to t1. Symbols in position 2 were reported almost as often as position 1, in 57.6% of the trials across all participants, and symbols on position 3 in 44.1% of the trials respectively. In line with results from t1, symbols displayed in the rightmost position (4), were reported significantly less than all other positions ($p < .001$) and in 31.3% of all trial reports.

5.1.5 Whole report performance as a function of reporting direction bias

Based on these results of children's performance in relation to symbol positions in the WR at both time points, further investigation looked into whether these position preferences indicate a left-to-right bias in the reports of tested children at both time points, a phenomena that would be expected from more experienced readers in English or other languages with a left-to-right writing direction (e.g. Spalek & Hammad, 2004). For each tested participant a left-to-right reporting bias was computed by subtracting the ratio of correctly reported symbols in the right most position from the ratio of correctly reported symbols in the leftmost position. While a score of +1 therefore indicated that the participant consistently reported symbols from left to right across all trials, a score of -1 defined the consistent report of symbols from right to left (Figure 5.10 and 5.11).

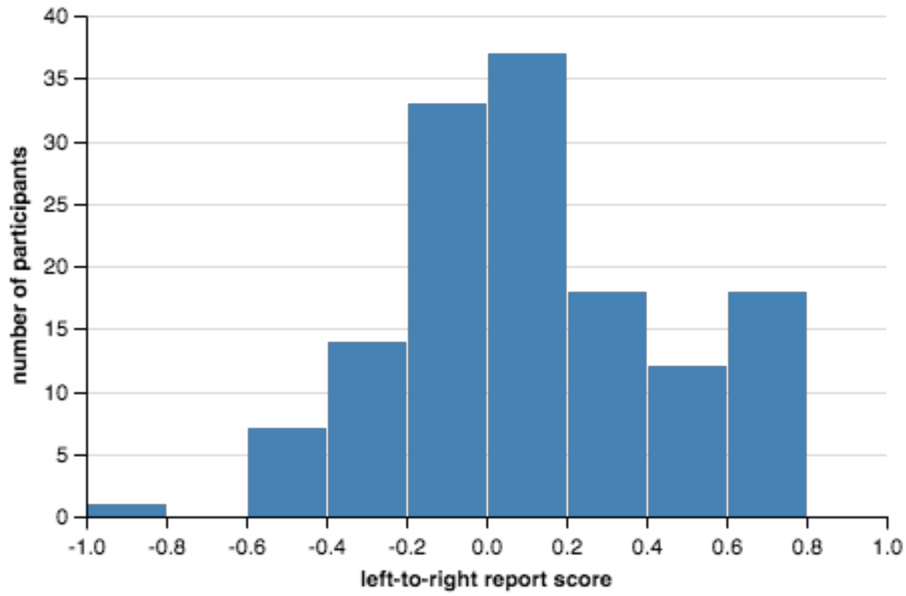

Figure 5.10 *Reporting direction bias in the whole report at t1*

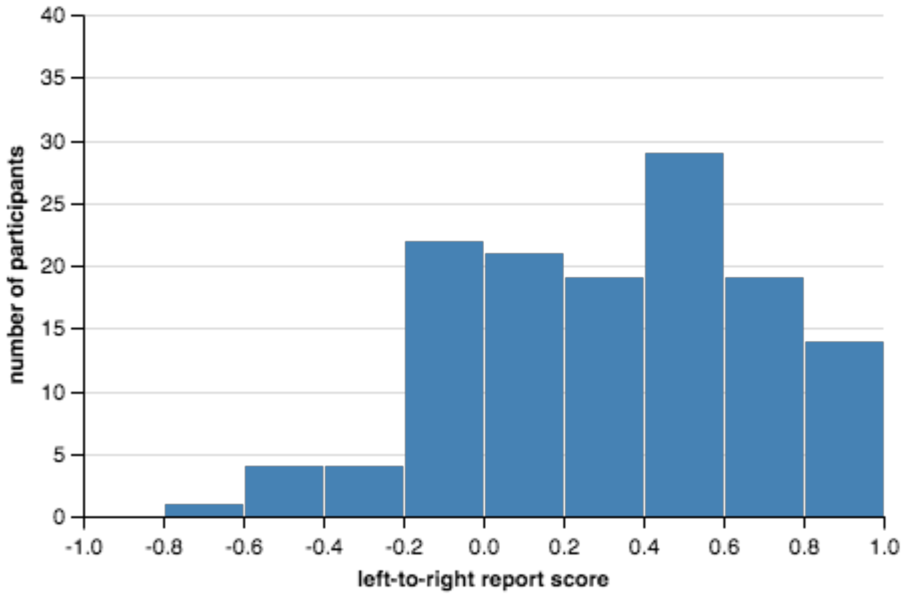

Figure 5.11 *Reporting direction bias in the whole report at t2*

As can be seen in the histograms above, the majority of participants tested at both time points showed a left-to-right reporting bias. However, there was a stark increase (20.1%) in the left-to-right bias across all tested participants after the first year of schooling, raising from 11.2% at t1 to 31.3% at t2.

5.2 Summary & Discussion

After having considered the performance of VA in a normative group of emerging readers at the start of primary school and after one year of schooling, this concluding section will now discuss the presented results in relation to how they address the research questions set out at the beginning of this chapter. Further, findings will be summarised and considered in relation to the literature, as well as to the results from the smaller-scale study conducted prior to this longitudinal project that focused on the development of the VA assessment (Chapter 3). This action is taken in order to further evaluate the suitability of the assessment, considered relevant for the potential application of the adopted VA assessment in future studies. Given that the WR task design deployed in the main study was exactly the same as the one applied in Study II of the smaller-scale study – with exception of the exchange of three symbols (see Section 3.6 for further details) – the decision was made to evaluate the WR results of the main study specifically in relation to findings of Study II. PR findings of the main study on the other hand, are considered in relation to both parts of the smaller-scale study – Study I & II, as the assessment design remained unchanged for all studies described in this work.

5.2.1 Emerging readers' profile of visual attention skills at school entry and after one year of schooling

5.2.1.1 Emerging readers' visual attention span

The WR was adopted in the study to evaluate participants' performance on how many symbols they were able to name in each trial on average, in relation to the five different exposure durations. This way possible differences between participants' VA span were yielded, defined as the amount of visual elements which can be processed in parallel in a multi-element array during a single fixation (Bosse et al., 2007). According to TVA (Bundesen & Habekost, 2008), a visual object is stored in an individual's visual short term memory (VSTM) by encoding of this object's features into the visual short-term memory store. However, this memory store only has very limited capacity, referred to as parameter *K*. In line with discussions related to the study design of the smaller-scale study (Chapter 3), it is argued that VSTM storage capacity K as computed by Bundesen and colleagues (Bundesen, 1998; Duncan et al., 1999) and VA span scores (Bosse et al., 2007) – albeit not being completely identical – closely correlate with each other. Therefore, data yielded from the WR task in the main study were only used to compute individuals' VA spans (Bosse et al., 2007), and thus the mean number of correctly identified symbols for each trial per participant. When considering children's performances on the WR at both time points, two observations can be made. First, a wide spread of scores was observed within t1 and t2 respectively with no evidence of floor or ceiling effects, suggesting that even amongst children assessed at a single time point, there was considerable variability in VA skills. Second, when comparing children's performance at both time points, it can be seen that children showed significantly better ability to report symbols after the first year of schooling, with the mean of reported symbols across all participants increasing by .48 ($F(1, 132) = 173.12$, $p < .001$).

When collating data yielded from the WR at t1 and t2 in the main study, with the results from Study II of the smaller-scale study, findings were comparable: There was no evidence of floor or ceiling effects in any of the studies, with all of them capturing a range of performance within the developmental age group concerned. When considering the fact that testing for Study II took place in June, with children having received roughly 10 months of instruction, compared to students at t1 having been in school for 1-2 months, and at t2 for 13-14 months at the time of the assessment, the mean of reported symbols across all participants at each time point is particularly interesting to look at. It ranged from 1.48 (SD = .14) at t1, and 1.66 (SD = .85) in Study II, to 1.96 (SD = .46) at t2. It is not possible to draw firm conclusions from this comparison given that results are based on different samples, however, this progression does hint at a steady developmental progression in performance on the task across the first year of formal schooling. This suggests that age of participants and / or time spent in school during the first year, have a significant impact on average number of reported items, which is presumed to index an individual's storage capacity of visual short-term memory. The observed relationship further goes in line with other reported findings of visual short-term memory capacity continuing to develop during early childhood (e.g. Riggs et al., 2011).

5.2.1.2 Emerging readers' efficiency of attentional control

The PR, being a target detection task, represented the second component of the VA assessment adopted in this study. It yielded data on how many targets and how many distractors participants reported on average in all of the tasks, and has been deployed in TVA-studies that follow Duncan and colleagues' (1999) design to investigate spatial bias of attention and top-down attentional control. Following decisions made on the assessment design for the PR in the smaller-scale study (Chapter 3), the PR was adopted in the main study to specifically focus on children's efficiency of attentional control by calculating a PR score, identifying children's ability to name targets while at the same time disregarding distractors. When comparing the performance of children at both time points of the main study it can be suggested that children showed enhanced skills of reporting targets while ignoring distractors after one year of schooling, compared to when they started formal education, with the PR score mean at t1 across all participants being .50 (*SD* = .28), compared to .72 (*SD* = .20) at t2. Repeated measures ANOVAs confirmed the suggested improvement in children's ability to report targets while disregarding distractors showing that children's performance at t2 was significantly better than twelve months earlier, at t1 ($F(1, 132) = 80.47$, $p < .001$).

When considering PR results at both time points of the main study in relation to findings from Study I & II of the smaller-scale study, a range of performance across all participants tested was observed, with a slight negative skew present at t2. The significantly higher performance of children after the first school year in the main study further highlighted a developmental progression, which seemed to be supported by results in Study I & II of the smaller-scale study. Given the sequential order of the studies, the mean age of the children in Study I and II differed by approximately four months (mean age of 4;9 years in Study I, mean age of 5;3 years in Study II). As noted in Chapter 3, a developmental progression on the PR was not as clear between Study I and Study II of the smaller-scale study. However, it appears that in relation to these earlier results, the PR score mean across all participants being .50 (*SD* = .28), at t1 and .72 (*SD* = .20) at t2 seem to show a developmental effect in the PR data of the main study. This suggests that in line with findings from the WR, age of participants and / or time spent in school during the first year, have a significant impact on children's target detection abilities and therefore their efficiency of attentional control.

In line with conclusions of the smaller-scale study, the following argument can be made based on the findings of both VA assessments of the main study regarding whether age or time of instruction have an impact on children's VA span and efficiency of attentional control. The children in the main study were tested at the beginning and after their first year of schooling and acquisition of skills such as letter knowledge have been shown to have a specific and measurable effect on early cortical visual processing (e.g. Maurer, Brem, Bucher, & Brandeis, 2005), that is separable to developmental maturation per se. While the main study was therefore not designed to differentiate the specific effect of formal instruction versus age on the development of VA, it can be noted that differing instructional environments may have an impact on VA development of children involved in the study, and thus the sensitivity of assessment measures across contexts. To tease apart these factors, future VA studies could specifically gather information on the nature and extent of formal literacy instruction children receive during the first year of schooling.

5.2.2 The impact of exposure duration on emerging readers' visual processing

Analysis of WR data in the main study regarding correctly reported symbols according to different exposure durations yielded similar results for both time points: While an overall increase in correctly reported symbols with a prolongation in exposure time was observed at both time points, the difference between the number of reported symbols per exposure duration was only significant between 150-200 ms at t1 and t2. However, the reported difference of the two exposure durations at both time points needs to be treated with caution as it does not withstand correction for multiple comparison using Bonferroni correction. These findings therefore go in line with results from Study II of the smaller-scale study: Whereas a positive relationship between an increase in the selected exposure durations and the number of symbols participants reported was observed, the effect for exposure duration on children's performance in the WR task was not significant, possibly suggesting a lack of statistical power. In line with suggestions made based on the findings of the smaller-scale study, the reduced number of overall trials to make the assessment more appropriate to young children, meant that further dividing results as a function of exposure duration may have made it difficult to discern statistically significant effects in the data.

Based on findings suggesting that children process information more slowly than adults (Riggs et al., 2006; Kail, 1991), as well as the results reported here – suggesting that exposure duration times used in Study II and the main study (70-100-150-200-250 ms) seem to only have a small impact on the symbols participants of the target age group were able to report in the WR task – puts further emphasis on the conclusion made in the discussion of the smaller-scale study: Studies of visual processing that have relied on adult models of gaze and saccade patterns may not be applicable to young children, especially those with minimal school experience (and thus reduced experience with processing strings of text and symbols). These findings therefore highlight the need for increased empirical research regarding childhood visual cognition in order to better understand the role of exposure duration in young children's visual processing, which in turn can provide a foundation for future improvements to the current VA assessment.

5.2.3 Reporting direction bias in emerging readers after the first year of schooling

A further investigation into preference of symbol position in children's performances across all WR tasks of the main study explored whether the exposure to a left-to-right writing system during the first year of schooling would increase children's tendency for a left-to-right report of the symbols. Whereas positions 2 & 3 in the middle of the screen were preferred during t1 testing, position 1 (first left on the screen) was reported the most across all participants at t2. Symbols displayed in the rightmost position (4) on the other hand, were reported significantly less than all other positions at both time points. Encouraged by these findings, a left-to-right report score was computed for all participants at both time points. The results confirmed a left-to-right bias for the majority of participants tested at t1 & t2, with a stark increase (20.1%) in a left-to-right bias across all tested participants after the first year of schooling. The observed phenomenon goes in line with studies looking at more advanced adult readers, with Spalek & Hammad (2004, 2005) for instance reporting a left-to-right bias in English speaking participants, in contrast to an opposite bias in a sample of Arabic speakers, reading text from right to left.

While some studies put an emphasis on suggesting that observed spatial biases in individuals' performances are caused by neurobiological determinants (e.g. Bradshaw, Nathan, Nettleton, Wilson, & Pierson, 1987; Nicholls & Roberts, 2002), others go in line with Spalek & Hammad (2004, 2005), highlighting the role of cultural factors – i.e. the acquisition of reading itself – as a modulator of visuospatial performance (Chokron, Kazandijan, & De Agostini, 2011; Chokron, 2002; Rinaldi, Di Luca, Henik, & Girelli, 2014). In addition, further evidence of the observed attentional asymmetry being caused by an individual's experiences with a certain text direction is provided by studies showing correlations between right-to-left reading routines and directional differences in perception of facial expressions (Vaid & Singh, 1989), aesthetic judgement (Chokron & De Agostini, 2000), as well as the direction of the pen in hand drawing (Vaid, Singh, Sakhuja, & Gupta, 2002). Finally, study results suggesting that the asymmetrical shift in the distribution of visuospatial attention only emerges after a child has acquired written language (Brucki & Nitrini, 2008; Dobel, Diesendruck, & Bölte, 2007; Fagard & Dahmen, 2003; Kebbe & Vinter, 2013; Woods et al., 2013), further highlight the impact of cultural practices on observed spatial-representational biases. The findings of the main study therefore provide evidence that English speaking children's left-to-right attentional biases increase after the first year of schooling, suggesting a possible link between exposure to formal literacy instruction and the development of reporting direction bias. Finally, main study results highlight the suitability of the WR task for investigating report direction bias in emerging readers as a potential precursor skill of reading.

5.2.4 Summary

Overall, the profile of VA skills in a normative group of emerging readers at school entry and after the first year of schooling is first characterised by a wide spread of scores with no extreme floor or ceiling effects at both time points. This suggested that even amongst children assessed at a single time point, there was considerable variability in VA skills. When comparing emerging readers' performance at school entry and after one year of schooling on both VA assessments to explore the development of VA skills, results showed that children performed significantly better at t2 in comparison to t1. Thus, children showed better ability in reporting symbols (VA span), as well as reporting targets while ignoring distractors (efficiency of attentional control) after one year of schooling.

Additional analyses from both tests suggested that age of participants and / or time spent in school during the first year, have a significant impact on children's VA development. In addition, results showed that the effect for exposure duration on children's performance in the VA span task was not significant at both time points. These results put further emphasis on the need for increased empirical research regarding childhood visual cognition in order to better understand the role of exposure duration in young children's visual processing. Finally, results from the VA span task provided evidence of a rise in English speaking children's left-to-right attentional biases after the first year of schooling, suggesting a possible link between exposure to formal literacy instruction and the development of reporting direction bias.

Chapter 6 – Traditional literacy precursor skills, visual attention, and children's digital exposure as potential predictors of single word reading after one year of schooling

This chapter draws on the results outlined in the previous chapter (Chapter 5) and will explore the relationships between the performance and development of traditional precursor skills of single word reading in a normative group of emerging readers, their visual attention (VA) skills and digital exposure at time point 1 (t1) and time point 2 (t2) of the study. The first time point conducted at the beginning of Reception will be referred to as 'at school entry' and the second time point carried out at the start of Year 1 will be referred to as 'after one year of schooling'. Research questions 3-6 as summarised in Chapter 2 will be considered within this chapter and are outlined in more detail below:

3) I. What is the performance and development of emerging readers on traditional linguistic and cognitive predictor variables of reading at school entry and after one year of schooling?
    a. Is there a wide range of scores across all linguistic and cognitive predictors at both time points?
    b. Is children's average performance on traditional linguistic and cognitive predictor variables of reading within the expected range of the age group at both time points?
    c. Are children making significant gains on traditional linguistic and cognitive predictor variables of reading after one year of schooling?

   II. What is the performance of emerging readers on the single word outcome measure after one year of schooling?
    a. Is children's performance on the single word reading outcome measure within the expected range when compared to the norm sample after one year of schooling?

4) What is the relationship between emerging readers' visual attention profiles and their performance on traditional linguistic and cognitive predictor variables of reading, including

   I. phonological awareness, letter-sound knowledge, receptive vocabulary, short-term memory, non-verbal ability at school entry, as well as

   II. phonological awareness, receptive vocabulary, short-term memory, attention & executive function, and the single word reading outcome after one year of schooling?

   Detailed research questions regarding the relationships between traditional cognitive and linguistic predictor skills:

   a. Are both phonological awareness (PA) measures (sound isolation and sound deletion) strongly and significantly correlated with each other at t1 and t2, confirming a strong and significant relationship between similar measures of PA?
   b. Are there strong and significant correlations between PA and letter-sound knowledge (LSK) at school entry highlighting a close relationship between the understanding of the principle of an alphabetic language and the awareness of sounds being mapped to letters during children's literacy development?
   c. Are there strong and significant correlations between PA and receptive vocabulary providing evidence for claims that language skills are strongly related to PA skills?
   d. Are there significant concurrent relationships between both PA measures and short-term memory (STM) at both time points, as phonological STM is being argued to influence literacy development indirectly through supporting the development of PA?
   e. Are concurrent relationships between LSK and STM at school entry significant, given the ongoing debate regarding the relationship between LSK and STM?
   f. Is there a close relationship between receptive vocabulary and STM for children at school entry and after one year of schooling?

Detailed research questions regarding the relationship between visual attention (VA) and traditional cognitive and linguistic predictor skills:

a. Are VA measures at school entry stronger correlated with the non-verbal ability (NVIQ) measure or with the language-based measures (phonological awareness, receptive vocabulary, STM)?
b. Are relationships between receptive vocabulary and the VA whole report measure stronger than the relationships between receptive vocabulary and the VA partial report measure, given that vocabulary skills were less needed for the performance on the latter?
c. Can found correlations between both VA measures, WR and PR, provide evidence to suggest that assessments are not identical but rather capturing slightly different facets of VA performance?
d. Can found concurrent correlations between VA measures and the attention & executive function measure provide evidence to suggest that the VA assessment of the study was sufficiently different from other more general measures of attention and executive function?
e. Are partial correlations controlling for receptive vocabulary reducing or increasing the relationships between measures at both time points?
f. Are partial correlations controlling for NVIQ reducing or increasing the relationships between measures at both time points?
g. Are the concurrent relationships between VA variables (WR and PR scores) and the outcome measure single word reading at t2 comparable in strength to the relationships between individually assessed traditional predictors and the outcome measure single word reading at t2?

5) Is there evidence of a relationship between
   I. parental reports on children's exposure to digital devices and digital device use prior to school-entry and a child's visual attention profile at school entry?
   II. children's self-reports on digital reading and digital device use frequency and a child's visual attention profile after one year of schooling?

6) Does visual attention contribute, over and above to the prediction of single word reading alongside traditional linguistic and cognitive predictor variables in emerging readers?

Detailed research questions regarding the predictive power of traditional cognitive and linguistic literacy precursor skills:

a. Are there strong and significant longitudinal relationships between both phonological awareness (PA) measures and the literacy outcome measure?
b. Is PA a significant, unique predictor for single word reading concurrently and longitudinally?
c. Are there strong and significant longitudinal relationships between letter-sound knowledge (LSK) and the literacy outcome measure?
d. Is LSK a significant and unique predictor of single word reading longitudinally?
e. Are there strong and significant longitudinal relationships between receptive vocabulary and the literacy outcome measure?
f. Is the receptive vocabulary measure a significant and unique predictor of single word reading both concurrently and longitudinally?
g. Are there significant longitudinal relationships between short-term memory and the literacy outcome measure?
h. Is short-term memory a unique predictor of single word reading both concurrently and longitudinally?

Detailed research questions regarding the predictive power of visual attention:

d. Are the longitudinal relationships between VA variables (WR and PR scores) at t1 and the outcome measure single word reading at t2 comparable in strength to the longitudinal relationships between individually assessed traditional predictors at t1 and the outcome measure single word reading at t2?
e. Does VA at the beginning of the school year contribute to the overall variance in reading performance after one year of schooling in a multiple regression analysis?

f. Does VA contribute unique variance concurrently in reading performance, over and above the variance accounted for by the potentially-similar measure of general attention and executive function?
g. Does VA contribute unique variance longitudinally in reading performance, fully distinct from the contributions of other literacy precursor variables measured at the same time point in individual hierarchical regression analyses?
    i. Does VA contribute more unique variance in comparison to language-based skills or in comparison to NVIQ?
    ii. Is the shared variance bigger between VA and NVIQ compared to the shared variance between VA and language-based skills?
h. Does VA contribute additional unique variance in reading performance over and above cognitive and linguistic predictor variables in both concurrent (t2) and longitudinal (t1 – t2) multiple hierarchical models?

These questions will be addressed using descriptive statistics, as well as correlational and regression analyses. Firstly, descriptive data of the children tested at t1 and t2 on traditional literacy predictor measures will be presented to help characterise the sample, followed by a report on the development of these skills between the two measurement points in school. Concurrent correlational analyses will be reported in the subsequent section to investigate the relationships between traditional predictor measures of reading and children's VA skills. In a next step, collected data on children's digital exposure intensity based on parental questionnaires at t1 and children's self-reports at t2 will be explored, in order to look into possible relationships with children's VA skills, as well as single word reading after the first school year. Finally, to examine the predictive relationships between variables at both times points and the single word reading outcome measure at t2, longitudinal correlations and (hierarchical) multiple regression analyses will be presented. In the summary and discussion section these results will be considered in relation to findings from previous literature.

Parametric assumptions were explored for all data used in the analyses presented in this chapter by investigating whether skewness and kurtosis for each measure were significantly different from the normal distribution. The vast majority of measures at both time points met parametric assumptions, apart from the short-term memory measure and the VA partial report (PR) task at t1 and t2, as well as the attention &

executive function accuracy measure at t2. Therefore, both parametric (independent t-tests) and nonparametric (Mann-Whitney U tests) tests were carried out. Significance values and effect sizes were very similar between the two approaches and thus parametric results will be reported for interval data throughout the chapter. However, given that the data yielded from the parent questionnaires and student interviews was ordinal, non-parametric correlations were maintained in instances when data from parental and student reports were included in the analyses.

6.1 Performance and development of cognitive and linguistic predictors of reading at school entry and after one year of schooling

In order to address research question 3, children's performance on measures of traditional cognitive and linguistic predictors of literacy will be considered for each time point, as well as their development between the two measurement points. For all cognitive and linguistic precursors of literacy, standardized scores were used in the analyses as these allow for easier reference to the group's performance in relation to the assessment's normative sample[7].

6.1.1 Children's performance on cognitive and linguistic predictors of reading at school entry – t1 results

Descriptive statistics for children's performance at t1 on all linguistic and cognitive predictors are shown in Table 6.1. Standard as well as raw scores are displayed. As can be seen in the table below, one child could not be included in the sample of the non-verbal ability measure (NVIQ) as he refused to participate in this assessment at the time of the testing. However, given that his performance was not outside the expected range in the remaining assessments of t1 & t2, the decision was made to otherwise keep him in the study sample.

[7] With the exception of the short-term memory assessment taken from the ERB (Seeff-Gabriel et al., 2008), for which raw scores had to be used. This action was taken because standardized scores for the ERB can only be derived if multiple subtests are administered.

Table 6.1 *Descriptives for all cognitive and linguistic measures at t1*

	N	*M*	*Mdn*	*SD*	*Range*
Sound isolation – raw (12)	140	3.98	4.00	3.15	0-12
Sound isolation – standard	140	102.85	103.00	12.06	72-127
Sound deletion – raw (12)	140	2.06	2.00	1.88	0-7
Sound deletion – standard	140	95.80	98.00	13.77	72-130
LSK – raw (17)	140	6.16	6.00	3.84	0-16
LSK – standard	140	99.71	100.00	13.12	72-128
RV – raw (168)	140	61.34	63.00	15.30	20-97
RV – standard	140	99.53	100.00	12.13	70-122
Short-term memory – raw (18)	140	12.99	14.00	3.45	1-18
NVIQ – raw (40)	139	20.44	20.00	3.85	11-32
NVIQ – scaled	139	8.19	8.00	3.39	2-16
Whole report t1 (4)	140	1.48	1.49	.14	.47-2.68
Partial report t1 (1)	140	.50	.58	.28	- .14- .99

Note. For each measure the maximum value is listed in parentheses. LSK = letter-sound knowledge; RV = receptive vocabulary; NVIQ = non-verbal intelligence quotient.

When considering children's phonological awareness (PA) skills[8], their performance on the sound isolation task was slightly better than their performance on the sound deletion task with standardised scores on the former being just above a standardised score of 100, defining the mean of the norm sample (*M* = 102.85, *SD* = 12.06). Further, scores on the sound deletion task were slightly below the mean, but still within the normal range (*M* = 95.80, *SD* = 13.77). Children's ability to connect letters to their associated sounds met the expected level for that age group (*M* = 99.71, *SD* = 13.12). This goes in line with children's performance on the receptive vocabulary assessment (*M* = 99.53, *SD* = 12.13). However, the range of scores reached on the BPVS was wide, with the difference in scores between the lowest and the best performing child being 52 scores on the standardised scale. Further, children showed average performance on the short-term memory assessment (*M* = 12.99, *SD* = 3.45), as well as on the NVIQ assessment (*M* = 8.19, *SD* = 3.39). In both of these tests, a wide range in task performance could be observed in children, and especially so on the NVIQ assessment (*M* = 8.19, *SD* = 3.39), where performances ranged from a very low raw score of 11, to a considerably higher raw score of 32, out of possible 40.

[8] *Note*. While the acronym PA was used when reporting and discussing the results in this and the following chapter (Chapters 6 & 7), the specific measures were phonemic awareness measures.

6.1.2 Children's performance on cognitive and linguistic predictors of reading after one year of schooling and on the reading outcome measure – t2 results

Descriptive statistics for children's performance on all linguistic and cognitive predictors after one year of attending formal education are shown in Table 6.2, where standard as well as raw scores are displayed.

Table 6.2 *Descriptives for all cognitive and linguistic measures at t2*

	N	*M*	*Mdn*	*SD*	*Range*
Sound isolation – raw (12)	133	10.08	11.00	2.14	0-12
Sound isolation – standard	133	110.56	113.00	14.78	72-130
Sound deletion – raw (12)	133	6.37	6.00	3.00	0-12
Sound deletion – standard	133	104.86	106.00	14.58	70-130
RV – raw (168)	133	76.53	77.00	11.94	44-113
RV – standard	133	94.17	93.00	10.29	70-118
Short-term memory – raw (18)	133	15.83	16.00	1.95	7-18
A & EF – accuracy score (1)	133	.77	.80	.21	.28-1.00
A & EF – RT (in ms)	133	1212.09	1188.21	511.13	125.24-2855.24
Whole report t2 (4)	133	1.96	1.85	.46	.88-3.37
Partial report t2 (1)	133	.72	.74	.20	- .04- .99
SWR – raw (90)	133	25.09	19.00	17.79	0-77
SWR – standard	133	107.25	106.00	15.71	70-130

Note. For each measure the maximum value is listed in parentheses. RV = receptive vocabulary; A & EF = attention and executive function; RT = reaction time; SWR = single word reading.

Children's performance at t2 on the sound isolation task (M = 110.56, SD = 14.78) was better than their performance on the sound deletion task (M = 104.86, SD = 14.58) with standardised scores on both tasks being very slightly above the mean of the norm sample. In comparison, children performed less well on the receptive vocabulary measure with the mean of performance across all participants being more notably below the mean of the norm, but still within the expected normal range (M = 94.17, SD = 10.29). Further, the range of scores reached was considerably wide spread with the difference in scores between the worst and the best performing child being 48 points on the standardised scale. The mean across all tested children regarding the short-term memory measure being well beyond 80 percent of the possible high score, suggested an overall average performance (M = 15.83, SD = 1.95).

In addition, attention & executive function (A & EF) skills were assessed for all children at the start of Year 1 (Table 6.2). Accuracy score results (M = .77, SD = .21) showed a wide range in participants' performances. With 34 participants reaching a very high score between .90-.99, resulting in the data being skewed overall. Additionally computed reaction times of correct trials across all participants (M = 1212.09 ms, SD = 511.13 ms) also showed a wide range in performances, spanning from a very short reaction time of an eighth of a second (125.24 ms), to a reaction time of almost three seconds (2855.24 ms).

Finally, gender differences were explored for all cognitive and linguistic precursors of literacy, as well as the VA scores at both time points of the study. This was carried out since previous studies (e.g. Below, Skinner, Fearrington, & Sorrell, 2010; Chatterji, 2006) have suggested gender differences in early literacy. Interestingly, no gender differences were found, with the exception of the attention & executive function task accuracy score, conducted at t2. Here, an independent t-test showed significant differences in gender, with girls outperforming boys ($t(131) = 2.41$, $p = .017$).

The outcome measure of this study – children's single word reading and therefore reading accuracy – was assessed at single word-level at t2. It was measured adopting the Diagnostic Test of Word Reading Processes (DTWRP), comprising of a nonword, exception word, and regular word reading task (Table 6.2). The total score yielded from across these three tasks was used for subsequent analyses. Standardised scores showed that the overall performance was within the expected level for that age group and slightly above the mean of the norm (M = 107.25, SD = 15.71). While in very few instances children failed to score at all in the test, there were also a few children in the sample who correctly read three times more words compared to the mean raw score of the group.

6.1.3 Performance development of children on cognitive and linguistic predictors of reading

Children's development from t1 to t2 was analysed using repeated measures ANOVAs. As mentioned earlier in this chapter, not all variables at both time points met parametric assumptions. To take these characteristics into account, nonparametric tests (Friedman's tests) were computed for all variables. Significance values and effect sizes were very similar between the two approaches and thus parametric results will be reported throughout the chapter. Overall, four predictors of reading – sound isolation, sound deletion, receptive vocabulary, short-term memory – were assessed at both time points. In the following, results will be presented showing the development of these four skills in tested children between the two measurement points.

As illustrated in the chapter sections above, children's performances on the PA measure (sound isolation, sound deletion) at t1 and t2 were within the expected range. The increases in scores were statistically significant for sound isolation ($F(1, 132) = 16.89$, $p < .001$) and sound deletion ($F(1,132) = 49.74$, $p < .001$) according to the repeated measures ANOVAs test. These results suggested that there was a significant improvement in children's PA skills from t1 to t2.

When considering children's development on the receptive vocabulary measure from t1 to t2, the mean raw scores increased from t1 to t2. On the other hand, standardised scores decreased from a value close to the mean of the normal range at t1 to 6 points below the mean at t2 (see Tables 6.1 and 6.2). Both the increase in raw scores ($F(1, 132) = 314.92$, $p < .001$), as well as the decline in standardised scores were statistically significant ($F(1, 132)$ 44.71, $p < .001$) according to the repeated measures ANOVAs test. This indicated that while children made concrete advances in their receptive vocabulary skills from t1 to t2, their performance after one year of schooling had declined relative to their normative peer group.

Finally, results of the repeated measures ANOVA of the short-term memory assessment showed a significant increase in children's performance during the first year of schooling ($F(1, 132) = 117.64$, $p < .001$).

6.2 Concurrent correlations between traditional predictors of reading and visual attention at school entry and after one year of schooling

In this work it was aimed to explore the relationships between traditional predictors of reading and VA skills in children at school entry and after the first year of schooling (research question 4), the concurrent relationships between variables at both time points were examined.

6.2.1 Relationships between traditional predictors of reading and visual attention at school entry (t1)

In Table 6.3 correlations at t1 between all measures of children's literacy predictor skills as well as their VA skills in the whole report (WR) and partial report (PR) of the VA assessment are shown.

Table 6.3 *Pearson's concurrent correlations between literacy predictor skills and visual attention measures at t1*

	1	2	3	4	5	6	7	8
1. Sound isolation								
2. Sound deletion	**.52*****							
3. Letter-sound knowledge	**.53*****	.23**						
4. Receptive vocabulary	.49***	**.54*****	.35***			.		
5. Short-term memory	.36***	.32***	.18*	.21**				
6. NVIQ	.21*	.30***	.23**	.22**	.07			
7. Partial report	.46***	.21*	.30***	.24**	.25**	.24**		
8. Whole report	.41***	.36***	.21*	.32***	.38***	.22**	.38***	

Note. Statistical significance is indicated with asterisks: * $p < .05$; ** $p < .01$; *** $p < .001$. Strong correlations ($r \geq .50$) are highlighted in bold. NVIQ = non-verbal intelligence quotient.

The table shows that at t1 all measures of children's literacy predictor skills correlated significantly with one another, with the majority showing weak (.10 – .30) to moderate (.30 – .50) correlations, albeit a few exceptions: sound deletion strongly correlated with receptive vocabulary ($r = .54$, $p < .001$) and sound isolation showed strong correlations with letter-sound knowledge ($r = .53$, $p < .001$). In addition, sound isolation and sound deletion strongly correlated with each other ($r = .52$, $p < .001$), a result that could have been expected, considering that they are both assessments of the YARC phonological awareness assessment.

Relationships between literacy precursor skills and VA measures showed significant and weak to moderate correlations across all measures. While the WR was moderately correlated with four out of five literacy predictor skills, with r ranging from .32 – .41 ($p < .001$), it showed a weaker correlation with letter-sound knowledge ($r = .21$, $p < .05$).

Correlations between PR and the other literacy predictor skills revealed slightly different results: While PR showed weak correlations with all but one literacy predictor skills, with *r* ranging from .21 ($p < .01$) to .30 ($p < .001$), correlations with sound isolation were clearly moderate ($r = .48$, $p < .01$).

Further, there were significant weak to moderate correlations between the non-verbal ability measure (NVIQ) and all other cognitive and linguistic predictors, as well as the VA assessment measures at t1, with the exception of short-term memory ($r = .07$; $p = .44$). Finally, moderate correlations between WR and PR ($r = .38$, $p < .001$) suggested a strong relation between the two VA assessments.

Following this initial investigation of the correlation, partial correlations were performed, controlling for the effect of receptive vocabulary, as well as NVIQ, to gain a better understanding of the data collected at t1 (Table 6.4 and 6.5).

Table 6.4 *Pearson's partial correlations controlling for receptive vocabulary (below diagonal) and Pearson's correlations (above diagonal) between literacy predictor skills and visual attention measures at t1*

	1	2	3	4	5	6	7
1. Sound isolation		**.52*****	**.53*****	.36***	.21*	.46***	.41***
2. Sound deletion	.45***		.23**	.32***	.30***	.21*	.36***
3. LSK	**.53*****	.18*		.18*	.23**	.30***	.21*
4. STM	.35***	.30***	.16		.07	.25**	.24**
5. NVIQ	.13	.23**	.17*	.03		.38***	.22**
6. Partial report	.34***	.07	.17*	.17*	.19*		.38***
7. Whole report	.32***	.25**	.16	.36***	.17*	.34***	

Note. Statistical significance is indicated with asterisks: * $p < .05$; ** $p < .01$; *** $p < .001$. Strong correlations ($r \geq .50$) are highlighted in bold. LSK = letter-sound knowledge; STM = short-term memory; NVIQ = non-verbal intelligence quotient.

When receptive vocabulary was controlled for, in almost all cases the strength of relationships was reduced, including four instances when relationships became very weak and therefore non-significant:

- NVIQ – sound isolation: $r = .13$, $p > .12$
- Short-term memory – letter-sound knowledge: $r = .16$, $p > .05$
- PR – sound deletion: $r = .07$, $p > .37$
- WR – letter-sound knowledge: $r = .16$, $p > .05$

Table 6.5 *Pearson's partial correlations controlling for NVIQ (below diagonal) and Pearson's correlations (above diagonal) between literacy predictor skills and visual attention measures at t1*

	1	**2**	**3**	**4**	**5**	**6**	**7**
1. Sound isolation		**.52*** **	**.53*** **	.49***	.36***	.46***	.41***
2. Sound deletion	**.93*** **		.23**	**.54*** **	.32***	.21*	.36***
3. LSK	**.92*** **	**.86*** **		.35***	.18*	.30***	.21*
4. RV	**.93*** **	**.93*** **	**.91*** **		.21**	.24**	.32***
5. STM	**.81*** **	**.80*** **	**.76*** **	**.79*** **		.25**	.38***
6. Partial report	**.53*** **	.43***	.47***	.46***	.45***		.38***
7. Whole report	**.76*** **	**.74*** **	**.69*** **	**.73*** **	**.72*** **	**.51*** **	

Note. Statistical significance is indicated with asterisks: * $p < .05$; ** $p < .01$; *** $p < .001$. Strong correlations ($r \geq .50$) are highlighted in bold. LSK = letter-sound knowledge; RV = receptive vocabulary; STM = short-term memory.

When NVIQ was controlled for, in all cases the strength of relationships was notably increased. While this resulted in significant and moderate correlations in four instances related to the PR, all other correlations turned into being strong and significant.

6.2.2 Relationships between traditional predictors of reading, single word reading outcome measure and visual attention after one year of schooling (t2)

In Table 6.6 correlations at t2 between all measures of children's literacy predictor skills as well as their VA skills in the whole report (WR) and partial report (PR) assessment are shown.

Table 6.6 *Pearson's concurrent correlations between literacy predictor skills and visual attention measures at t2*

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. Sound isolation								
2. Sound deletion	**.66*** **							
3. Single word reading	**.59*** **	**.74*** **						
4. Receptive vocabulary	.38***	**.51*** **	.49***					
5. Short-term memory	.33***	.43***	.44***	.24**				
6. A & EF: accuracy score	.27**	.28***	.31***	.20*	.24*			
7. A & EF: reaction time	.12	.14	.02	.07	.07	.30***		
8. Partial report	.31***	.33***	.32***	.19*	.26**	.29***	.004	
9. Whole report	.21*	.32***	.33***	.34***	.21*	.31***	.18*	.39***

Note. Statistical significance is indicated with asterisks: * $p < .05$; ** $p < .01$; *** $p < .001$. A & EF = attention and executive function. Strong correlations ($r \geq .50$) are highlighted in bold.

The table above shows that at t2 all measures of children's literacy predictor skills were significantly correlated, with the majority showing moderate (r = .30 - .50) correlations. However, there were two instances where strong (r > .50) correlations, could be observed: receptive vocabulary (r = 51, p < .001) strongly correlated with sound deletion, which also strongly correlated with sound isolation (r = .66, p < .001).

When looking at the relationships between attention and executive function (A & EF) scores and literacy predictor skills, results differed significantly between accuracy scores and reaction time: While accuracy scores were weakly to moderately correlated with all literacy precursor skills, *reaction time* was not significantly correlated with any of them.

Relationships between literacy precursor skills and VA measures showed significant and weak to moderate correlations across all measures. While the WR was moderately correlated with four out of six literacy predictor skills, with r ranging from .32 - .34 (p < .001), it showed a weaker correlation with sound isolation (r = .21, p < .05) and short-term memory (r = .21, p < .05). Correlations between PR and the other literacy predictor skills showed similar results: While PR showed moderate correlations with three out of six literacy predictor skills, with r ranging from .31 - .33 (p < .001), correlations with receptive vocabulary (r = .19, p < 0.05), and short-term memory were weak (r = .26, p < .01). While A & EF accuracy scores correlated weakly (r = .29, p < .01) with the PR, and moderately (r = .31, p < .001) with the WR, A & EF reaction time only correlated weakly with the WR (r = .18, p < .05), and not with the PR (r = .004, p = .96) Finally, moderate correlations between WR and PR (r = .39, p < .001) were observed.

When considering the concurrent correlations between the single word reading outcome measure and the predictor measures tested at the same time point the following was observed: Single word reading correlated significantly and strongly with both PA measures, sound isolation: r = .59, p < .001, and sound deletion: r = .74, p < .001. With the exception of the A & EF accuracy score, the single word reading outcome measure was further significantly and moderately correlated with the other predictor measures.

In line with data analysis at t1, partial correlations were performed on t2 data controlling for receptive vocabulary and NVIQ (Table 6.7 and 6.8).

Table 6.7 *Pearson's partial correlations controlling for receptive vocabulary (below diagonal) and Pearson's correlations (above diagonal) between literacy predictor skills and visual attention measures at t2*

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. Sound isolation		**.66*****	**.59*****	.33***	.27**	.12	.31***	.21*
2. Sound deletion	**.63*****		**.74*****	.43***	.28***	.14	.33***	.32***
3. Single word r.	**.56*****	**.68*****		.44***	.31***	.02	.32***	.33***
4. Short-term memory	.49***	.46***	.45***		.24*	.07	.26**	.21*
5. A & EF: AS	.29***	.26**	.29***	.28**		.30***	.29***	.31***
6. A & EF: RT	.13	.02	.14	27**	**.69*****		.004	.18*
7. Partial report	.32***	.31***	.30***	.29***	29***	.09		.39***
8. Whole report	.15	.21*	.23**	.19*	.28**	.09	.37***	

Note. Statistical significance is indicated with asterisks: * $p < .05$; ** $p < .01$; *** $p < .001$. Strong correlations ($r \geq .50$) are highlighted in bold. A & EF = attention and executive function; AS = accuracy sore; RT = reaction time.

When receptive vocabulary was controlled for, the majority of measures did not experience a strong change in strength of relationships. However, the strength of relationships between WR, and the other assessment battery measures was reduced, including two instances when the strength of relationships became very weak and therefore non-significant.

- WR – sound isolation: $r = .15$, $p > .08$
- WR – A & EF: reaction time: $r = .09$, $p > .31$

When controlled for NVIQ, results are very similar to what has been observed at t1 (Table 6.8). All relationships, including the non-significant correlations between the A & EF: reaction time measure and the vast majority of all other assessment battery measures, showed strong and significant correlations with each other, ranging from $r = .53$ ($p < .001$), to $r = .69$ ($p < .001$).

Table 6.8 *Pearson's partial correlations controlling for NVIQ (below diagonal) and Pearson's correlations (above diagonal) between literacy predictor skills and visual attention measures at t2*

	1	2	3	4	5	6	7	8	9
1. SI		**.66*****	**.59*****	.38***	.33***	.27**	.12	.31***	.21*
2. SDl	**.95*****		**.74*****	**.51*****	.43***	.28***	.14	.33***	.32***
3. SWR	**.94*****	**.96*****		.49***	.44***	.31***	.02	.32***	.33***
4. RV	**.94*****	**.93*****	**.93*****		.24**	.20*	.07	.19*	.34***
5. STM	**.93*****	**.92*****	**.92*****	**.92*****		.24*	.07	.26**	.21*
6. A & EF: AS	**.74*****	**.73*****	**.75*****	**.73*****	**.75*****		.30***	.29***	.31***
7. A & EF: RT	**.64*****	**.60*****	**.62*****	**.63*****	**.65*****	**.69*****		.004	.18*
8. Partial report	**.75*****	**.74*****	**.75*****	**.72*****	**.74*****	**.65*****	**.53*****		.39***
9. Whole report	**.78*****	**.79*****	**.80*****	**.81*****	**.80*****	**.69*****	**.50*****	**.72*****	

Note. Statistical significance is indicated with asterisks: * $p < .05$; ** $p < .01$; *** $p < .001$. Strong correlations ($r \geq .50$) are highlighted in bold. SI = sound isolation; SDl = sound deletion; SWR = single word reading; RV = receptive vocabulary; STM = short-term memory; A & EF: AS = attention & executive function accuracy score; A & EF: RT = attention & executive function reaction time.

6.3 Relationships between children's digital exposure intensity, visual attention, and single word reading

This section addresses research question 5 and explores possible relationships between children's digital exposure intensity and their VA skills, as well as possible correlations between children's digital exposure intensity and single word reading after one year of schooling. At t1 parents or children's primary care givers[9] were asked to report on how long their children had been using digital devices before entering school, and how often they had been using digital devices for a range of activities. At t2 it was decided to directly capture views of participating children on the frequency of reading on digital devices, as well as on their overall digital device use frequency. First, results from the data collection at both time points will be presented separately. In a second step, data obtained by parent questionnaires at t1 and student interviews at t2 will be investigated in relation to children's VA skills at both time points. Additional investigations into digital exposure intensity data and the single word reading outcome measure will conclude this chapter section.

[9] For better readability, parents and primary caregivers, are referred to as 'parents' throughout this work.

6.3.1 Parental reports on children's digital exposure intensity and visual attention skills at school entry – t1

In order to address the first half of the fifth research question, focusing on the relationships between VA and parental reports on children's digital exposure intensity at t1, 110 returned parent questionnaires on children's digital media use were analysed. While the parent questionnaire administered in this study covered a range of questions on children's digital device use prior to entering school, it was decided to specifically look at two questions, considered to be the most informative regarding a child's digital exposure intensity (for more information on the selection process see Section 4.3.3). The two selected questions covered the following areas: a) overall exposure time to digital devices, and b) frequency of digital device use.

6.3.1.1 Parental reports on children's exposure time to digital devices

To investigate children's exposure time to digital devices, participating parents were asked the following question:

- How old was your child when they first used a digital device?

Subsequently, they were invited to choose one of the following answers: never; 4-5 years of age; 3-4 years of age; 2-3 years of age; 1-2 years of age; under 1 (Figure 6.1).

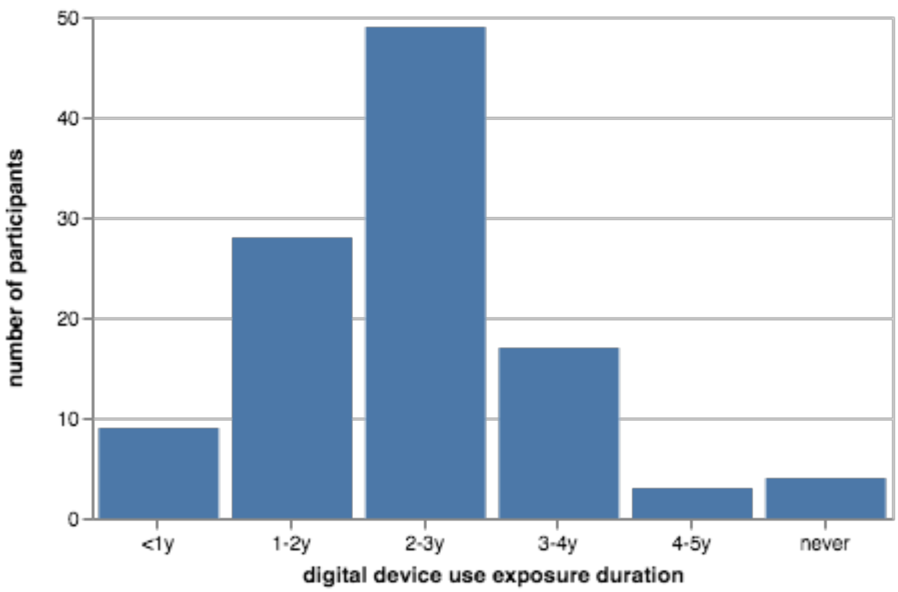

Figure 6.1 *Overview of answers to question on children's exposure time to digital devices*

A wide range of answers was given, with the middle age range being the most frequent response (*n* = 49; 44.5%), suggesting that children from parents who have chosen this answer were between 2-3 years of age when they first used a digital device. Further, a sizeable group of parents stated that their child was even younger when first using a digital device: While 28 (25.5%) parents reported that their children were between the ages of 1-2, 9 parents (8.2%) said that their children started to use digital devices before their first birthday. In comparison, 17 (15.5%) parents claimed that their children were between 3-4 years of age when first using digital devices, and 3 (2.7%) parents reporting that their children have started to use digital devices only after their fourth birthday. 4 (3.6%) parents indicated that their children had never used digital devices prior to entering school.

6.3.1.2 Parental reports on children's digital device use frequency

To explore children's digital device use frequency, parents were asked the following question:

- In the 6 months before starting Reception, how often did your child spend 5 minutes or more using the following devices: smartphone; e-reader; tablet/Ipad; PC/laptop.

This time, they were invited to choose from the following options: More than 1x/day; 1x/day; 3-4x/day; 1x/week; less than 1x/week; never.

Answers on this question were weighted: 5 points were awarded for each 'More than 1x/day' answer, 4 points for each '1x/day', 3 points for each 3-4x/week, 2 points for each '1x/week', 1 point for each 'less than 1x/week answer, and 0 points for each question that was answered with 'never'. The more often a device was used, the more scores an answer received, with 20 being the maximum possible score, given in instances when parents stated that their child used all listed digital devices more than once very day (Figure 6.2).

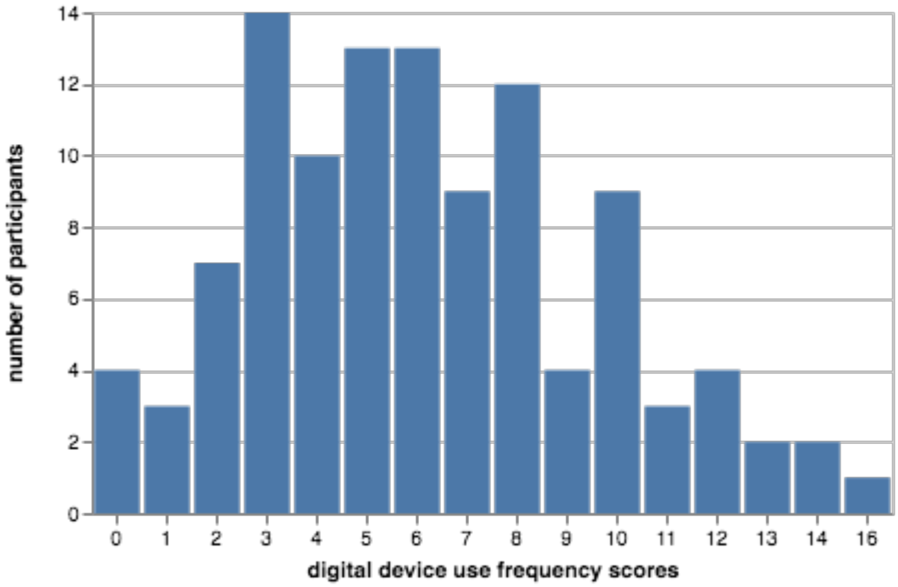

Figure 6.2 *Overview of answers to question on children's digital device use frequency*

As can be seen from the figure above, a wide range of answers was given, ranging from 0-16 scores, with the mean score across all tested children being 6.16 (*SD* = 3.44). The majority of parents (*n* = 71; 64.5%) reported frequencies that scored between 3 to 8, indicating that their children were using digital devices at least a number of times a week. A small group of parents (*n* = 14; 12.7%) reported usage frequencies resulting in scores between 0 to 2, equating to their children having either never used a digital device before entering school, or having used them only infrequently. On the other end of the scale, a considerable group of parents indicated that their children were frequent digital device users: 20 parents (18.2%) scored 9-12 points, with 5 parents (4.6%) scoring the highest, reaching 13-16 points on this question.

6.3.2 Children's self-reports on digital exposure intensity and visual attention skills after one year of schooling – t2

In order to address the second half of the fifth research question, focusing on the relationships between VA and children's self-report on their digital reading and digital device use frequency at t2, all 133 participating children at t2 were interviewed once during their assessment sessions. While the student interviews explored children's reading habits in a broader sense, as well as their exposure to digital devices with a number of questions, it was decided to specifically look at two questions here, considered to be the most informative regarding children's reading habits on digital devices and their frequency of using digital devices (see Appendix E for detailed results of answers to these two questions).

6.3.2.1 Children's self-report on digital reading frequency

To investigate children's reading on digital devices, participants were asked the following two questions:

- How often do you read/ look at stories on the tablet/IPad/etc. together with grown-ups?
- How often do you read/ look at stories on the tablet/IPad/etc. on your own?

Children were then asked to choose one of the following answers for each question: every day – sometimes – never. Answers on both of these questions were weighted: 2 points were awarded for each 'every day' answer, 1 point for each 'sometimes' answer, and 0 points for each question that was answered with 'never'. In a final step, children were put into three groups: Children scoring 0 points on both questions were classified as never using digital devices, children scoring 1 point on one or both questions were considered to sometimes use digital devices, and children scoring 2 points on at least one of the questions were considered to use digital devices every day (Figure 6.3).

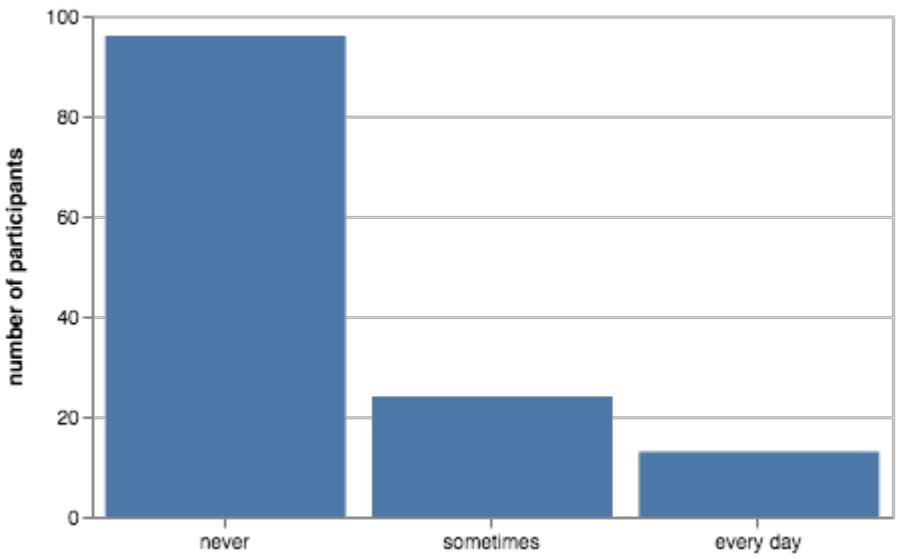

Figure 6.3 *Overview of participants' answers to their frequency of reading on digital devices*

As can be seen in the figure above, the vast majority of children (n = 96; 72.2%) reported that they did not use digital devices at home for reading/ looking at stories on their own or together with their parents. This is followed by a group of 24 children (18.0%), indicating that they were using digital devices for reading sometimes during the week. A group of 13 children (9.8%), was considered to consist of very frequent users of digital devices for reading, as they reported to read or look at stories on their own or together with grown-ups every day.

6.3.2.2 Children's self-report on overall digital device use frequency

To explore participants' frequency of digital device use in a more general sense, children were asked the following question:

- How often do you use tablets/ Ipads/ computers/ laptops/ phones to do the following: playing games for fun, playing educational apps, watching programmes or clips, watching music videos, communicating with people, reading stories, using children's websites, finding things out.

Children were subsequently asked to answer each sub-question by choosing from the following options: every day – sometimes – never. Answers on the question were weighted: 2 points were awarded for a 'every day' answer, 1 point for a 'sometimes' answer, and 0 points for a question that was answered with 'never'. An overview of the answers given by all children to each sub-question is presented in Table 1.9 below.

Table 6.9 *Descriptives of children's answers to the sub-questions of the digital device use frequency item at t2*

	N	*M*	*Mdn*	*SD*	*Range*
1. Playing games for fun	133	1.39	1	.56	0-2
2. Playing educational apps	133	.50	0	.71	0-2
3. Watching programs	133	1.47	2	.66	0-2
4. Watching music clips	133	.92	1	.69	0-2
5. Using FaceTime / Skype	133	.32	0	.56	0-2
6. Using children's websites	133	.66	1	.63	0-2
7. Reading stories	133	.40	0	.66	0-2
8. Finding things out	133	.59	1	.65	0-2

When considering the means and medians of the sub-questions displayed above, *playing games for fun*, as well as *watching programs* seemed to be the two activities children engaged with the most. *Using FaceTime / Skype*, *reading stories*, and *playing* *educational apps* on the other hand seemed to be activities least popular in participating children, with the remaining sub-items –*watching music clips*, *using children's websites, finding things out* – identifying activities children occasionally occupy themselves with. To get a better sense of children's overall digital device use frequency, answers on all of the sub-questions were subsequently added up to create a digital device use frequency score for each child. The more often a device was used, the more scores an answer received, with 16 being the maximum possible score, indicating that children used digital devices for all listed activities every day (Figure 6.4).

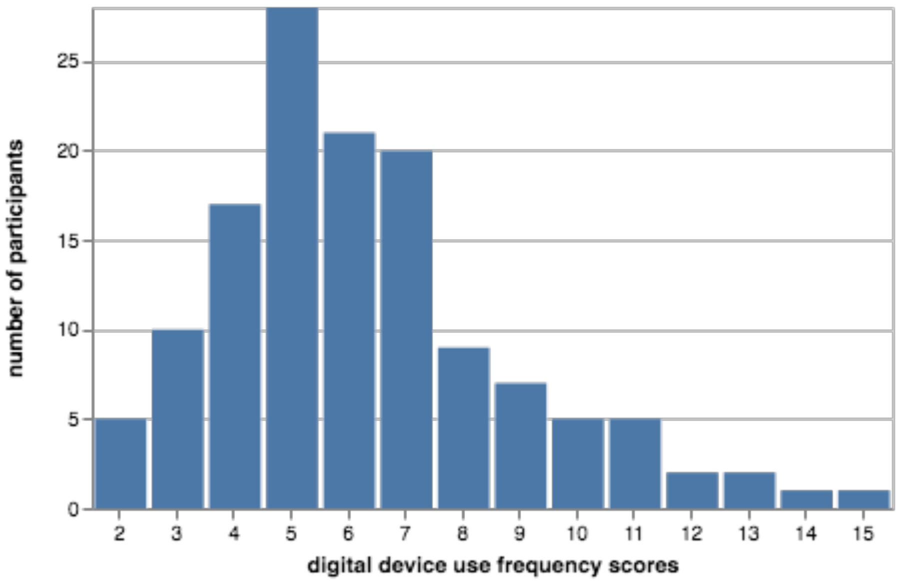

Figure 6.4 *Overview of participants' overall digital device use frequency*

A wide range of answers was given, resulting in children's device use frequency score ranging from 2 to 15, with the mean score across all tested children being 6.26 (*SD* = 2.61). The vast majority of children (*n* = 110, 82.7%) had a score between 2 and 8. This suggested that most of the children asked did not frequently use digital devices for a wide range of activities listed, but rather engaged in some of the activities, mainly in moderation. In comparison, only 23 children (17.3%) reached a score of 9 or higher, indicating that they often used digital devices for a range of activities in their everyday life.

6.3.3 Relationships between children's exposure to digital devices and their visual attention skills

To investigate the relationships between children's VA skills and their digital exposure intensity, concurrent data from both, parent questionnaires and children's self-reports were considered in relation to the VA data.

6.3.3.1 Relationships between visual attention and parental reports on digital exposure intensity at t1

Spearman's correlations between answers to both of the parent questionnaire items used to identify children's digital exposure intensity at school entry, as well as VA scores on the two tasks (WR and PR) assessed at t1 were examined (Table 6.10).

Table 6.10 *Spearman's concurrent correlations between children's visual attention and digital exposure intensity at t1*

	t1 Exposure time to digital devices	t1 Device use frequency
t1 Device use frequency	.39***	
t1 Partial report	.12	.09
t1 Whole report	.16	.11

Note. Statistical significance is indicated with asterisks: *** $p < .001$.

Whereas both questionnaire items were moderately and significantly correlated with each other ($r_s = .39$; $p < .001$), no significant relationship was found between the two VA elements and children's exposure time to digital devices, as well as their device use frequency.

6.3.3.2 Relationships between visual attention and children's self-report on digital exposure intensity at t2

To verify the investigation conducted at the first time point, it was decided to explore the relationships between children's VA skills and their digital exposure intensity at the second time point. In line with the analysis conducted above, relationships between children's overall answers on the two questionnaire items (digital reading frequency and digital device use frequency), as well as their answers on the sub-questions on the digital device use frequency item, and VA scores on the two tasks (WR and PR) at t2 were also examined (Table 6.11).

Table 6.11 *Spearman's concurrent correlations between the digital reading frequency item, the digital device use frequency item, sub-questions of the digital device use frequency item, and visual attention scores at t2*

	t2 Whole report	t2 Partial report	t2 Digital reading frequency
t2 Digital reading frequency	-.01	-.13	---
t2 Digital device use frequency	-.17	-.09	.43***
1. Playing games for fun	-.17	-.10	.18*
2. Playing educational apps	-.07	-.06	.38***
3. Watching programs	-.08	-.10	.07
4. Watching music clips	-.09	-.16	.14
5. Using FaceTime / Skype	.16	.20*	-.02
6. Using children's websites	-.07	.04	.05
7. Reading stories	-.04	-.17	**.84*****
8. Finding things out	-.08	.03	.26**

Note. Statistical significance is indicated with asterisks: * $p < .05$; ** $p < .01$; *** $p < .001$. Strong correlations ($r \geq .50$) are highlighted in bold.

While there was a significant and moderate correlation between digital device use frequency and children's digital reading frequency ($r_s = .43$, $p < .001$) – suggesting that children who frequently used digital devices for reading, also used them for other activities –, there was no significant relationship between both VA assessment results and children's self-reports on their frequency of reading on digital devices, as well as on their overall frequency of digital device use. These results were therefore not suggesting a relationship between digital exposure intensity and children's VA. Nevertheless, it was decided to further explore the different sub-elements of the digital device use frequency item to better understand their relationship with the digital reading frequency item, as well as the two VA measures at t2.

In line with the findings from the analysis of the relationship between VA and the two overall items of children's self reports, performance on the WR and PR at t2 was not correlated with the individual elements of the digital device use questionnaire item, with one exception: A weak correlation was found between using FaceTime or Skype and PR at t2 ($r_s = .20$, $p < .05$).

When considering the relationships between answers on the two questionnaire items however, some weak to moderate correlations were found:

- Reading on digital devices and playing educational apps ($r_s = .38$, $p < .001$).

- Reading on digital devices and finding things out (r_s = .26, p < .01).
- Reading on digital devices and playing games for fun (r_s = .18, p < .05).

Finally, a strong significant correlation (r_s = .84, p < .001) was found between answers to the digital reading questionnaire item and answers to the question item 7 in Table 6.11 above, regarded as control question as it was capturing the same matter, suggesting that children's answers were consistent across both items.

6.3.3.3 Longitudinal relationships parental reports on digital exposure intensity at t1 and visual attention at t2

When finally looking at the longitudinal relationships between parental reports on children's digital device use and children's performance on the VA assessments after one year of schooling the results were in line with concurrent relationships reported above (Table 6.12).

Table 6.12 *Spearman's longitudinal correlations between children's digital exposure intensity at t1 and visual attention skills at t2*

	t1 Exposure time to digital devices	t1 Device use frequency
t2 Partial report	.06	-.02
t2 Whole report	.10	-.09

Both questionnaire items at t1 had no significant relationship with the WR and PR children obtained at t2.

6.3.4 Relationships between children's digital device use and single word reading after one year of schooling

In a final step, concurrent and longitudinal correlations (Spearman's *rho*) between the outcome variable single word reading after one year of schooling and parental reports on their children's digital exposure intensity prior to entering school, as well as children's self-reports on digital exposure intensity at t2 were explored (Table 6.13). This investigation was carried out in order to provide a full exploration of the questionnaire data.

Table 6.13 *Spearman's concurrent and longitudinal correlations between parental reports of children's digital device use frequency at t1 and reading outcome variables at t2*

	t1 Exposure time to digital devices	t1 Device use frequency	t2 Digital reading frequency	t2 Device use frequency
t2 Single word reading	.12	.002	-.11	.06

Relationships between parental reports on children's digital exposure intensity collected at t1 and children's reading performance at t2 suggest that there no significant correlation between children's exposure time to digital devices prior to entering school and their reading performance after one year of formal education. In addition, no correlation was found between children's device use frequency and the reading measure at t2. This goes in line with what was found for the presented concurrent correlations: There were no significant relationships between children's performance on the single word reading task at t2 and their self-reports on digital reading and digital device use frequency at the same time point.

Based on these findings, suggesting no relationship between the collected data on children's digital exposure intensity and their VA skills, as well as the reading outcome variable after one year of schooling, it was decided to end the exploration of digital exposure data at this point and to subsequently exclude parent questionnaire and children's self-report data from further regression analyses (Section 6.4 below).

6.4 Predictors of single word reading skills after one year of schooling

In this section, longitudinal relationships between children's VA skills, as well as potential linguistic and cognitive literacy predictor skills and the outcome measure single word reading will be explored during the first year of formal education. In addition to longitudinal correlations, hierarchical multiple regression analyses will be carried out to consider the individual contributions of precursor variables to predict single word reading at t2 (research question 6).

6.4.1 Longitudinal correlations between tested measures across both time points

6.4.1.1 Longitudinal correlations between traditional predictor variables and visual attention

Longitudinal correlations (Pearson's *r*) between potential traditional predictor skills of reading and VA were computed to explore how individually tested variables were related to each other (Table 6.14).

Table 6.14 *Pearson's longitudinal correlations between literacy predictor skills and visual attention measures at t1 and t2*

	t1 SI	t1 SDl	t1 LSK	t1 RV	t1 STM	t1 PR	t1 WR
t2 SI	.43***	.29***	.41***	.25**	.29***	.14	.13
t2 SDl	**.57*****	.49***	.33***	.39***	.36***	.32***	.32***
t2 RV	**.52*****	.43***	.47***	**.69*****	.13	.20*	.32***
t2 STM	.40***	.35***	.13	.25**	.41***	.26**	.29***
t2 PR	.22*	.16	.23**	.24**	.38***	.40***	.39***
t2 WR	.27**	.31***	.15	.29***	.28**	.33***	**.53*****

Note. Statistical significance is indicated with asterisks: * $p < .05$; ** $p < .01$; *** $p < .001$. Strong correlations ($r \geq .50$) are highlighted in bold. SI = sound isolation; SDl = sound deletion; RV = receptive vocabulary; STM = short-term memory; PR = partial report; WR = whole report.

As can be seen in the table above, traditional predictor measures correlated significantly and strongly ($.52 \leq r \geq .69$) with each other, especially in cases when t1 and t2 results of the same measure were explored. The vast majority of the relationships were moderate and significant, with only two non-significant exceptions:

- letter-sound knowledge (t1) and short-term memory (t2): *r* = .13; *p* > .14
- short-term memory (t1) and receptive vocabulary (t2): *r* = .13; *p* > 13.

Longitudinal correlations between the two VA measures revealed one significant and strong correlation between WR at t1 and t2 ($r = .53$; $p > .001$), and were otherwise moderate. The majority of the longitudinal relationships between VA and traditional predictors of reading were significant and weak to moderate, with four non-significant correlations:

- sound deletion (t1) and PR (t2): *r* = .16; *p* > .06
- PR (t1) and sound isolation (t2): *r* = .14; *p* > .10
- letter-sound knowledge (t1) and WR (t2): *r* = .15; *p* > .08
- WR (t1) and sound isolation (t2): *r* = .13; *p* > .13

6.4.1.2 Longitudinal correlations between literacy predictors and visual attention at t1 and outcome variable single word reading at t2

As part of the analysis, longitudinal correlations (Pearson's *r*) between traditional predictor and VA variables were computed to explore how individual assessed measures at t1 were related to the outcome measure single word reading at t2 (Table 6.15).

Table 6.15 *Pearson's longitudinal correlations between literacy predictor skills and visual attention measures at t1 and reading outcome variables at t2*

	t1 SI	t1 SDl	t1 LSK	t1 RV	t1 STM	t1 PR	t1 WR
t2 Single word reading	**.57*****	.44***	**.54*****	.42***	.42***	.28**	.37***

Note. Statistical significance is indicated with asterisks: ** $p < .01$; *** $p < .001$. SI = sound isolation; SDl = sound deletion; LSK = letter sound knowledge; RV = receptive vocabulary; STM = short-term memory; PR = partial report; WR = whole report. Strong correlations ($r \geq .50$) are highlighted in bold.

There were strong significant correlations between children's performance on the single word reading outcome measure at t2 and their results on the sound isolation ($r = .57$; $p < .001$) and letter-sound knowledge ($r = .54$; $p < .001$) tasks. In addition, the single word reading measure correlated moderately and significantly with sound deletion ($r = .44$; $p < .001$), receptive vocabulary ($r = .42$; $p < .001$), and short-term memory ($r = .42$; $p < .001$).

When considering longitudinal correlations between single word reading and VA skills at the beginning of the school year, there was a significant and moderate correlation (r = .37; p < .001) between children's performance on the WR with the reading outcome measure, and a significant weak correlation (r = .28; p < .01) between PR at t1 and children's single word reading skills at t2.

Having explored linear relationships between variables using correlational analysis, as a next step regression analyses were undertaken. This decision was made in order to more fully explore the relative strength of variables at both time points in *predicting* performance in single word reading at t2. Of particular interest was the predictive power of the VA measures, developed as part of this thesis.

6.4.2 Regression Analyses

Multiple and hierarchical regression analyses were conducted to explore the role of VA in relation to traditional literacy predictor skills (sound isolation, sound deletion, letter-sound knowledge, short-term memory, receptive vocabulary, NVIQ, attention & executive function) for predicting outcome variable single word reading after the first year of schooling. In a first step, multiple regression was used to get a sense of the predictive power of the VA parameters (WR and PR) in relation to the other traditional precursor skills when considering single word reading. Following Schumacker & Lomax (2004), multiple regression analyses are accepted and widely used by researchers in the fields of behavioural science and educational research. In this study, all the requirements for conducting multiple regression analyses were met, including independence of errors, normal distribution of standardised residuals, outliers impacting the model, as well as homoscedasticity (Field, 2013). Apart from the two PA measures (sound isolation, sound deletion), multicollinearity was also not a reason for concern. According to Tabachnick & Fidell (1989), reliable multiple regression analyses operate with a minimum of 10 data points per predictor variable. Since the sample size of this study was rather big (N = 133 for t2 and longitudinal analyses), there would have been no need to reduce the number of predictor variables incorporated into the model. Nevertheless, it was decided to use principal component analysis (PCA) in order to combine the two PA measures – sound isolation and sound deletion – in order to overcoming the multicollinearity exhibited by these two variables.

The PCA will be presented first alongside correlations between the single word reading outcome and the newly created phonological awareness factor. This is followed by multiple regression analyses to get an initial idea of the contribution of VA (WR and PR) alongside the other traditional literacy precursor skills tested at t1 and t2 in relation to the single word reading component concurrently in Year 1, and longitudinally from Reception to Year 1.

In a final step, further hierarchical regression analyses were conducted in order to create two predictor models (concurrent and longitudinal) showing the individual unique contributions of VA, alongside other traditional predictor variables for single word reading at t2, as well as the shared variance between them. To determine the unique variance each variable contains over the other predictors, the model was run multiple times and each time with variables entered into the model in a different order, so that each variable was once entered in the final step.

6.4.2.1 Data preparation - Creating a combined phonological awareness score

According to Field (2013) PCA (= principle component analysis) is a dimensionality reduction technique that can be adopted to deal with multicollinearity in the variables. Using this method one can ‘determine the linear combinations of the measured variables that retain as much information from the original measured variables as possible’ (Fabrigar, Wegener, MacCllum, & Strahan, 1999, p. 275). In this study, PCA was used to create a composite phonological awareness score (= PA score) from the sound isolation and sound deletion variables. The rationale behind this were the strong correlations between these two variables at both time points ($r > .5$, see Section 6.2, Tables 6.3 & 6.6). Table 6.16 below shows the factor loadings of the PCA. To rule out issues around sampling adequacy a Kaiser-Meyer-Olkin test was computed for the dataset: Since only two variables were included in the PA composite, the *KMO* was .05. When considering all four individual variables (sound isolation at t1 and t2, sound deletion at t1 and t2), it was further verified that the sample adequacy was at least good, with Field (2013) suggesting a *KMO test score of* > .7 for all variables to be adequate. In addition, Bartlett’s test of sphericity was run which provided further confirmation that the correlation between the two variables included in the composites was sufficiently strong for them to be included in a PCA. Subsequently, eigenvalues for each principle component were obtained. Both components had eigenvalues of Jolliffe’s

(1972; 2002) criterion of .7: The principle component t1 PA had an eigenvalue of .77, t2 PA an eigenvalue of .82.

Table 6.16 below shows the factor loadings, which represent the importance of a variable to a factor (Field, 2013). According to Stevens (2002, cited in Field, 2013), the threshold for interpreting factor loadings are absolute values greater than .4 (16% of variance in the variable):

Table 6.16 *Reception and Year 1 PCA factor loadings for the PA principle component (N = 133)*

	Factor Loadings	
	Reception (t1)	Year 1 (t2)
Measure	PA	PA
Sound isolation	.72***	.60***
Sound deletion	.69***	.80***

Note. Statistical significance is indicated with asterisks: *** $p < .001$. PA = phonological awareness.

As can be seen from the pattern matrix above, regression coefficients between the two variables and the PA combined score, and thus the unique contribution of the variables to the PA principle component, was rather high, with coefficients ranging between .60 $\leq r \geq$ .80.

To finalise the combination of the two PA scores into the PA combined score, a correlational analysis was run between the outcome measure at t2 and the PA scores at t1 and t2. Results show that both newly combined predictive measures were strongly correlated with the single word reading outcome measure (Table 6.17).

Table 6.17 *Pearson's longitudinal correlations between literacy predictor skills and the compound PA score at t1 and t2*

	t1 PA	t2 PA
t2 Single word reading	**.57*** **	**.76*** **

Note. Statistical significance is indicated with asterisks: *** $p < .001$. PA = phonological awareness. Strong correlations ($r \geq .50$) are highlighted in bold.

6.4.2.2 Multiple regression

Multiple regressions were conducted for the outcome variable single word reading for an initial investigation into the amount of overall variance explained by traditional precursors of reading as well as the VA measures. First, the concurrent regressions between traditional predictors of reading and VA for single word reading after one year of schooling were explored (Table 6.18).

Table 6.18 *Multiple regression for single word reading at t2 and predictor variables at t2*

	B	*SE B*	*β*	R^2	Adj R^2
				.60***	.58***
t2 Receptive vocabulary	.22	.10	.14		
t2 Short-term memory	.94	.52	.12		
t2 Phonological awareness	.54	.07	.60		
t2 Whole report	2.79	2.32	.08		
t2 Partial report	.86	5.02	.01		
t2 A & EF: accuracy score	1.61	5.17	.02		
t2 A & EF: reaction time	.003	.002	.08		

Note. Statistical significance is indicated with asterisks: *** $p < .001$. A & EF = attention & executive function.

The concurrent model outlined above was highly significant: $F(7, 125) = 26.92$, $p < .001$. The amount of overall variance explained by the seven potential predictor variables entered into the model was 58%. When looking at the standardised β values of the potential predictor variables, PA had the highest value, with a β of .60. This was followed by the contributions of receptive vocabulary ($\beta = .14$) and short-term memory ($\beta = .12$) skills to the model. The contribution of the WR and attention and executive function (A & EF) reaction time was the same, with β being .08 for both. The PR on the other hand had the weakest β value, suggesting that it had next to no contribution ($\beta = .01$) to the concurrent model for single word reading. This goes in line with the accuracy score of the A & EF measure which equally had very low contribution to the overall variance explained by the model ($\beta = .02$).

To further explore how VA contributed to the amount of overall variance in relation to the other traditional predictors of reading entered into the model, longitudinal multiple regressions between traditional literacy predictors and VA at t1 and the single word reading outcome measure at t2 were explored (Table 6.19).

Table 6.19 *Longitudinal Regression for Single word reading at t2*

	B	*SE B*	*β*	R^2	*Adj* R^2
				.46***	.43***
t1 Receptive vocabulary	.06	.11	.04		
t1 Short-term memory	1.10	.33	.25		
t1 letter-sound knowledge	.32	.08	.32		
t1 phonological awareness	.21	.09	.23		
t1 NVIQ	.15	.33	.03		
t1 Partial report	-2.77	4.46	-.05		
t1 Whole report	4.52	2.74	.13		

Note. Statistical significance is indicated with asterisks: *** $p < .001$. NVIQ = non-verbal intelligence quotient.

In line with the concurrent model, the longitudinal multiple regression model above was significant: $F(7, 125) = 15.47$, $p < .001$. The amount of overall variance explained by the variables entered into this longitudinal model was 43% and therefore 15% lower than the concurrent model. In this longitudinal model, letter-sound knowledge had the highest β value of .32. This was followed by short-term memory, which longitudinally contributed to the variance more than twice as much as in the concurrent model, with a β value of .25. Next was the contribution of PA, with a β value of .23. While this can be considered as a rather high β value, it went down considerably by .37 in comparison to the concurrent model. In line with these findings, the contribution of receptive vocabulary knowledge (β = .04) to the overall variance of the model went down by .10. Notably, the contribution of children's performance on the NVIQ assessment to the amount of overall variance explained by the model for single word reading after one year of schooling was only small, with a β value of .03.

When considering the amount VA scores contributed to the variance in this longitudinal multiple regression model, results from the concurrent analysis were confirmed and became clearer: While the PR task yielded a negative β value of -.05, indicating that it made no contribution to the model, the β value of the WR (.13) was more encouraging, giving a hint that children's performance on the WR at the beginning of the school year contributed to the overall variance explaining reading performance after one year of schooling.

Based on this initial investigation it was decided to exclude the PR task from further regression analyses and to focus on investigating the possible predictive power of the remaining VA assessment measure – WR.

6.4.2.3 Hierarchical regression

Since it was suggested by the multiple regression analyses discussed above that there might be a unique variance which is picked up by the WR within a predictor model for single word reading, hierarchical regressions for the single word reading component with one VA component and selected concurrent year 1 (t2) variables, as well as longitudinal Reception (t1) to year 1 (t2) variables, will be presented. This is carried out to explore the potential independent contribution of the VA measure in relation to the other traditional predictors of literacy. For these hierarchical regressions, each predictor was entered in a first step, and then together with one of the VA factors (WR) in a second step. The first step was therefore used to identify the percentage of independent variance of each variable. The second step meant that the specific traditional predictor entered first was controlled for, which made it possible to explore the additional variance the VA variable (WR) contributed over and above the other literacy skills, which in previous research studies have been established as robust predictors of single word reading in emerging readers. Some concurrent hierarchical regression analyses (after one year of schooling) are presented first, followed by the presentation of the longitudinal hierarchical regression results (development during the first year of schooling).

6.4.2.3.1 Relationships between whole report and attention & executive function skills for the concurrent prediction of single word reading

For the concurrent hierarchical regression models of single word reading, the decision was made to focus on two models, exploring the WR in relation to both A & EF function scores (Table 6.20). This was carried out in order to investigate whether the VA measure is addressing different skills than the A & EF measure in relation to single word reading. The remaining concurrent hierarchical regression models for single word reading exploring the predictive power of the WR in relation to traditional precursor skills tested at t2 are displayed in Appendix F.

Table 6.20 *Summary of individual hierarchical regression analyses for whole report in relation to attention & executive function accuracy score, and attention & executive function reaction time predicting Year 1 single word reading*

Step and predictor variable	Year 1				
	B	***SE B***	***β***	***Adj. R^2***	***Adj. Δ R^2***
Step 1:				.090***	
t2 A & EF: accuracy score	23.849	6.377	.322		
Step 2:				.144***	.054***
t2 A & EF: accuracy score	17.745	6.496	.231		
t2 Whole report	8.924	2.912	.259		
Step 1:				-.007	
t2 A & EF: reaction time	-.001	.003	-.024		
Step 2:				.096***	.103***
t2 A & EF: reaction time	.001	.003	.036		
t2 Whole report	11.581	2.895	.336		

Note. Statistical significance is indicated with asterisks: *** $p < .001$. A & EF = attention & executive function.

While both steps from the first model looking at A & EF accuracy score and WR were significant, this was only the case for step 2 of the second model, considering A & EF reaction time and the VA measure:

t2 single word reading – t2 A & EF accuracy score & WR*:*

Step 1: $F(1,131) = 13.98$, $p < .001$

Step 2: $F(2,130) = 12.13$, $p < .001$

t2 single word reading – t2 A & EF reaction time & WR*:*

Step 1: $F(1,131) = .08$, $p = .78$

Step 2: $F(2,130) = 8.05$, $p < .001$

Based on the table above it can be suggested that the WR is significantly contributing to the variance of a single word reading prediction model over and above the A & EF measure. The first model revealed that the shared variance between the WR and A & EF: accuracy score entered into the concurrent model was 14.4%. Further, the individual unique contribution of the WR over and above the accuracy score of A & EF within this concurrent model was 5.4%. In the second model looking at the WR in relation to A & EF reaction time score, the shared variance between both predictors entered into the model was slightly lower, with 9.6%. However, the first step of the model investigating the individual contribution of A & EF reaction time score was not significant.

Results from both concurrent models seem to suggest that while the VA and A & EF assessments share some overlapping variance, both assessments are also tapping somewhat separable skills.

6.4.2.3.2 Relationships between whole report and traditional reading precursor skills for the longitudinal prediction of single word reading

Table 6.21 below summarises the longitudinal hierarchical regression models predicting the single word reading component at t2. The decision was made to investigate the variance of the predictor variable WR at t1 in relation to all assessed traditional precursor skill variables of the same time point in individual models. Given the lack of knowledge concerning this variable, the aim here was to understand its specific relationship to each other variable individually, to best understand its contribution and relationship to other variables before creating more complex models.

Table 6.21 *Summary of individual hierarchical regression analyses for whole report in relation to letter sound knowledge, receptive vocabulary, short-term memory, phonological awareness and NVIQ predicting Reception to Year 1 single word reading*

Step and predictor variable	Reception to Year 1				
	B	***SE B***	***β***	***Adj. R^2***	***Adj. Δ R^2***
Step 1:				.260***	
t1 Letter-sound knowledge	.509	.074	.515		
Step 2:				.341***	.081***
t1 Letter sound knowledge	.438	.072	.444		
t1 Whole report	10.411	2.505	.302		
Step 1:				.147***	
t1 Receptive vocabulary	.504	.103	.392		
Step 2:				.227***	.080***
t1 Receptive vocabulary	.369	.105	.287		
t1 Whole report	10.681	2.803	.310		
Step 1:				.190***	
t1 Short-term memory	1.986	.351	.443		
Step 2:				.250***	.060***
t1 Short-term memory	1.502	.367	.335		
t1 Whole report	9.507	2.823	.276		
Step 1:				.297***	
t1 Phonological awareness	.497	.066	.550		
Step 2:				.325***	.028*
t1 Phonological awareness	.415	.072	.460		
t1 Whole report	6.956	2.753	.202		
Step 1:				.040*	
t1 NVIQ	1.024	.400	.218		
Step 2:				.171***	.131***
t1 NVIQ	.645	.381	.137		
t1 Whole report	13.015	2.796	.378		

Note. Statistical significance is indicated with asterisks: * $p < .05$; *** $p < .001$. NVIQ = non-verbal intelligence quotient.

Each of the individual models above were significant:

t2 single word reading – t1 letter-sound knowledge & WR:

Step 1: $F(1,131) = 47.27$, $p < .001$

Step 2: $F(2,130) = 35.20$, $p < .001$

t2 single word reading – t1 receptive vocabulary & WR:

Step 1: $F(1,131) = 23.75, p < .001$

Step 2: $F(2,130) = 20.36, p < .001$

t2 single word reading – t1 short-term memory & WR:

Step 1: $F(1,131) = 32.03, p < .001$

Step 2: $F(2,130) = 22.95, p < .001$

t2 single word reading – t1 PA & WR:

Step 1: $F(1,131) = 56.86, p < .001$

Step 2: $F(2,130) = 32.79, p < .001$

t2 single word reading – t1 NVIQ & WR:

Step 1: $F(1,131) = 6.54, p < .05$

Step 2: $F(2,130) = 14.62, p < .001$

For the longitudinal models of single word reading after one year of schooling, the amount of shared variance explained by the WR and the other potential predictor models ranged from 34.1% (letter-sound knowledge and WR) to 17.1% (NVIQ and WR).

When considering the individual unique variance WR adds to individual models above and beyond other assessed traditional predictors, the following observations were made: In the prediction model entailing the VA measure and NVIQ, WR explained 13.1% of the variance above and beyond the non-verbal ability measure, making it the largest significant gain in comparison to all other models. In contrast to this, the VA measure only predicted an additional – albeit still significant – 2.8% of the variance in single word reading above and beyond that predicted by the PA measure. In comparison to these two models being on the opposite ends of the results' range, models investigating the predictive power of the VA measure in relation to letter-sound knowledge (8.1%), receptive vocabulary (8.0%), and short-term memory (6.0%), showed some further evidence that in relation to the single word reading outcome measure, the WR task predicts a degree of unique variance in single word reading, that is distinct from the variance explained by individual traditional predictor measures.

In summary, results from these individual hierarchical regression models suggested that the assessment of the *WR* at the beginning of the school year is measuring abilities that are predictive of variance in single word reading performance after one year of schooling. As a final step a series of *multiple* hierarchical regression analyses were undertaken with single word reading as the dependent variable, to investigate the predictive strength of variables within a more complex, multivariate context.

6.4.2.4 Prediction models for single word reading

This section presents the results from overall hierarchical regression analyses that explored the unique predictive power of the traditional predictor skills and the WR for single word reading. Two prediction models, one concurrent and one longitudinal, are presented below. Variables were entered into the model in varying order, to identify the variance each predictor could explain uniquely (i.e. when entered last) and therefore over and above the other predictors.

6.4.2.4.1 Concurrent prediction model for single word reading after one year of schooling

At first, a concurrent prediction model was created for data collected after one year of schooling to further explore the unique predictive power of each traditional literacy predictor measure and the WR task for single word reading after one year of schooling (Table 6.22).

Table 6.22 *Results from the hierarchical multiple regression analyses predicting single word reading at t2 from predictor skills at t2*

	R^2	Adj. R^2
Overall prediction model	.601***	.582***
Predictors	Entered Last	
	ΔR^2	Δ Adj. R^2
t2 Receptive vocabulary knowledge	.014	.011
t2 Short-term memory	.005	.008
t2 Phonological awareness	.361	.221
t2 A & EF: accuracy score	.000	-.003
t2 A & EF: reaction time	.005	.002
t2 Whole report	.005	.002

Note. Statistical significance is indicated with asterisks: *** $p < .001$. A & EF = attention & executive function.

The overall concurrent model including all predictors was highly significant ($F(6,126) = 31.65$, $p < .001$). In order to establish the unique contribution of each variable, the model was run six times, each of which a different predictor was entered in last. Unexplained variance was computed based on the predictive power of the overall model, leading to the determination of shared variance. The pie chart below shows the unique, shared and unexplained variance for each of the components incorporated into the model (Figure 6.5).

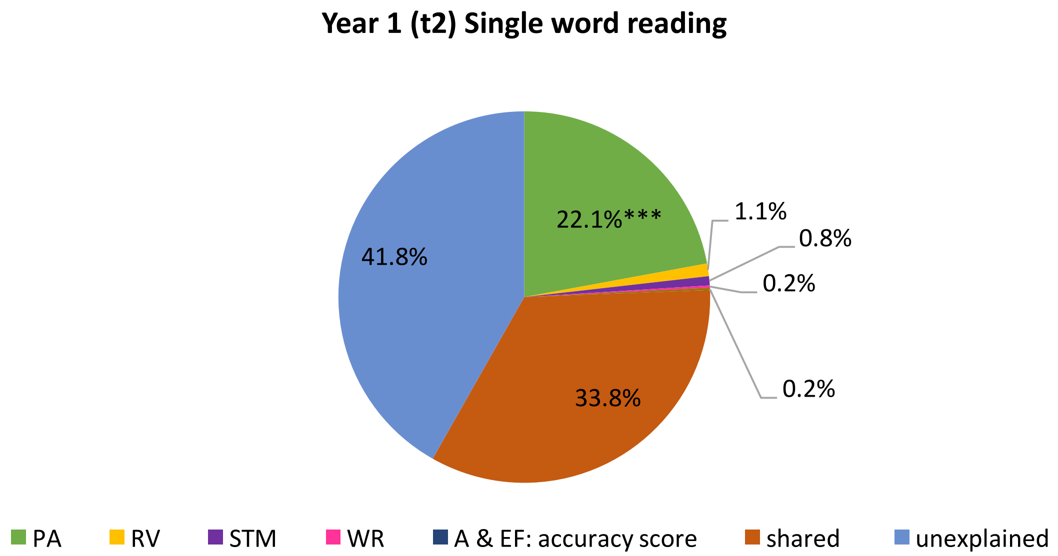

Figure 6.5 *Pie chart showing unique, shared and unexplained variance for phonological awareness (PA), receptive vocabulary (RV), short-term memory (STM), visual attention measure whole report (WR), attention & executive function (A & EF) accuracy score, predicting Year 1 (t2) single word reading outcome measure. Note. Statistical significance is indicated with asterisks: *** $p < .001$.*

In this concurrent model, PA was a highly significant, unique predictor for single word reading, explaining a considerable share of 22.1% of the variance. In comparison to this, receptive vocabulary (1.1%), and short-term memory (.8%) were not significant and only contributed very little to the concurrent predictor model for single word reading after one year of schooling. Results further revealed that WR (.2%) and both A & EF measures (.2% and .0%) did not contribute to the prediction model. Since the predictive power of almost all components entered into the model was low – with the exception of PA – the shared variance between all entered predictors was 33.8%. This led to 41.8% unexplained variance for the concurrent single word reading model.

6.4.2.4.2 Longitudinal prediction model for single word reading after one year of schooling

The longitudinal prediction model created looked at the unique predictive power of each traditional literacy predictor measure entered into the model, as well as of the WR task assessed at the beginning of schooling for single word reading after one year of schooling (Table 6.23).

Table 6.23 *Results from the hierarchical multiple regression analyses predicting single word reading at t2 from predictor skills at t1*

	R^2	Adj. R^2
Overall prediction model	.463***	.437***
Predictors	Entered Last	
	ΔR^2	Δ Adj. R^2
t1 Receptive vocabulary	.002	-.003
t1 Short-term memory	.045	.042
t1 Phonological awareness	.024	.020
t1 Letter-sound knowledge	.075	.073
t1 NVIQ	.011	.006
t1 Whole report	.001	-.004

Note. Statistical significance is indicated with asterisks: *** $p < .001$. NVIQ = non-verbal intelligence quotient.

The overall longitudinal model including all predictors was highly significant ($F(6,126) = 18.07$, $p < .001$). The same principle adopted in the concurrent model above was applied here to establish the unique contribution of each variable. The pie chart below shows the unique, shared and unexplained variance for each of the components incorporated into the longitudinal model (Figure 6.6).

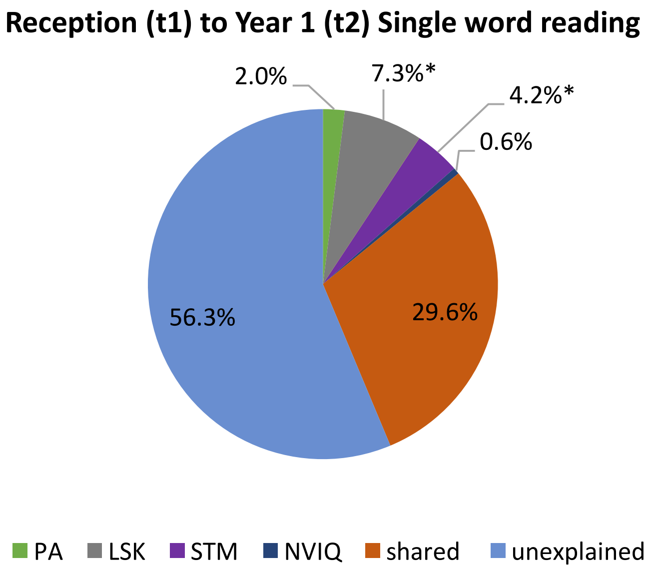

Figure 6.6 *Pie chart showing unique, shared and unexplained variance for phonological awareness (PA), letter-sound knowledge (LSK), receptive vocabulary (RV), short-term memory (STM), non-verbal IQ (NVIQ), and visual attention whole report (WR) predicting the Reception to Year 1 (t2) single word reading outcome measure. Note. Statistical significance is indicated with asterisks: * p < .05.*

In this longitudinal model, letter-sound knowledge was the strongest and significant unique predictor for single word reading explaining 7.3% of the variance. Followed by the second strongest predictor, short-term memory uniquely and significantly contributing 4.2% to the model. Compared to the concurrent model, the predictive power of short-term memory on single word reading therefore seemed to be bigger (+ 3.4%) longitudinally. The opposite effect was observed for PA: While this predictor had the strongest predictive power for single word reading in the concurrent model, PA uniquely contributed only 2.0% to the longitudinal model. Interestingly, NVIQ (.6%) did not contribute to the longitudinal predictor model for single word reading after one year of schooling, as did the one remaining traditional literacy predictor skill, receptive vocabulary (.0%). Finally, results regarding the predictive power of the WR in the longitudinal model for single word reading went in line with the concurrent model as no unique variance (.0%) was found.

In comparison to the concurrent model, the shared variance between all entered predictors was slightly lower with 29.6%. This resulted in a considerable share of 56.3% unexplained variance for the longitudinal single word reading model.

6.5 Summary & Discussion

This section will summarise the findings and will relate them to the research questions set out at the beginning of this chapter. Further, results will be discussed in relation to findings from published literature.

At first, the performance of emerging readers on the traditional linguistic and cognitive predictor variables measured at school entry and after one year of schooling will be considered and related to the literature. In a next step, the concurrent relationships between VA and individual cognitive and linguistic predictor measures will be explored, looking at the results from t1 (at school entry) and t2 (after one year of schooling) for participating children. Results from the parental reports and children's self-reports on children's digital exposure intensity will further be discussed with findings from previous studies looking at children's engagement with digital technology prior to school entry. Findings concerning VA as a potential digitally-relevant precursor skill of reading will be summarised and discussed next. Finally, results regarding the predictive power of literacy precursor skills used in the hierarchical multiple regression models for single word reading – letter-sound knowledge, phonological awareness, short-term memory, receptive vocabulary – will be discussed individually and in relation to findings from the literature at the end of this chapter.

6.5.1 Emerging readers' performance on linguistic and cognitive literacy predictor measures at school entry and after one year of schooling

In this section, the results will be discussed concerning the third research question set out at the beginning of this chapter: children's performance on the assessed literacy predictor skills at both time points. All predictor measures presented in section 6.1 will be considered and discussed in relation to the literature. Measures that acted more as control variables - NVIQ (t1), as well as attention & executive function (t2) will be examined separately in later sections (see 6.5.2 & 6.5.4).

6.5.1.1 Phonological awareness

Children's phonological awareness (PA) skills at school entry and after one year of schooling were assessed using sound isolation and sound deletion measures. Explicit

PA assessments, such as the ones adopted in this study, aim to assess whether the child is able to reflect upon and manipulate the speech sounds in individual words (Gombert, 1992). Children performed well on the PA measure of sound isolation, with standardised scores being very close to the mean of the normative sample at t1 (102.85). By t2, the group's standardised scores had risen to 113, which represents a notable increase in performance level, approaching one standard deviation above the mean. The mean standardised score of the sound deletion PA measure at t1 was lower than that for sound isolation, but also within the normal range, suggesting that children's ability to reflect upon and to delete speech sounds was within the expected norm at school entry. During the first year of schooling children made significant progress in their sound deletion skills. While performance at t2 was within the normal range, there was again an observable increase in the relative placement of the participant group in relation to the normative sample after one year of schooling.

The fact that children's performance on the sound isolation task was slightly better than their performance on the sound deletion task at both testing points may provide evidence of the different task requirements, with the storage and processing demands of deleting a sound arguably exceeding those of simple identification (Tunmer & Hoover, 1992). However, it has to be noted that sound deletion tasks are not always more difficult than sound isolation tasks, for example in those instances when children are required to delete the sound at the end of the word. In these cases children could arguably use the strategy of saying the words out loud and then just stopping before saying the final sound. Equally, depending on whether it is required to isolate all sounds versus just an intial sound, sound isolation can be more difficult or more easy in comparison to sound deletion tasks.

6.5.1.2 Letter-sound knowledge

Letter knowledge in children was tested at the beginning of Reception using a measure of letter-sound knowledge (LSK), as UK children tend to be more exposed to letter-sounds over letter-names in conjunction with phonics in early literacy instruction (Ellefson et al., 2009). LSK was only assessed at school entry since a number of studies (e.g. Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Seymour, Aro, & Erskine, 2003) suggested that LK reaches ceiling in a normative group of English speaking children within the first year of formal education. The ability of children included in the study to connect letters to their associated sounds when tested at school entry met the expected level for the age group.

6.5.1.3 Short-term memory

Children's short-term memory, and therefore their ability to store linguistic information, was assessed adopting a serial recall measure – nonword repetition – at both time points. At t1 & t2, children showed an overall average performance on the nonword repetition task, with further analysis confirming a significant increase in children's performance when tested after the first year of schooling compared to at school entry. In addition, there was a wide range of performance at both time points. This finding provided converging evidence for Gathercole (2006), who suggested that big variation in children's skill to repeat multisyllabic nonwords during childhood made it one of the most effective precursors to look at when assessing children's language learning ability.

6.5.1.4 Vocabulary

While the results regarding all assessed cognitive and linguistic literacy predictors were in line with previous findings from the literature, this was not the case for the vocabulary measure used in this study – receptive vocabulary. At school entry, children's performance on this measure was at an expected level, with a standardised score of 99.53. After one year of schooling however, the mean standardised performance across all participants, albeit still being within the expect range, had dropped to 94.17. While raw score increases between t1 and t2 showed that children made concrete advances in their receptive vocabulary performance, the positioning of the group relative to the norm sample had slightly dropped. Looking beyond the group mean, there was a wide spread of scores across all participants, with the difference in scores between the highest and lowest performing child being 52 points at t1 and 48 points at t2 on the standardised scale. It was thought that perhaps one reason for this decline in relative performance could be e.g. the "Matthew Effect", a term coined by Keith Stanovich (1986) whereby if some of the group were struggling to learn to read, this could be perniciously reducing their rate of receptive vocabulary growth. Although the reading performance of the group as a whole (see next section 6.5.1.5) did not appear to support this, one follow-up hypothesis was that perhaps children in the cohort from lower socioeconomic environments had a slower rate of language growth compared to children from higher socioeconomic environments (Hoff, 2013), which could be driving this effect. To investigate this hypothesis empirically, children's degree of receptive vocabulary growth was examined in relation to two proxies of socioeconomic status (SES). Firstly, a t-test was carried out comparing the vocabulary growth scores for children eligible for free school meals at t2 (n = 32, M = -5.60, SD = 9.46) and those not eligible (n = 101, M = -5.08, SD = 8.86). This found no significant difference in vocabulary growth between the two groups, t(131) = - .27, p = .79. Converging evidence compared performance growth between children at t2 attending School B (n = 46, M = -4.54, SD = 7.14), located in a more affluent area, and children from the three other schools included in the study (n = 87, M = -5.55, SD = 9.83), with the increase in receptive vocabulary performance between groups also not being significantly different, t(131) = .68, p = .50. Thus, no clear reason could be found for the slight decline in relative performance on receptive vocabulary across time, however it should also be noted that the group mean remained well within the normal range.

6.5.1.5 Outcome measure single word reading

Children's single word reading skills were assessed on a reading accuracy measure comprising of nonwords, exception words, and regular words. Performance on the overall outcome measure single word reading after one year of schooling showed that the performance across all tested children was above the expected level for that age group. At the same time however, scores observed were on a wide spectrum, ranging from a few children failing to score at all in the test, to children performing on an average level, to another small group of children displaying much more advanced skills, scoring three times higher than the mean raw score of the overall group. This range of reading abilities observed in children being exposed to comparable amounts and intensities of literacy instruction was arguably highlighting the challenges teachers face to design learning environments adequate for all children in a class.

6.5.1.6 Summary of emerging readers' performance on linguistic and cognitive literacy predictor measures

Descriptive statistics for participants' performance on all linguistic and cognitive predictors at both time points showed a wide range of scores across all measures. When considering standardised scores at t1, the average performance of all participants was within the normal range at t1. Results from the first time point thus indicated that the initial goal to recruit a normative sample for this study was met. In line with results at t1, participants' performance at t2 was similar when considering standardised scores, with the average performance across tested measures, including the single word reading outcome measure, being within the norm. Analyses of the development of literacy predictor skills in tested children revealed that children made appropriate gains, with a significant rise in children's performance on the phonological awareness measures (sound isolation, sound deletion), as well as on the short-term memory measure. This was not the case for the receptive vocabulary measure, where, despite an increase in raw scores across the two time points, the groups' relative standing as measured by standardised scores fell slightly. However, at both time points the group performed within the normal range. Equally, follow-up analyses to look at the possible impact of SES on receptive vocabulary growth did not reveal any clear relationship.

6.5.2 Concurrent relationships between visual attention and cognitive and linguistic predictors in emerging readers at school entry and after one year of schooling

This section will consider the findings of the concurrent relationships between the individual cognitive and linguistic predictor measures, including the VA measure at school entry and after one year of schooling. In addition, the concurrent correlations between NVIQ, attention & executive function, as well as the outcome measure single word reading with the other predictors will be summarised. In the following, measures included in the study will be considered separately in their relation to the other predictors. In order not to repeat results, each predictor section will only discuss those relationships which were not considered in previous sections. Finally, *r* but not *p*-values will be included when significant correlations ($p \leq .05$) are discussed in the following sections: $r \geq .50$ indicates strong, $.30 < r < .50$ moderate, and $.10 < r < .30$ weak correlations (Cohen, 1988).

6.5.2.1 Concurrent relationships between phonological awareness and other cognitive and linguistic predictors

Children's phonological awareness (PA) was assessed using sound isolation and sound deletion measures. Both PA measures being of the same construct, were significantly and strongly correlated with each other (t1: $r = .52$; t2: $r = .66$) at both time points, with the relationship increasing in strength after one year of schooling compared to at school entry. These findings further confirmed that children's sound isolation and sound deletion skills were very closely related with each other. In addition, these concurrent results provided initial justification for the creation of a combined PA score in the subsequent regression analyses. Overall, results of the study went in line with a number of findings reported in the literature. Lonigan, Burgess, Anthony, & Barker (1998) for instance suggested a strong and significant relationship between similar measures of PA in a sample of 4- to 5- year olds. In addition, Wagner et al. (1997) found that different measures of PA correlated highly with each other in children in the process of learning to read, with Anthony & Lonigan (2004) further highlighting that PA was a unified construct.

At school entry, the PA measure sound isolation and letter-sound knowledge (LSK) were strongly and significantly ($r = .53$) correlated with one another. These results go in line with findings suggesting that PA and LSK seemed to be in a close and reciprocal relationship in preschool-age children (Bowey, 2005; Burgess & Lonigan, 1998; Lerner & Lonigan, 2016). Although the current work could not address whether there was a reciprocal relationship between these two constructs, the results did suggest that LSK and PA – the understanding of the principle of an alphabetic language and the awareness of the sounds that can be mapped to letters (Bowey, 2005) – were related during children's literacy development. It could thus be argued that they are together essential for children learning the alphabetic principle (Byrne & Fielding-Barnsley, 1989).

The PA measure sound deletion was significantly and strongly correlated with the receptive vocabulary measure at school entry as well as after one year of schooling (t1: $r = .54$; t2: $r = .51$). Furthermore, relationships between the other PA measure sound isolation and receptive vocabulary were almost strong and significant ($r = .49$) at school entry, as well as moderate and significant ($r = .38$) after one year of schooling. Results therefore provided evidence for claims that language skills, and especially receptive vocabulary skills were strongly related to PA skills (Sénéchal et al., 2006; Storch & Whitehurst, 2002), for instance by playing a key role in the development of PA in children (Metsala & Walley, 1998).

In line with the relationships discussed so far, the concurrent relationships between both PA measures and short-term memory (STM) were all moderate and significant ($.32 \leq r \geq .43$) at both time points. Relationships between these two measures have been suggested in the literature, with phonological STM being argued to influence literacy development indirectly through supporting the development of PA (Gathercole, Tiffany, Briscoe, & Thorn, 2005). Interestingly, the relationship between STM and sound isolation was slightly stronger (compared to sound deletion) at school entry, with the opposite being the case after one year of schooling. Arguably these slight differences in relationships again reflected the diverging task requirements, with storage and processing demands of some sound deletion tasks, for instance identifying a medial sound, possibly being more difficult that the simple identification of sounds (Tunmer & Hoover, 1992).

6.5.2.2 Concurrent relationships between letter-sound knowledge, receptive vocabulary, and short-term memory

The concurrent correlation between letter-sound knowledge (LSK) and receptive vocabulary at school entry was moderate and significant (r = .35). This suggested that while LSK seemed to be in close relationship with skills tested in the PA assessments, children's receptive vocabulary knowledge was only little overlapping with skills tested in the LK assessment. Anthony et al. (2009), researching bilingual children, has shown that LSK is highly dependent on informal and formal teaching practices, and results from a study looking at a normative group of emerging readers have not found vocabulary to predict children's LSK (de Jong & Olson, 2004). One possible interpretation of the observed moderate – and compared to PA – weaker concurrent relationship between LSK and receptive vocabulary could therefore be that literacy teaching had a bigger impact on children's LSK, in comparison to receptive vocabulary knowledge.

LSK and short-term memory (STM) were only assessed simultaneously at school entry showing a weak and nonsignificant (r = .18) relationship. There has been an ongoing debate regarding the relationship between LK and STM. One interpretation offered by de Jong and Olson (2004) is that STM plays a role in the acquisition of LK, as phonological representations of a word need to be stored in STM store in order to be linked with their orthographic representation and to be subsequently secured in long-term memory. However, based on the findings it could be suggested that the lack of relationship between these variables reflected that children were able to access their LSK relatively automatically without much involvement from STM.

When finally considering the concurrent relationships between receptive vocabulary and STM for children at school entry and after one year of schooling, their relationships were only weak, although in both cases significant (t1: r = .21; t2: r = .24). Results therefore slightly deviated from previous studies, suggesting a close relationship between children's performance on NWR tasks and their language development, and more specifically highlighting links between NWR and vocabulary growth in young children (e.g. Gathercole, Willis, Emslie, & Baddeley, 1992). The observed weak concurrent relationships were therefore not expected and difficult to interpret.

6.5.2.3 Concurrent relationships between visual attention and other cognitive and linguistic predictors

At school entry, as well as after one year of schooling, relationships between literacy precursor skills and VA measures showed significant weak to moderate correlations across all measures.

At t1 whole report (WR) was significantly and moderately correlated with both phonological awareness (PA) measures (sound isolation: r = .41; sound deletion: r = .36), receptive vocabulary (r = .32), and short-term memory (r = .38). These significant and moderate relationships seemed to suggest that performance on the VA assessment is related to language performance. One reason for this correlation could be the task requirements of the VA assessment, with verbal responses required in order to report the symbols seen. In comparison to these moderate correlations WR showed weak albeit significant correlations with letter-sound knowledge (r = .21) at school entry. Whilst the VA assessment deliberately chose not to use letters, to circumvent the need for automaticity in this skill, the quick retrieval of words that correspond to symbols may tap somewhat similar processing demands.

After one year of schooling at t2, concurrent moderate and significant relationships were still observed with the PA measure sound deletion (r = .32), and receptive vocabulary (r = .34), with relationships turning weak and significant between WR and the PA measure sound isolation, as well as between WR and short-term memory (r = .21, in both cases). These results further emphasise that receptive vocabulary knowledge may play a role in the performance on the VA span assessment (WR). Another alternative hypothesis, more difficult to test here, is that the relationship between vocabulary and VA is mediated by a third, latent variable.

In contrast, children's short-term memory abilities were less related to performance on the WR task after one year of schooling. One reason for this could be that as children's STM capacity grows, variability in STM plays a reduced role in the WR task. The WR task, more than the PR, relies notably upon STM in order to retain in mind the symbols seen and repeat them back to the examiner. Although not possible to confirm here, growth in STM capacity could also explain the reduction in relationship between WR and PA, both these tasks requiring STM for successful completion.

Relationships of the second VA measure, PR, with all other literacy predictors measures were significant at weak to moderate levels ($.21 \leq r \geq .30$) at school entry, with its relationship with the PA measure sound isolation at t1 particularly standing out (r = .48). This relationship between sound isolation and PR is interesting. Again, while any attempt to explain this is rather speculative, overlap of task demands is arguably the most plausible explanation for this relationship. Within the sound isolation task children hear a whole nonword, e.g. "drick" and are asked to isolate/say the first sound in the nonword. A child may need to employ inhibitory processes to be able to identify one particular sound against a context of the other "non-target" parts of the word – skills that have parallels within the PR task.

When children were re-tested after one year of schooling, only slight changes in relationships were observed overall, with PR showing moderate correlations with both PA measures, sound isolation (r = .31) and sound deletion (r = .33), and weak but significant relationships with receptive vocabulary (r = .19), and short-term memory (r = .26). The weaker relationships of receptive vocabulary knowledge with the PR in comparison to the WR, further highlights that while vocabulary skills were still needed for performance on the target detection tasks, the measure was arguably drawing less on vocabulary skills in comparison to the VA span task. Finally, moderate and significant (t1: $r = .38$; t2: $r = .39$) correlations between both VA measures, WR and PR, at school entry as well as after one year of schooling confirmed a relation between the two VA assessments. At the same time, these moderate concurrent correlations also provided evidence to suggest that both assessments were not identical but rather captured slightly different facets of VA performance.

6.5.2.4 Concurrent relationships between visual attention and the attention & executive function measure

The attention & executive function (A & EF) measure was included in the assessment battery of the second testing point to investigate whether the VA assessment of the study was sufficiently different from other more general measures of attention and executive function. When considering the concurrent relationships between attention and executive function and both visual attention measures, the A & EF *accuracy score* correlated weakly but significantly ($r = .29$, $p < .01$) with the PR, and moderately and significantly ($r = .31$, $p < .001$) with the WR. These results therefore suggest that while similar skills are needed, task demands of the VA assessment are still different to the more general A & EF measure adopted in the study. Indeed, the A & EF flanker task involves targets and distractors, similarly to the PR, however in the flanker task these require less specific, overt identification compared to the PR. Further, there is also less positional variation in targets/distractors in the flanker task compared to the PR, making the PR task deliberately more equivalent to text processing. In addition, the A & EF flanker task required no verbal response, but rather a button press.

The A & EF *reaction time* measure on the other hand was only correlated weakly and significantly with the WR ($r = .18$), but not with the PR ($r = .004$). In fact, when considering the A & EF concurrent correlations with traditional predictors compared to all other correlations, the reaction time measure appeared to be an outlier: While accuracy scores were weakly to moderately correlated with all literacy precursor skills, reaction time was not significantly correlated with any of the same variables. This may be due to the qualitatively different nature of a response time measurement as compared to accuracy judgement (all other variables were scored for accuracy as opposed to reaction time). Equally, it may be that for this particular assessment, with this particular age group, the signal-noise ratio of the reaction time data collected was too high for the variable to be a sensitive index of processing speed.

6.5.2.5 Concurrent relationships between cognitive and linguistic predictors, and visual attention when controlled for NVIQ and receptive vocabulary

At both time points, partial correlations controlling for receptive vocabulary and NVIQ were performed to reach a deeper understanding of the discussed concurrent relationships between the traditional predictor skills and the VA assessment.

When receptive vocabulary was controlled for at school entry, partial correlations revealed that in almost all of the cases the strength of relationships between variables was reduced, including four instances when the strength of relationships became very weak and therefore nonsignificant. Partial correlations performed after one year of schooling showed that controlling for receptive vocabulary did not cause a big change in the strength of relationships for the majority of measures. However, the strength of relationships between the VA measure WR and the other assessment battery measures was reduced, including two instances when it turned weak and therefore nonsignificant. When comparing these partial correlations with the non-partial correlations at both time points, the following interpretation could be made: In the reported non-partial correlations discussed above, receptive vocabulary was contributing to the relationships between other predictor skills. When receptive vocabulary was controlled for on the other hand, correlations decreased, suggesting that some of the strength of those relationships between assessed literacy predictors and VA was likely mediated by broader verbal language ability.

The non-verbal ability measure was included in the assessment battery at school entry. Concurrent relationships between the non-verbal ability measure (NVIQ) and all other cognitive and linguistic predictors at t1, were significant and moderate with PA sound deletion (r = .30), weak and significant with PA sound isolation (r = .21), letter-sound knowledge (r = .23), and receptive vocabulary (r = .22), as well as nonsignificant with short-term memory (r = .07).

When partial correlations were conducted controlling for NVIQ, the opposite effect of what was observed when controlling for receptive vocabulary, occurred at both time points. At school entry, relationships between all variables increased, with almost all reaching strong correlations. Partial correlations controlling for NVIQ after one year of schooling further caused all relationships, including the nonsignificant correlations between the A & EF reaction time measure, to become strong and significant, ranging from ($.53 \leq r \leq .96$). Stronger relationships manifesting between variables when NVIQ was controlled for appears to suggest that rather than contributing to the strength of relationships between variables, variability in NVIQ potentially obscured the extent of these relationships.

6.5.2.6 Concurrent relationships between outcome measure single word reading, cognitive and linguistic predictors, and visual attention

When considering the concurrent correlations between the single word reading outcome measure and the predictor measures tested at the same time point, single word reading correlated significantly and strongly with both PA measures ($r = .59$; $r = .74$), as well as moderately and significantly with receptive vocabulary ($r = .49$), and short-term memory ($r = .44$). In addition, comparable significant and moderate concurrent relationships were found between single word reading and both VA measures ($r = .32$; $r = .33$).

6.5.2.7 Summary of concurrent relationships

Overall, the analysis of the relationships between all assessed measures at both time points revealed significant correlations, with the vast majority being moderate to weak at t1, and moderate at t2, except for the A & EF reaction time measure. The strongest concurrent correlations were found between PA and letter-sound knowledge, as well as the PA measure sound deletion and receptive vocabulary, while the weakest were identified between letter-sound knowledge and short-term memory. Both VA measures tended to be concurrently correlated most strongly with PA. Furthermore, the WR task correlated significantly and moderately with receptive vocabulary at both time points highlighting the relationship between language-based skills and specifically, the VA span task demands (WR). The PR task on the other hand was less correlated with receptive vocabulary. In addition, both VA measures displayed moderate correlations with the A & EF accuracy score measure suggesting that they were related but yet distinct measures drawing on at least somewhat divergent processing skills. Partial correlations controlling for receptive vocabulary revealed that some of the strength of relationships between assessed literacy predictors and VA was likely mediated by broader verbal language ability. In contrast, partial correlations controlling for NVIQ suggested that children's variation in non-verbal ability reduced, rather than strengthened the relationships between traditional predictors. Finally, all measures were significantly moderately to strongly correlated with the outcome measure single word reading.

It is important to recognise that zero-order correlations need to be treated with caution as they cannot determine the direction of effects and are vulnerable to the influences of other variables. However, it can be argued that findings based on the concurrent relationships presented above suggested that the patterns between cognitive and linguistic skills in children tested were overall comparable to those found in previous studies. Finally, these initial results also suggested that VA measures applied in this study could be included in further analyses.

6.5.3 Relationships between children's digital exposure intensity and visual attention

The results discussed above will now be considered in relation to the fifth research question set out at the beginning of this chapter, investigating possible relationships between children's digital exposure intensity and VA. Answers to individual questions will be summarised and considered in relation to the literature first, followed by an examination of the links between VA and children's digital exposure.

Results presented in this chapter considering parental reports on children's exposure to digital devices suggested that there was a wide range in the amount of time children had been exposed to digital devices prior to school entry. The most frequent response of parents asked was that their child had started to engage with digital devices at the age of 2-3 years. On the other hand, a sizeable group of parents stated that their child was exposed to digital technology from one or two years of age, with yet another small group of parents indicating that this had happened before the first birthday of their children. This was particularly interesting as the guidance from the American Academy of Paediatrics published in 2016 recommended for children under the age of 18 months not to be exposed to any digital devices, with the exception of video-chatting (American

Academy of Pediatrics Council on Communications and Media, 2016). While there were therefore children in the sample who started to use digital devices earlier than recommended, there was also a considerable group of parents who were on the other end of the spectrum. The majority of these parents stated that their child was between 3-4 years of age when first using digital devices, with a handful of parents going even further, claiming that their child had never used digital devices prior to entering school.

One can never have certainty that a questionnaire respondent is interpreting a statement in the exact way intended by the questionnaire author; however, these results do suggest that some of the parents asked seemed to make the conscious decision to restrict their child's exposure to digital devices. In addition, these reservations against children's use of digital devices go in line with parental reports published by the US survey Scholastic (2014) regarding children's use of print versus digital devices for reading activities. When reading books for fun was concerned, more than half of all participating parents (63%) of 6- to 8- year olds reported that they would prefer their child to read print books over ebooks.

Findings regarding parental reports on children's frequency of digital device use reflected the results from the previous questionnaire item. Based on parental reports the overall sample of children participating in the study consisted of a few very infrequent digital device users, a considerable group of children engaging frequently or very frequently with digital devices, with the remaining and biggest proportion being defined as moderate digital device users. Results from children's self-reports on their frequency of digital device use yielded a year later, showed converging evidence. In addition, it seemed that only a small group of children frequently used digital devices for a range of activities in everyday life, with the vast majority stating that they would use them in moderation for a few listed activities, such as watching programs or playing games for fun. Further, these findings from the parental and children self-reports highlighted that digital technologies have become an integral part of home settings, and thus emphasised the need to no longer ask the question *if* a child should have access to digital devices, but rather *in what manner* and *how much* (Thomson et al., 2018).

When considering children's self-reports on their digital device use for reading activities, results suggested that only a small proportion engaged in reading activities with digital devices on a daily basis. While a small group of participating children indicated that they would infrequently use digital devices for reading activities at home, the vast majority of the sample stated not to engage in any reading related activities on digital devices at home. These findings went in line with results from a US-wide survey conducted by Scholastic (2014) with slightly older children aged 6-8. In this survey, 84 per cent of children belonging to that age group reported that most of the books they read were in print. However, while findings therefore suggested that digital devices were only used a little for reading within the participant group sampled here, it remained unclear from these results whether the overall reported infrequent use of digital devices for reading was based on a general lack of engagement with text across different modalities, or a preference for print books.

Overall, the analysis of parent questionnaires at t1 revealed a wide range in children's exposure to digital devices, as well as their digital device use frequency before entering school. Analyses of follow up children's self-reports conducted a year later at t2 revealed that the vast majority of children did not use digital devices to read or look at stories on their own or together with adults. Results relating to digital device use frequency of participants confirmed findings from t1, showing a wide range in children's user intensity of digital devices for different activities.

When exploring the relationships between digital exposure intensity and VA, results considering parental reports at t1 and children's self-reports at t2 were comparable: For t1, no significant relationship was found between the two parameters of a child's digital exposure intensity and the VA assessment scores (WR and PR) tested at school entry. The decision to gather additional data on children's digital exposure intensity after one year of schooling by interviewing participants themselves, was initially made to reach more conclusive results regarding the relationships between children's VA and digital exposure intensity. When looking at correlations between these two variables at t2 however, no significant relationships were found between a child's reading frequency on digital devices and a more general frequency of digital device use and the VA assessment scores. The results were finally confirmed by the concluding longitudinal analysis: There were no significant relationships between parental reports of children's digital device use and digital exposure intensity before entering school and their performance on the VA measure after one year of schooling.

In a last step, additional analyses looked into possible connections between digital exposure and single word reading, to explore data from the parental reports, as well as children's self-reports in relation to the outcome measure of this study. No significant relationships were found concurrently or longitudinally between collected data on children's digital exposure intensity and the single word reading outcome measure. Findings therefore suggested a lack of relationship between digital usage and VA as measured here, as well as digital usage and achievement on the single word reading measure. While one can only speculate about possible reasons at this point in time. One explanation for not seeing stronger links between digital exposure and academic development could be that the majority of the group tested in this study, either because of their young age or SES background, had not been using digital devices in an extensive way. However, it needs to be considered that children's digital exposure was aimed to be characterised with only two questionnaire items for each time point and that additional limitations at t1 were caused by incomplete parent questionnaires. It was therefore felt that the reported non-significant correlations between VA and digital device use in this study did not provide strong enough evidence to make assumptions either way on relationships between children's VA and their digital exposure intensity.

6.5.4 Predictive relationships between visual attention, traditional cognitive and linguistic predictors, and single word reading in emerging readers

This section will address the sixth research question and will thus discuss the findings of the concurrent and longitudinal hierarchical multiple regression models, in relation to the longitudinal correlations, in predicting single word reading in emerging readers after the first year of schooling. Results for VA as a potential digitally-relevant predictor skill for single word reading after one year of schooling will be addressed first. This will be followed by a discussion of the unique predictive significance of the traditional predictors PA, letter-sound knowledge, receptive vocabulary, and short-term memory for children's single word reading.

6.5.4.1 Visual attention as predictor of single word reading

The main aim of this study was to investigate VA as a potential digitally-relevant predictor skill of reading in the light of children's increased exposure to digital devices in the early years. Thus, after considering concurrent relationships between VA and the other predictors of reading (see section 6.5.2), longitudinal relationships between both VA measures and the other traditional predictor skills were evaluated. Longitudinal relationships between VA at school entry and the outcome measure single word reading after one year of schooling yielded statistically significant weak and moderate correlations between the VA measures assessed at t1 and the reading outcome measure at t2 (WR: r = .37; PR: r = .28). While relationships between performance on the VA assessment at t1 and children's single word reading after one year of schooling (t2) were slightly weaker compared to the relationships between traditional predictor skills of reading and the outcome measure, the significant correlations observed were considered as positive evidence for a longitudinal relationship between VA and single word reading.

To explore how VA contributed to the overall variance in reading performance, in relation to the other predictors of reading, concurrent and longitudinal (non-hierarchical) multiple regressions between traditional literacy predictors, VA (WR) and the outcome measure at t2 were explored. In full-model multiple regressions, with all relevant predictors included as independent variables in a single step, the beta values for WR were .08 and .13 respectively, with overall models having adjusted R-squared values of .58 and .43 respectively. These findings suggested that children's performance on the WR at the beginning of the school year contributed to the overall variance in reading performance after one year of schooling. For the PR on the other hand, the contribution to variance in reading performance was negligible, leading to its exclusion from following analyses.

Hierarchical regressions were carried out next, to look more specifically at whether performance on the WR task at t1 contributed *unique* variance in reading performance, fully distinct from the contributions of other literacy precursor variables measured at the same time point. First, concurrent t2 individual hierarchical regressions were carried out, with single word reading as the dependent variable, attention and executive function (A & EF) entered as step one and then WR added at the second step. The rationale here was to determine whether the WR task contributed unique variance in reading performance, over and above the potentially-similar measure of executive function – i.e. is there something specific to the VA assessment in its relationship to the outcome variable of reading. This preliminary analysis confirmed that the WR indeed contributed significantly to the variance in reading performance over and above the variance accounted for by the flanker task, a measure used to assess more general attention and executive function.

Following this, another series of individual hierarchical regressions were carried out, again with single word reading after one year of schooling as the dependent variable. Five two-step hierarchical regressions were carried out, in order to be able to observe the relative predictive role of the WR task in relation to each individual variable; each variable (i.e. PA, LSK, receptive vocabulary, short-term memory, and NVIQ) was entered at step one and then in step two, WR was also added. All two-step models were significant, with the adjusted R-squared values ranging from 17.1% (NVIQ and WR) to 34.1% (LSK and WR). Equally, in all cases, the addition of the WR at step 2 significantly increased the overall R-squared value; VA contributed an additional 13.1% of the variance to the model that incorporated non-verbal IQ, 8.1% to the model with letter-sound knowledge, 8% to the model with receptive vocabulary, 6% with short-term memory, and 2.8% with PA. While an initial idea at the beginning of the study was that performance on the VA measures might be more related to participants' NVIQ as opposed to language processing, results from these two-step hierarchical regression models seemed to suggest otherwise, with skills needed for the VA assessment perhaps overlapping more with the skills assessed by more language-focused predictor measures.

Finally, both concurrent (t2) and longitudinal (t1 – t2) multiple hierarchical models were carried out. Here all independent variables except for one were entered at step one and then the remaining measure was added at step two, to see if the latter contributed additional unique variance in reading performance over and above all the other variables. In neither the concurrent nor longitudinal model was the WR a unique contributor of variance in single word reading performance. The shared variance across all independent variables in each model was high, being 33.8% in the concurrent model, and 29.6% for the longitudinal model. Thus, while children's VA performance at school entry contributed to this shared variance, its influence overlapped considerably with the other traditional literacy precursor skills.

6.5.4.2 Traditional cognitive and linguistic predictors of single word reading

6.5.4.2.1 Phonological awareness as predictor of single word reading

In line with the strong and significant concurrent relationships between both PA measures and the literacy outcome measure, longitudinal correlations between PA at school entry and single word reading after one year of schooling were significant and strong (sound isolation: r = .57), as well as significant and moderate (sound deletion: r = .44). These findings therefore provided converging evidence with results from the meta-analysis conducted by the NELP (National Early Literacy Panel, 2008), reporting that PA in children between the ages of 0-5 showed moderate significant correlations with later skills in decoding (r = .40). In addition, comparable findings were reported by Swanson et al. (2003), suggesting significant and moderate correlations between real word reading and PA (r = .48), as well as by Melby-Lervåg and colleagues (2012) highlighting a significant and strong correlation between phonemic awareness and decoding (r = .57). Current findings further emphasised suggestions made by Vellutino and colleagues, highlighting that children's phonemic awareness skills seemed to have a direct impact on their word-level reading performance (Vellutino et al., 2007).

Many studies have highlighted the key role of PA on children's later literacy skills, with Storch and Whitehurst (2002) for instance emphasising that reading abilities of children at primary school level were mainly determined by their PA skills at the beginning of formal education. Further, Oakhill and Cain (2012) found converging evidence that phonemic awareness predicted children's later performance on a word reading accuracy task, with Manis and colleagues (2000) reporting children's phonological skills having a strong contribution to their abilities in nonword decoding. Finally, Melby-Lervåg and colleagues concluded based on their findings that phonemic awareness was a key predictor of individual differences in reading development, leading to the claim of a possible causal relationship between phonemic skills and reading (Melby-Lervåg et al., 2012).

Looking at the multiple hierarchical regressions for this variable only (Tables 6.22 & 6.23), the concurrent (t2) hierarchical multiple regression analyses of this study (Table 6.22) revealed that PA was a highly significant, unique predictor for single word reading*,* explaining a considerable and significant share - 22.1% - of the variance. However, contrary to expectations, in the longitudinal (t1-t2) hierarchical multiple regression model, PA contributed a non-significant 2.0% to the model when added as the last step (Table 6.23). Given that PA has consistently been highlighted as a very strong predictor of reading achievement for typically developing children (Anthony & Lonigan, 2004; Muter et al., 1997; Wackerle-Hollman et al., 2015), the results of the longitudinal model were therefore somewhat surprising. However, when considering just the first step of the longitudinal hierarchical regression model for single word reading before PA was entered into the model (see Appendix F) and comparing it to the overall longitudinal hierarchical regression model (Table 6.23), LSK was already contributing the biggest proportion of variance within the model. LSK was not measured at t2, given the ceiling effects the measure would have yielded, and thus perhaps in its absence, PA could manifest as the strongest predictor in the concurrent hierarchical multiple regression models. However, with LSK in the model at t1, the construct's closer relationship with reading, in terms of task demands, may have given it the more predictive role at t1, in comparison to PA. Compared to PA, which includes sound knowledge only, LSK also involves letter-sound knowledge directly.

6.5.4.2.2 Letter-sound knowledge as predictor of single word reading

There were strong and significant longitudinal correlations between children's letter-sound knowledge at school entry and their performance on the single word reading outcome measure after one year of schooling (r = .54). These results went in line with the findings by the NELP meta-study conducted a decade earlier, in which strong average correlations were reported between LK and decoding (r = .50) (National Early Literacy Panel, 2008). Similar, albeit even stronger findings were further yielded by Muter and colleagues (2004) showing that LK in 4- to 5- year old UK children at the beginning of formal schooling was significantly and strongly (r = .71) correlated with children's reading skills after one year of schooling (Muter et al., 2004). Finally, Schatschneider and colleagues' (2004) study conducted with the same age group in the US, equally revealed that LSK corrrelated significantly and strongly (r = .50) with children's ability to decode words.

Following the consistently found strong longitudinal relationships between LK and word reading, many studies have repeatedly found children's LK knowledge before entering school to be an important predictor of early reading, partly independent of effects of PA and phonological processing (Muter et al., 2004). Further evidence was provided in a study conducted by Foulin (2005) who summarised studies reporting converging evidence for letter-name knowledge as a good predictor of reading.

Repeatedly provided evidence that LSK was a reliable predictor of reading acquisition alongside PA was further validated by Hulme and colleagues (2012), concluding that there is a causal influence of LSK alongside PA on the development of children's skills in early literacy.

The longitudinal multiple hierarchical regression model for single word reading after one year of schooling of this study went in line with these findings, showing that LSK was the strongest and most significant unique predictor compared to the other predictors entered into the model, explaining 7.3% of the variance (Table 6.23). In addition, this uniqueness of LSK in comarison to other predictors has also been found by a number of other studies. Burgess & Lonigan (1998), McBride-Chang (1999), as well as Wagner and colleagues (1994) not only consistently identified LNK and LSK as strong predictors of early literacy but also emphasised that they had stronger predicitve power compared to PA or oral language. One of the key meta-analyses of prediction studies discussed in this context provided further evidence. In her study, Scarborough (1998) identified kindergarten children's letter-name knowledge as the strongest single predictor of reading in the first year of schooling. These findings are finally comparable with results from Hammill's (2004), as well as Schatschneider and colleagues' (2004) studies, highlighting LK as the best predictor of children's later reading and spelling skills.

6.5.4.2.3 Receptive vocabulary as predictor of single word reading

In line with significant and moderate concurrent relationships between both receptive vocabulary and the literacy outcome measure, longitudinal correlations between receptive vocabulary at school entry and single word reading after one year of schooling were significant and moderate (r = .42). While these initial findings gave reason to suggest that receptive vocabulary would be a predictor of single word reading, regression analyses yielded different results. When considering both predictor models (Tables 6.22 & 6.23), receptive vocabulary was not a significant predictor and only contributed insignificant 1.1% to the concurrent model for single word reading after one year of schooling (Table 6.22). Predictive power of receptive vocabulary went further down in the longitudinal model (Table 6.23), with receptive vocabulary at school entry not at all contributing to the prediction of single word reading after one year of schooling.

While these findings were comparable with other studies, which also failed to find evidence of a direct relationship between vocabulary and decoding (Metsala, 1997; Muter et al., 2004), they were somewhat unexpected, given that vocabulary has been found to have predictive power on children's early reading skills in a number of previous studies. Bowey (1995) for instance reported that receptive vocabulary in kindergarten children predicted 20-27% of variance in their reading skills at the end of Grade 1. In addition, a recent study conducted by Duff and colleagues in the UK suggested that infant vocabulary knowledge accounted for 11% of variance in later reading accuracy (mean age: 6;1), with authors concluding that there was good evidence for vocabulary being a plausible causal influence of later reading accuracy (Duff et al., 2015). Findings from this study were further in line with results from a large-scale study conducted by Lee (2011) in the US, with vocabulary production at the age of 24 months explaining 5% of the average variance in reading accuracy when children started attending school. One explanation for this mix of findings may be that the influence of vocabulary on reading is not a single influence. Vocabulary knowledge is an integral part of language comprehension, which is known in models of reading – such as the Simple View of Reading (Gough & Tunmer, 1986) – to be a critical precursor, alongside decoding, of reading comprehension. While early assessment measures of reading focus more upon single word recognition as opposed to text comprehension, even at the single word level, vocabulary knowledge may be needed to a greater or lesser extent. For instance, if a study measures early reading accuracy using nonwords, links between such a reading measure and vocabulary knowledge may be lower than, for example, in a test using only real words. The assessment adopted for this study – the Diagnostic Test of Word Reading Processes (Forum for Research in Literacy and Language, Institute of Education, 2012) – tested both, children's ability to read nonwords as well as real words.

While the relationships discussed so far concern relatively direct links between vocabulary knowledge and reading, there are also some researchers, who argue for the need to consider more indirect effects. Advocates of the Lexical Restructuring Hypothesis (Metsala & Walley, 1998) for instance argue that vocabulary growth, especially in preschool years, may in fact drive a child's subsequent development of PA, which in turn will facilitate early letter-sound knowledge. Supporting evidence for the indirect relationship between reading and vocabulary has been provided by a number of studies (e.g. Goodrich & Lonigan, 2015; Metsala & Walley, 1998; Walley et al., 2003). Others have further highlighted the significant relationships between oral language skills (i.e. vocabulary) and code-related skills (i.e. PA) in preschool as well as in the first years of formal education (Burgess & Lonigan, 1998; Lonigan et al., 1998; Sénéchal et al., 2006; Storch & Whitehurst, 2002; Vellutino, Scanlon, Small, & Tanzman, 1991).

While numerous previous studies have reported that children's early vocabulary is significantly contributing to their word reading skills (Kirby et al., 2008; Nation & Snowling, 2004; Ricketts et al., 2007), code-related skills such as PA or letter knowledge, are still argued to be stronger predictors of decoding in young readers (Storch & Whitehurst, 2002). Thus, the current findings arguably support the idea that while vocabulary might be contributing to children's early word reading, its influence in the early phase of literacy development is either smaller than or overlapping with code-related variables.

6.5.4.2.4 Short-term memory as predictor of single word reading

Longitudinal correlational relationships between short-term memory at school entry and single word reading after one year of schooling were significant and moderate (r = .42). These findings were similar, albeit slightly stronger, than results from the meta-analytic study conducted by the National Early Literacy Panel (2008), suggesting weak correlations for STM assessed before or during kindergarten, and decoding (r = .26). Further, converging evidence was reported in two studies by Gathercole and colleagues (2005, 1992). In the first study, significant correlations were reported between word reading and 5- to 7- year olds' performance on the nonword repetition task, leading authors to suggest a causal relation between phonological memory and reading development (Gathercole et al., 1992). In the second, more recent study, findings were replicated with 4- year olds, with their performance on the NWR task significantly correlating with early reading skills assessed a year later (Gathercole et al., 2005).

When considering the concurrent hierarchical regression model for single word reading after one year of schooling in this study (Table 6.22), short-term memory was not a significant predictor and only contributed less than one per cent to the model. However, the predictive power of short-term memory at school entry was much bigger in the longitudinal model, uniquely and significantly predicting 4.2% of single word reading after one year of schooling, which was an increase of 3.4% from the concurrent model. In comparison to these results, numerous studies suggested that STM was not a unique predictor of single word reading if measures of PA and RAN were controlled (Caravolas et al., 2012; Melby-Lervåg et al., 2012; Nation & Hulme, 2011; Ziegler, Pech-Georgel, Dufau, & Grainger, 2010). Another interesting perspective was offered by Nation and Hulme (2011). Their study findings suggested that although no unique relationship was found between STM and learning to read during the first year of schooling, reading skills at the age of 6 predicted the growth in performance on the NWR task when assessed one year later (Nation & Hulme, 2011). Based on these results authors argued for the need to look into a potential reciprocal relationship between short-term memory and reading, with reading development influencing children's performance on the NWR task.

6.5.4.3 Summary of the predictive power of cognitive and linguistic predictors and visual attention for single word reading

This section first considered this study's findings in relation to VA as a potential digitally-relevant predictor skill for single word reading after one year of schooling. Second, it explored the unique predictive significance of the traditional literacy precursor skills PA, letter-sound knowledge, receptive vocabulary, and short-term memory for children's single word reading after one year of schooling. VA at school entry was found to contribute to shared variance in reading performance at the end of the first school year. However, both concurrent (t2) and longitudinal (t1-t2) multiple hierarchical regression analyses confirmed that this contribution was not statistically unique when all other traditional predictor variables were also included in the model. This study further found that relationships between cognitive and linguistic predictors of literacy were broadly in line with previous research. In the concurrent hierarchical multiple regression model, PA was the only significant unique predictor of single word reading, explaining a considerable share of 22.1% of the variance. Receptive vocabulary, short-term memory and both attention & executive function measures did not contribute significantly to the model, over and above the other variables. In the longitudinal hierarchical multiple regression model, letter-sound knowledge was found to be the strongest and most significant unique predictor for single word reading, explaining 7.3% of the variance. Short-term memory further uniquely and significantly contributed 4.2% to the model. While PA was the strongest predictor concurrently, it uniquely contributed only little and insignificantly (2.0%) to the longitudinal model, arguably due to the greater predictive influence of LSK, measured at t1 only. In addition, NVIQ did not contribute longitudinally to single word reading after one year of schooling, nor did the remaining traditional literacy predictor skill, receptive vocabulary. Finally, the considerable share of unexplained variance in both models – 41.8% concurrently, 56.3% longitudinally – highlighted the need to put future research efforts into exploring different, currently not considered cognitive and linguistic skills, which may have an impact on children's reading, alongside other potential influential factors such as heredity, environment, or the effects of schooling.

Chapter 7– General Discussion

Within the context of children being exposed to digital devices from a very young age, the current study set out to examine visual attention (VA) as a potential digitally-relevant predictor of reading alongside other traditional literacy precursor skills. Thus, a VA assessment for 4- to 5 year olds was developed to explore the longitudinal relationships between children's exposure to digital devices, VA development, traditional literacy predictors and the relative impact of all these factors upon word reading after the first school year. The findings from Chapters 3, 5 and 6 will now be revisited, followed by a discussion of the strengths, limitations, as well as practical implications specifically for assessing VA. Future directions will be considered throughout this chapter.

7.1 Summary of experimental findings

7.1.1 Emerging reader's visual attention profile

In order to explore VA in emerging readers, a newly adapted and simplified version of a VA assessment based on Bundesen's (1990; 1998) TVA was first validated. Two smaller-scale consecutive experimental studies (Study I & Study II; Chapter 3) were carried out to ensure the assessment's suitability for investigating 4- to 5-year old children's VA profile at school entry in the UK. A slightly amended version of this assessment was subsequently adopted in the main longitudinal study comprising of two time points – at school entry (t1) and after one year of schooling (t2) (Chapter 5). Since both, the smaller-scale and the main study presented in this work, were conducted with children of roughly the same age, albeit from different cohorts, results will be considered collectively in this section.

By combining a VA span task (whole report – WR) and a target detection task (partial report – PR) it was argued that a simplified TVA-based assessment can better provide data that specifically targets VA in young children. This argument was specifically made in comparison to ANT based assessments (Posner & Petersen, 1990) comprising of a flanker task (Erkisen & Eriksen, 1974) and a spatial cueing task (Posner, 1980) predominantly used in previous early childhood studies. Individuals' VA spans (Bosse et al., 2007) were computed by calculating the mean number of correctly identified symbols for each trial per participant. The PR on the other hand, specifically focused on children's efficiency of attentional control by identifying children's ability to name targets while at the same time disregarding distractors. The two main adjustments to both measures of the VA assessment was a significant reduction in the number of trials, as well as the exchange of commonly used letter stimuli with simple black and white symbols.

Based on findings from the smaller-scale and the main study, the adapted VA assessment demonstrated good internal consistency and showed no evidence of adverse floor or ceiling effects. Therefore it captured a range of performance within the targeted developmental age group, suggesting that even amongst young children assessed at a single time point, there was considerable variability in VA skills. When comparing children's performance at both time points of the main study, children showed significantly better ability to report symbols on the VA span task after the first year of schooling, with the mean of reported symbols across all participants increasing by .48 ($p < .001$). Converging evidence was yielded for the target detection task, with children's efficiency of attentional control after one year of schooling being significantly better than at school entry ($p < .001$).

When considering both, the results of the smaller-scale and the main study, one finding regarding the role of age in children's performance on the VA assessments particularly stood out. When comparing results from the WR tasks of both studies, the mean of reported symbols across all participants ranged from 1.48 (SD = .14) at t1 (1-2 months of instruction), and 1.66 (SD = .85) in Study II (10 months of instruction), to 1.96 (SD = .46) at t2 (13-14 months of instruction). While it was not possible to draw firm conclusions from this comparison given that results were based on different samples, this progression did hint at a steady developmental progression in performance on the task across the first year of formal schooling. This suggests that age of participants and / or time spent in school during the first year have a significant impact on average number of reported items, which is presumed to index an individual's storage capacity of visual short-term memory (VSTM). The observed relationship further goes in line with other reported findings of VSTM capacity (K) continuing to develop during early childhood (e.g. Riggs et al., 2011). In addition, similar conclusions were drawn from the

PR results, suggesting that age of participants and / or time spent in school during the first year, also have a significant impact on children's target detection abilities and therefore their efficiency of attentional control (α). The children in the main study were tested at the beginning and after their first year of schooling and acquisition of skills such as letter-sound knowledge have been shown to have a specific and measurable effect on early cortical visual processing (e.g. Maurer, Brem, Bucher, & Brandeis, 2005), that is separable to developmental maturation per se. While the main study was therefore not designed to differentiate the specific effect of formal instruction versus age on the development of VA, it can be noted that differing instructional environments may have an impact on VA development of children involved in the study, and thus the sensitivity of assessment measures across contexts. All in all, the results of the smaller-scale study (Chapter 3) and the main study (Chapter 5) highlight the difficulties in teasing apart the influence of two crucial factors – age versus amount of literacy instruction – on children's performance on a VA assessment and further emphasise the complexity of measuring VA. One possibility to discern the effect of development not attributable to formal instruction from literacy instruction effects on children's VA performance in future would be to replicate the study in a different educational context in which children are exposed to literacy instruction later on in their lives, for instance in Austria, Germany, France, or Italy where the compulsory age of starting school is six, or in Sweden, where children start formal education at the age of seven and thus two to three years after their UK peers.

Additional emphasis was put on exploring the effect of stimulus exposure duration on children's performance on the WR task. This was carried out in order to explore the basic speed with which children can not only process something visually, but also act on that information with relatively advanced cognitive processing, important for complex activities, such as reading. Investigation yielded unexpected results, showing a lack of significant effect for exposure duration on children's performance in the VA span task in both studies. Having reduced the number of overall trials to make the assessment more appropriate to young children, this means that further dividing results as a function of exposure duration may have made it difficult to discern statistically significant effects in the data. Findings suggesting that children process information more slowly than adults (Riggs et al., 2006; Kail, 1991), as well as the results reported here – showing that exposure duration times used in Study II and the main study (70-

100-150-200-250 ms) seemed to only have a small impact on the symbols participants of the target age group were able to report in the WR task – puts further emphasis on the conclusion made in the discussion of the smaller-scale study. There it was pointed out that studies of visual processing that have relied on adult models of gaze and saccade patterns may not be applicable to young children, especially those with minimal school experience and thus reduced experience with processing strings of text and symbols. These findings therefore highlight the need for increased empirical research regarding childhood visual cognition in order to better understand the role of exposure duration in young children's visual processing, which in turn can provide a foundation for future improvements to the current VA assessment.

Finally, a further investigation into preference of symbol position in children's performances across all WR tasks of the main study, as well as the subsequent left-to-right report score confirmed a left-to-right bias for the majority of participants tested at t1 & t2. The observed phenomenon goes in line with studies looking at more advanced adult readers, with Spalek & Hammad (2004, 2005) for instance reporting a left-to-right bias in English speaking participants, in contrast to an opposite bias in a sample of Arabic speakers, reading text from right to left. With previous study results suggesting an asymmetrical shift in the distribution of visuospatial attention only emerging after a child has acquired written language (Brucki & Nitrini, 2008; Dobel et al., 2007; Fagard & Dahmen, 2003; Kebbe & Vinter, 2013; Woods et al., 2013), the findings of the main study provide evidence that there is an increase in English speaking children's left-to-right attentional biases after the first year of schooling. These results therefore not only suggest a possible link between exposure to formal literacy instruction and the development of reporting direction bias, but also highlight the suitability of the WR task for investigating report direction bias in emerging readers as a potential precursor skill of reading in future studies.

7.1.2 Traditional literacy predictors in emerging readers

Descriptive statistics for participants' performance on all linguistic and cognitive predictors at both time points showed a wide range of scores across all measures. Children's performance at both time points on the phonological awareness (PA) measure sound isolation, and short-term memory (STM), as well as letter-sound knowledge (LSK) at school entry, PA measure sound deletion and the outcome measure single word reading after one year of schooling was within the expected range, being either slightly above or below the mean norm, defined as a standardised score of 100. The mean standardised score of the sound deletion PA measure at t1 was lower than that for sound isolation, but also within the normal range, suggesting that children's ability to reflect upon and to delete speech sounds was within the expected norm at school entry. During the first year of schooling children made significant progress in their sound deletion skills. While performance at t2 was within the normal range, there was again an observable increase in the relative placement of the participant group in relation to the normative sample after one year of schooling. Analysis of the development of literacy predictor skills tested in children at both time points not only revealed that children made appropriate gains, with a significant rise in children's performance, on the STM assessment, but also on both PA measures (sound isolation, sound deletion). A surprising result was yielded in relation to the receptive vocabulary measure. While children's receptive vocabulary skills were at an expected level at school entry, the mean standardised performance across all participants, albeit still being within the expect range, had slightly dropped relative to the norm sample after one year of schooling. Findings from further analysis confirmed that children's skills did not develop as expected during the first year of schooling on that measure. An additional investigation finally rejected the hypothesis that this decline in relative performance could be caused by the "Matthew Effect", a term coined by Keith Stanovich (1986) whereby if some of the group were struggling to learn to read, this could be perniciously reducing their rate of vocabulary growth. Thus, no clear reason could be found for the slight decline in relative performance on vocabulary across time, however it should also be noted that the group mean remained well within the normal range.

Further analysis of the concurrent relationships between all assessed measures at both time points revealed significant correlations, with the vast majority being moderate to weak at t1, and moderate at t2. The strongest concurrent correlations were found between PA and LSK at t1, as well as the PA measure sound deletion and vocabulary at both time points, while the weakest were identified between LSK and STM at t1. In addition, all measures were significantly moderately to strongly correlated with the t2 outcome measure, single word reading. It is important to recognise that zero-order correlations need to be treated with caution as they are unable to determine the direction of effects and are vulnerable to the influences of other variables. However, findings based on these concurrent relationships suggested that the patterns between cognitive and linguistic skills in children tested were comparable overall to those found in previous studies. In addition, the findings also highlighted that the initial goal of the current study to recruit children from a normative sample was met. In a next step, longitudinal correlations between predictor skills and the outcome measure were considered first, followed by regression analyses that explored the role of the measured variables in explaining variance in children's single word reading after one year of schooling. While PA and LSK are the most proximal predictors of early reading, receptive vocabulary and STM have also been shown to play notable roles in children' early reading performance.

When considering LSK at school entry, strong and significant longitudinal correlations were found between this measure and children's performance on the single word reading outcome measure after one year of schooling (r = .54). These results went in line with the findings by the NELP meta-analysis conducted a decade earlier, in which strong mean correlations were reported between LK and decoding (r = .50) (National Early Literacy Panel, 2008), as well as Schatschneider and colleagues' (2004) study conducted with 4- to 5- year olds, equally revealing that LSK corrrelated significantly and strongly (r = .50) with children's ability to decode words. The longitudinal hierarchical multiple regression model for single word reading after one year of schooling of the current study showed that LSK was the strongest and most significant unique predictor compared to the other predictors entered into the model, explaining 7.3% of the variance. This result goes in line with findings from Burgess & Lonigan (1998), McBride-Chang (1999), as well as Wagner and colleagues (1994) consistently identifying LNK and LSK as strong predictors of early literacy. In addition, findings are also comparable to Scarborough (1998) who identified kindergarten children's letter-name knowledge as the strongest single predictor of reading in the first year of schooling.

Longitudinal correlations between PA at school entry and single word reading after one year of schooling were significant and strong (sound isolation: r = .57), as well as significant and moderate (sound deletion: r = .44). Comparable findings were reported by Swanson et al. (2003), suggesting significant and moderate correlations between real word reading and PA (*r* = .48), as well as by Melby-Lervåg and colleagues (2012) highlighting a significant and strong correlation between phonemic awareness and decoding (*r* = .57). While the concurrent (t2) hierarchical multiple regression analyses of the current study revealed that PA was a highly significant, unique predictor for single word reading, explaining a considerable share of 22.1% of the variance, this was not the case longitudinally with PA uniquely contributing only insignificant 2.0% to the model. Given that PA has consistently been highlighted as a very strong predictor of reading achievement for typically developing children (Anthony & Lonigan, 2004; Muter et al., 1997; Wackerle-Hollman et al., 2015), the results of the longitudinal model were therefore somewhat surprising. However, additional analysis showed that before PA was entered into the model, LSK was contributing the biggest proportion of variance within the model. LSK was not measured at t2, given the ceiling effects the measure would have yielded, and thus perhaps in its absence, PA could manifest as the strongest predictor in the concurrent hierarchical multiple regression models. However, with LSK in the model at t1, the construct's closer relationship with reading, in terms of task demands, may have given it the more predictive role at t1, in comparison to PA, which includes sound knowledge only, as opposed to LSK which also directly involves letter-sound knowledge.

Apart from the most direct predictors for single word reading – LSK and PA, analyses of the results regarding receptive vocabulary and STM as literacy precursor skills yielded interesting results. Longitudinal correlations between receptive vocabulary at school entry and single word reading after one year of schooling were significant and moderate (*r* = .42). While these initial findings gave reason to suggest that receptive vocabulary would be a predictor of single word reading, the opposite was the case, with receptive vocabulary only contributing insignificant 1.1% to the concurrent model, and not at all to the longitudinal model for single word reading after one year of schooling. While these findings were comparable with other studies, which also failed to find evidence of a direct relationship between vocabulary and decoding (Metsala, 1997; Muter et al., 2004), they were somewhat unexpected, given that vocabulary was repeatedly found to have predictive power on children's early reading skills in a number of previous studies (Bowey, 1995; Duff et al., 2015; Lee, 2011). However, it has to be noted that for younger readers, code-related skills such as PA or LSK, were often considered to be stronger predictors of reading accuracy as opposed to oral language, such as vocabulary (Storch & Whitehurst, 2002). Further, it was reported that the contributions of oral language have repeatedly been found nonsignificant after PA and LSK were also considered as predictors of literacy (Muter et al., 2004). Thus, the current findings suggesting no direct relationship between decoding and receptive vocabulary, arguably support the idea that while vocabulary might be contributing to children's early word reading, its influence in the early phase of literacy development is either smaller than or overlapping with code-related variables. Finally, STM had significant and moderate (r = .42) longitudinal correlational relationships with single word reading after one year of schooling. Within hierarchical multiple regression analyses, while STM was not a significant contributor to the variance in reading concurrently, it uniquely and significantly contributed to 4.2% of variance of single word reading after one year of schooling longitudinally. These findings were comparable with results yielded in McCallum and colleagues' study (2006), showing that STM uniquely predicted reading after controlling for PA and rapid automatised naming (RAN) (McCallum et al., 2006).

Overall, while PA was the only significant unique predictor of single word reading concurrently, explaining a considerable share of 22.1% of the variance, LSK was found to be the strongest and most significant unique predictor for single word reading in the longitudinal model, explaining 7.3% of the variance. In addition, only STM further uniquely and significantly contributed 4.2% to the longitudinal model, with receptive vocabulary and PA, alongside NVIQ, and both attention & executive function measures not contributing significantly to the model. The results regarding the predictive power of PA was arguably caused by the greater predictive influence of LSK, measured at t1 only. The non-significant results concerning receptive vocabulary however, suggested that while vocabulary might be contributing to children's early word reading, its influence in the early phase of literacy development is either smaller than or overlapping with code-related variables. Finally, the high share of unexplained variance in both models – 41.8% concurrently, 56.3% longitudinally – highlighted the need to put future research efforts into exploring different, currently not considered cognitive and linguistic skills which may have an impact on children's reading, alongside other potential influential factors such as heredity, environment, or the effects of schooling.

7.1.3 Visual attention as a potential predictor of reading

The main aim of this study was to investigate VA as a potential digitally-relevant predictor skill of reading in the light of children's increased exposure to digital devices in the early years. Concurrently, both VA measures tended to be correlated the strongest with PA. Furthermore, the whole report (WR) measure correlated significantly and moderately with receptive vocabulary at both time points highlighting a potentially close relationship between language-based skills and the VA span task demands. This finding highlighted that retrieving and producing the name of a symbol, even though the items were chosen to be familiar, still depends on an individual's vocabulary skills. The potential close relationship between language-based skills and VA span task demands was further emphasised by partial correlations controlling for receptive vocabulary. The PR task on the other hand was only weakly correlated with receptive vocabulary. This finding suggested that while vocabulary skills were still needed for performance on the target detection tasks, the measure was arguably drawing less on language skills in comparison to the VA span task. Further, the A & EF *accuracy score* correlated weakly but significantly (r = .29, p < .01) with the PR, and moderately and significantly (r = .31, p < .001) with the WR. These results therefore suggest that while similar skills are needed, task demands of the VA assessment are still different to the more general A & EF measure adopted in the study. Indeed, the A & EF flanker task involves targets and distractors, similarly to the PR, however in the flanker task these require less specific, overt identification compared to the PR. Further, there is also less positional variation in targets/distractors in the flanker task compared to the PR, making the PR task deliberately more equivalent to text processing. In addition, the A & EF flanker task required no verbal response, but rather a button press.

Longitudinal relationships between VA at school entry and the outcome measure single word reading after one year of schooling yielded significant weak and moderate correlations between the VA measures assessed at t1 and the outcome measure at t2 (WR: r = .37; PR: r = .28). To further explore how VA contributed to the overall variance in reading performance, in relation to the other predictors of reading, concurrent and longitudinal (non-hierarchical) multiple regressions between traditional literacy predictors, VA and the outcome measure at t2 were explored. Findings suggested that children's performance on the WR at the beginning of the school year contributed to the overall variance in reading performance after one year of schooling.

For the PR on the other hand, the contribution to variance in reading performance was negligible, leading to its exclusion from following analyses. Hierarchical regressions were carried out next, to look more specifically at whether performance on the WR task at t1 contributed *unique* variance in reading performance, fully distinct from the contributions of other literacy precursor variables measured at the same time point. First, concurrent t2 individual hierarchical regressions were carried out, with single word reading as the dependent variable, attention and executive function (A & EF) entered as step one and then WR added at the second step. This preliminary analysis confirmed that the WR contributed significantly to the variance in reading performance over and above the variance accounted for by the flanker task, a measure used to assess more general attention and executive function.

Following this, another series of individual hierarchical regressions were carried out, again with single word reading after one year of schooling as the dependent variable. Five two-step hierarchical regressions were carried out, in order to be able to observe the relative predictive role of the WR task in relation to each individual variable. All two-step models were significant, with the adjusted R-squared values ranging from 17.1% (NVIQ and WR) to 34.1% (LSK and WR). Equally, in all cases, the addition of the WR at step 2 was significant and increased the overall R-squared value; VA contributed an additional 13.1% of the variance to the model that incorporated non-verbal IQ, 8.1% to the model with letter-sound knowledge, 8% to the model with receptive vocabulary, 6% with STM, and 2.8% with PA. While an initial idea at the beginning of the study was that performance on the VA measures might be more related to participants' NVIQ as opposed to language processing, results from these two-step hierarchical regression models seemed to suggest otherwise, with skills needed for the VA assessment perhaps overlapping more with the skills assessed by more language-focused predictor measures. Both concurrent (t2) and longitudinal (t1- t2) multiple hierarchical models carried out in a final step, showed that the WR was not a unique contributor of variance in single word reading performance. The shared variance across all independent variables in each model was high, being 33.8% in the concurrent model, and 29.6% for the longitudinal model. Thus, while children's VA performance at school entry contributed to this shared variance, its influence overlapped considerably with the other traditional literacy precursor skills.

7.1.4 Children's digital exposure and its impact on reading development

The analysis of parent questionnaires at t1 revealed a wide range in children's exposure to digital devices, as well as their digital device use frequency in the 6 months immediately prior entering school. Complementary analyses of follow up children's self-reports conducted at t2 revealed that the vast majority of children did not use digital devices to read or look at stories on their own or together with adults. Results relating to digital device use frequency of participants confirmed findings from t1, showing a wide range in children's user intensity of digital devices for different activities. However, subsequent investigations found no significant longitudinal nor concurrent relationships between children's digital device use and digital exposure intensity before entering school and their performance on the VA measure. In a final step, additional analyses looked into possible connections between digital exposure and single word reading. Again, no significant relationships were found concurrently or longitudinally between collected data on children's digital exposure intensity and the single word reading outcome measure. This lack of significant relationships lead to the exclusion of the digital exposure measure in following analyses.

When reflecting on these results it needs to be recognised that data was obtained from the vast majority of parents from children participating in the study (n = 110 out of 140) at school entry, as well as from all children (n = 133) re-assessed after one year of schooling. However, while this fact gives evidence to suggest that results accurately represented digital exposure of children participating in the study, it was still felt that reported non-significant correlations between VA and digital device use did not provide strong enough evidence to draw definite conclusions. First, it proved harder than expected to get nuanced data regarding the pattern of children's digital device use in the early years. The process of collecting the data at t1 not only revealed that digital behaviour seemed to be incredibly complex, but also that receiving voluntary responses from parents was a difficult task. This resulted in a complex conflict between a research demand for nuanced responses and a practical demand for brevity and simplicity. In addition, it needs to be considered that children's digital exposure was aimed to be characterised with only two questionnaire items for each time point and that additional limitations at t1 were caused by incomplete parent questionnaires, forcing the author to make decisions on how to score unanswered questions. Finally, there was also the issue around parents second-guessing the agenda of the questionnaire, which resulted in wider questions regarding the accuracy of the responses to an admittedly brief questionnaire. The chosen measures adopted for this study were thus found insufficient in gathering data on children's digital device use, a limitation which is further discussed in the subsequent section of this chapter. However, while one can only speculate about possible reasons at this point in time, one explanation for not seeing stronger links between digital exposure and single word reading, arguably standing for children's academic development, could be that the majority of the group tested in this study, either because of their young age or SES background, had not been using digital devices in an extensive way. Equally, it could also be the case that the found non-significant results were not caused by insufficient modes of collecting the data, but rather due to the fact that there may be no close links between digital device use in the early years and children's later literacy skills.

In order to find more definite answers, there is a need to gather data on children's digital exposure in a more effective manner. One possible option would be to use "nudging": Sending parents of young children regular reminders, for instance via text messages, to log their children's digital device use. Positives effects of nudging has for instance been reported by intervention studies (Hurwitz, Lauricella, Hanson, Raden, & Wartella, 2015; Kraft & Monti-Nussbaum, 2017) which adopted text messages to send regular reminders to parents to encourage home literacy activities. It is therefore argued that text message reminders could also be utilised to gather data on children's digital exposure in real time and thus in a more accurate manner. Another option to explore in future studies could finally be to monitor children's digital device use by utilising programs or apps which automatically record information, such as types of activities a child engages in, or the frequency a device has been used.

7.2 Strengths and limitations of the current study

The completion of a research project often marks the starting point for planning subsequent future projects that can built upon the knowledge gained from the current one. In this section, the strengths and limitations of the project are thus summarised and complemented by considerations for follow-up studies.

The main strength of the current study lies in its novel and explorative nature. To the author's knowledge, it marks the first study that looked into VA as a potential digitally-relevant predictor skill for reading in a group of young emerging readers. In addition, it investigated for the first time potential links between VA and traditional literacy predictor skills and showed how VA impacts single word reading, albeit not as an independent unique predictor. In doing so, the relatively large proportion of unexplained variance in both presented models for single word reading further highlighted the need to look into not yet investigated factors that potentially impact children's reading development in future studies.

In addition, the smaller-scale study (Chapter 3) presented in this thesis introduced a newly adapted version of VA assessment based on Bundesen's Theory of visual attention (TVA) (Bundesen, 1990, 1998) for 4- to 5-year old emerging readers. The main intention to create this tool was to allow both, the assessment of young children who are yet unable to read – by exchanging letter stimuli with simple black and white symbols –, and a more in-depth investigation of storage capacity of VSTM, and efficiency of attentional control in comparison to other, simpler VA span tasks (e.g. Bosse & Valdois, 2009; Prado et al., 2007; Valdois et al., 2003). Overall, results of the smaller-scale study as well as the main study which also adopted the newly developed assessment, showed that measuring VA based on TVA appears feasible in such a young age group and that the test is suitable for exploring the role of VA in early learning. It is thus hoped that the dissemination of the assessment will offer an alternative to the currently mainly used assessments of VA for young children based on Posner's (Posner & Petersen, 1990) ANT (e.g. Mezzacappa, 2004; Mullane, et al., 2011; Mullane, et al., 2016; Rueda et al., 2004) and will trigger its broader application in future studies.

A further strength of this thesis lies in the fact that it eluded to the relationship between children's exposure to digital devices prior to school entry and their VA skills, which has not been addressed in previous studies. In addition, the study not only relied on parental reports at t1 but also conducted short interviews in order to obtain children's self-reports at t2, which has so far only been carried out by a few previous studies (e.g. Ofcom, 2014; Scholastic, 2014, 2016). Finally, the main study comprised of a relatively large sample size (n = 140 at t1) and low attrition levels (n = 133 at t2) making it a robust study. Overall, the current study was situated in the UK context and focused on emerging readers during their first year of formal education. More specifically, it targeted a normative group of 4- to 5- year olds and re-assessed them a year later, having received specific literacy instruction in their first school year. Based on these characteristics, the study is considered to make a relevant contribution in providing new insight into the relationships between VA, digital exposure, and more traditional literacy predictor skills, as well as the potential impact of VA on single word reading.

While it is further argued that current findings are largely generalizable, the impact of age versus exposure to formal literacy instruction on children's performance on the VA assessments highlights their potential specificity to the UK context. As mentioned above, children in other European countries, such as Germany or Finland, are exposed to explicit literacy instruction up to two years later in their lives. Thus the argument can be made for the need to replicate the study in a different educational context where children are older at school entry, helping to discern age effects from instruction influences when considering relationships between early reading and VA.

In addition to this potential confinement of this study's findings to the UK context, two further key limitations have been identified that need to be taken into account when considering the current results, as well as thinking about the design of future studies. Following the discussion of the non-significant findings regarding the relationships between digital exposure, children' VA and single word reading skills in an earlier section of this chapter, a wider question needs to be asked regarding the suitability of the chosen mode of collecting early childhood digital exposure data. As mentioned earlier in this chapter, the author got the impression during the process of collecting and analysing the data at t1 that adopting a parent questionnaire was potentially problematic, as it seemed to trigger some parents to give what they deemed to be 'socially-acceptable' answers. This impression was especially created in instances when parents reported that their child had no access to digital devices prior to school entry. As discussed earlier, it would therefore be beneficial in future studies to be aware of certain elements potentially hindering parents reporting honestly when administering parental questionnaires, or to explore other, more reliable ways of collect data from children's digital device use prior to school entry, for instance through the above mentioned method of "nudging".

A further main limitation concerns the comparatively brief time span of the study. Although the current main study was set out as a one year longitudinal project from the start, it would have been worth retrospectively to extend it into a two year project. This way it would have been possible to investigate the relationships between VA and reading more comprehensively, by exploring the impact of VA at school entry on more advanced reading skills, such as reading speed or reading comprehension. Notably, the relationship between VA and reading has so far only been considered by assessing children's word reading abilities (e.g. Lobier, Dubois, & Valdois, 2013; Prado et al., 2007), with the exception of a research project conducted by Chen and colleagues (2016). In their study on individuals with developmental dyslexia, authors examined whether VA span could facilitate reading by not only supporting the individual to combine graphemes within a word level, but also to connect and comprehend words at a sentence level. Reported findings showed a significant direct effect of VA span on reading comprehension when assessed on a text of an advanced level (Chen et al., 2016). While VA was not found to be a unique predictor of single word reading in the current study, it is thus argued that it would have been interesting to investigate its impact on children's more advanced abilities to process a text. It is suggested that an extended longitudinal study would add valuable knowledge regarding possible connections between children's VA at the beginning of formal schooling and children's more advanced reading skills later on in their school career, and thus inform the design of future studies.

In addition, this study can be viewed as a valuable and critical first step in gaining an understanding of the role of VA on digital literacy. An extension of the study over a longer period of time would thus also enable the investigation of differences in the changing role of VA on reading on digital devices versus on paper as children develop their literacy skills, for instance by the adoption of eye-tracking. Furthermore, the use of eye-tracking or webcam measurements would allow for taking observed behavioural preferences of text reading and determine whether these preferences associate with distinctive patterns of visual attention allocation, memory performance and other aspects of cognition. One hypothesis driving this research would be the prediction that young children's visual attention profiles have different predictive power for different modes of text presentation, making it necessary to look into the relationship between readers' visual attention profiles and their reading performance across a range of print and digital text formats. At a more detailed level, it would be expected that readers differ in their ability to process text that varies across parameters that include letter spacing, text window and amount of non-relevant visual information, making it necessary to look into different modes of text presentation in future studies. While it is difficult to give clear predictions at this point in time, given the novelty of this area of research, one possible outcome could be that children with poorer VA skills might show better reading performance when reading a text on a screen versus on paper, if it is presented in shorter line lengths, as shown by a study conducted by Schneps and colleagues (2013) with adolescent struggling readers. It is expected that answers gained from this research might help to adapt text according to children's cognitive profile, making it possible to individually and effectively support children in their literacy development.

Finally, future research also needs to be conducted to gain a deeper understanding of the impact of children's exposure to digital text on their screen reading behaviour. Possible questions leading these studies might be whether there is a difference in where children look at a screen depending on their exposure to digital text, or whether there is a difference in reading speed and reading accuracy depending on children's exposure to digital text. Research results would allow for a better understanding regarding the impact that pre-school experience with digital text may have on children's engagement with digital text, making it possible to provide informed advice regarding the nature and extent of early exposure to digital media to parents and early years practitioners.

7.3 Practical implications for assessing visual attention

The development of a VA assessment for 4- to 5- year olds for the current study was considered to be a success, as it allowed to yield meaningful and more fine grained data from children who are yet unable to read based on Bundesen's (1990, 1998) TVA. At the same time however, findings from the current study also revealed that even when adjusting testing parameters (total number of trials, test stimuli) to the needs of the target age group, it still proved to be very difficult to isolate VA skills in young children from language demands and thus to measure it, despite its potential theoretical interest. Considering that VA could not be identified as a strong unique predictor skill for single word reading as expected in the study, the following reflections can be made: First, findings could be interpreted as a hint that young children utilize VA in reading in a way which is very inter-twined with other literacy skills, something that was argued based on the considerable amount of shared variance in both predictor models. One potential conclusion of this could be that the measurement of VA in young children to inform our knowledge concerning their reading readiness should not necessarily be a research priority.

Given the undeniable importance of visual cognition in the process of reading however, perhaps a second, more moderate recommendation could be that the lack of predictive power of VA on single word reading in the current study stems from the fact that reading success is more related to visual search – defined as the ability to actively scan a visual environment for a target object amongst distractor objects (Treisman & Gelade, 1980) – and less to VA. This hypothesis could be explored by conducting a study which was investigating the relationships between reading skills and both, VA and visual search in a group of emerging readers.

A third recommendation holds on to the belief that VA is influencing reading performance in emerging readers and argues for the need to investigate other ways of measuring VA based on Bundesen's TVA that can diminish the impact of language skills on individuals' performance on the VA measure. While it is at present seen difficult to take the language component – required verbal response for each trial – out of the VA span task (WR), it is argued that the target detection task (PR) could be adapted more easily. One option could be to reduce oral responses of seen targets to simple "yes" or "no" responses, an approach which was for instance taken in Banfi et al.'s (2018) study. Another possibility would be to go a step further by avoiding verbal responses altogether and replacing them with binary button press responses, similar to the test design of the attention & executive function measure included in this study. However, it needs to be acknowledged that by adopting this assessment method is still not possible to fully exclude the impact of language demands on assessment performance. Language demands not only impact verbal responses but also cognitive retrieval processes of the representation of a symbol. Thus, future studies not only face the difficulty to design a VA assessment not verbally mediated but also need to acknowledge the fact that 'non-verbal' tests like the matrices arguably still require some verbal mediation.

A third possibility to be less dependent on not only children's verbal, but also motor responses, would for instance be the additional utilization of eye-tracking devices in future studies adopting a TVA-based VA assessment. Deploying this method would have the potential to provide valuable information regarding children's symbol fixation during task performance. While adopting eye-tracking still requires the processing of symbols, it enables to capture behaviour at a slightly earlier, preconscious stage, which is less influenced by linguistic processing, considered as a slightly higher level operation. Finally, measuring pupillary dilation (e.g. Hoeks & Levelt, 1993) as a means of exploring an individual's VA skills might arguably be another option in future to measure VA in a 'purer', less language-skills mediated way.

7.4 Conclusions

The introduction of digital text into today's classrooms and homes has not only caused a shift in the patterns of readings, but also has had an impact on the skills children and young people are expected to acquire for successful and efficient reading in a digital environment. Technology can be both, engaging and distracting, which is why it has become necessary for readers to acquire robust meta-cognitive skills to successfully negotiate an interactive, on-screen environment. Since researchers have only started to explore cognitive demands needed for processing digital text, it is vital to explore cognitive processes, such as VA, alongside working memory, executive control, and meta-cognition, in relation to reading on screen. In addition, more research is needed to fully understand reading development in the digital context in order to best support children in their literacy development in a world characterised by a mixture of both digital and non-digital environments. Almost all our current knowledge about early predictors of reading success has been accrued by examining literacy precursor skills (e.g. PA, LK, vocabulary) in relation to print reading. While several influential models of reading have served researchers, educators and policy makers well in terms of explaining what reading involves and in permitting predictions about performance and outcomes, none of these models were intended to describe or facilitate predictions about reading digital text. Considering existing conceptualisations of the reading process for the digital environment and to develop new conceptualisations if required is thus deemed necessary.

The aim of this study was to gain a better understanding of the complex interplay between VA, digital exposure and established literacy predictor skills in relation to emerging reading in young children. Study results demonstrated moderate correlations between VA and traditional precursor skills of reading at both time points, but no relationships between children's digital exposure and their VA skills. Findings further showed that an individual's VA skills do significantly contribute to single word reading over and above other individual literacy precursor skills. However, within a subsequent hierarchical multiple regression VA was not found to be an individual unique predictor of single word reading after accounting for other key predictors such as PA or LSK, both concurrently and longitudinally. This study therefore extends our knowledge concerning the role of VA and digital exposure as potential new precursor skills for reading and provided foundational knowledge for future studies to look into different ways of gathering data on children's digital exposure, as well as into longitudinal relationships between VA and more advanced reading skills.

Finally, the study also highlighted the range of individual variation across all skills related to early reading and so it is hoped that an increase in knowledge about the role of cognitive processes in reading, such as VA, might inform the development of digital technology and its associated potential to adapt text on several dimensions according to the needs or preferences of a reader. This includes linguistic and structural complexity of a text, its length, as well as the extent to which text content is presented independently or integrated with other sources (e.g. through hyperlinks). While these levels of adaptability of digital text would require significant technological advances, as well as further progress in our understanding of individual differences in reading, it might be achievable in future to adapt text at a personal level, through provision of data for instance about their VA skills, working memory capacity, or their tendency to be distracted. As a result, teachers and parents might then be in the position to vary texts for children on dimensions relating to their cognitive and motivational profile. Such actions would help to realise one of the exciting affordances that digital reading can offer: an unprecedented opportunity to individually tailor reading material to the skill and interest profile of each unique reader.

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Appendices

Appendix A: Departmental ethics approval for the smaller-scale study

The University Of Sheffield.

Downloaded: 13/03/2018
Approved: 10/02/2016

Tanja Prieler
Registration number: 150111481
Human Communication Sciences
Programme: PhD Human Communication Sciences

Dear Tanja

PROJECT TITLE: Children's experience with digital text
APPLICATION: Reference Number 007436

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 10/02/2016 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 007436 (dated 20/01/2016).
- Participant information sheet 1014826 version 1 (20/01/2016).
- Participant information sheet 1014825 version 1 (20/01/2016).
- Participant consent form 1014829 version 1 (20/01/2016).
- Participant consent form 1014827 version 1 (20/01/2016).

The following optional amendments were suggested:

See amendments above and in comments. Approved with suggested amendments Blanca Schaefer I expect the applicants to make changes according to my concrete comments about rewording/clarifying or adding information. However, my suggestions for changes regarding style/complexity of information I leave to the applicants discretion to decide how to amend the text to make it more accessible for the parents. Approved with suggested amendments Sarah Spencer I agree with the suggestions made my Blanca Schaefer and Jane McCormack. Good luck with data collection - it sounds like a great project. Approved with suggested amendments Jane McCormack This looks like a very interesting study and it will be great to see the results. I hope the feedback provided here is helpful in clarifying the aims and methods to be utilised within the study.

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Yours sincerely

John Mason
Ethics Administrator
Human Communication Sciences

Appendix B: Departmental ethics approval for the main study

The University Of Sheffield.

Downloaded: 13/03/2018
Approved: 27/07/2016

Tanja Prieler
Registration number: 150111481
Human Communication Sciences
Programme: PhD Human Communication Sciences

Dear Tanja

PROJECT TITLE: Childrens experience with digital text
APPLICATION: Reference Number 010950

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 27/07/2016 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 010950 (dated 27/07/2016).
- Participant information sheet 1022275 version 3 (27/07/2016).
- Participant consent form 1022276 version 3 (27/07/2016).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Yours sincerely

John Mason
Ethics Administrator
Human Communication Sciences

Appendix C: Main study parent questionnaire

DigiRead

Parent/ carer Questionnaire

Please return to class teacher

Child's name:

1. Which of the following *digital devices* has your child used? (Tick all that apply)

	At home	At child care	At friends' or family's	Out and about (eg in the car/ café/ shopping)
Smartphone (touchscreen)				
E-reader (eg Kobo, Kindle)				
Tablet (including iPad)				
Pc/laptop				

2. How old was your child when;

	Under 1	1-2	2-3	3-4	4-5	Never
You started reading books to them						
They first used a digital device						

3. In the 6 months before starting Reception, how often did your child spend **5 minutes or more** using the following things?

		More than once a day	Once a day	3-4 times a week	Once a week	Less than once a week	Never
	Smartphone						
	E-reader						
	Tablet/iPad						
	PC/laptop						
	Printed book						

4. Please put an **X** next to the one they used the most.

5. When reading with your child (in the 6 months before starting Reception) did you tend to read print books or e-books more? (please circle)

Only print books	Mainly print books	Print books and e-books equally	Mainly e-books	Only e-books

6. How often did your child use digital devices for the following activities in the 6 months before starting Reception?

	More than once a day	Once a day	3-4 times a week	Once a week	Less than once a week	Never
Playing games for fun						
Playing educational apps (letters or numbers)						
Watching programmes or clips						
Watching/ listening to music						
Communicating with people (eg facetime)						
Using children's websites						
Reading e-books						
Finding things out						

7. Which do you think your child would pay attention to for the longest? (please circle)

Print book E-book

8. What are the benefits of your child using a digital device (if any)?

____

____

____

9. What are the downsides of your child using a digital device (if any)?

____

____

____

Thank you for taking the time to complete this questionnaire

If you have any questions about this project please contact Jen Roche or
Principle Investigator Dr Jenny Thomson;
Department of Human Communication Sciences,
University of Sheffield,
362 Mushroom Lane,
Sheffield S10 2TS,
Tel: 0114 222 2426

The University Of Sheffield.

The Leverhulme Trust

Appendix D: Main study student interview questions

STUDENT INTERVIEW

1. Are you reading stories together with your parents, grandparents, etc.?

☐ 1.1 YES ☐ 1.2 NO

2. When reading with your parents or grandparents or other adults, would you say, that you…

2.1 Only read paper books	2.2 Mainly read paper books	2.3 Read stories in both paper books and on the tablet/ipad/etc.	2.4 Mainly read stories on the tablet/ipad/etc.	2.5 Only read stories on ipad/tablet/etc.

3. How often do you read stories / look at…

	More than once a day	Once a day	3-4 times a week	Once a week	Less than once a week	Never
3.1 Paper books together with grown ups						
3.2 Stories on the tablet/ipad/etc. together with grown-ups						
3.3 Paper books on your own						
3.4 Stories on the tablet/ipad/etc on your own						

4. What do you like more:

☐ 4.1 Reading stories in paper books ☐ 4.2 Reading on the tablet / ipad / computer

5. Why?

____

____

____

1

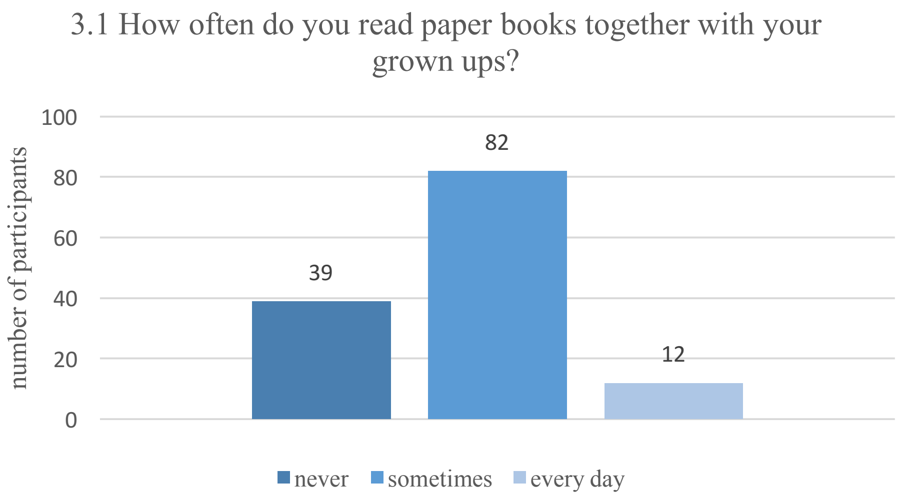
6. How often do you use tablets/ipads/computer/laptop/phone to do the following:

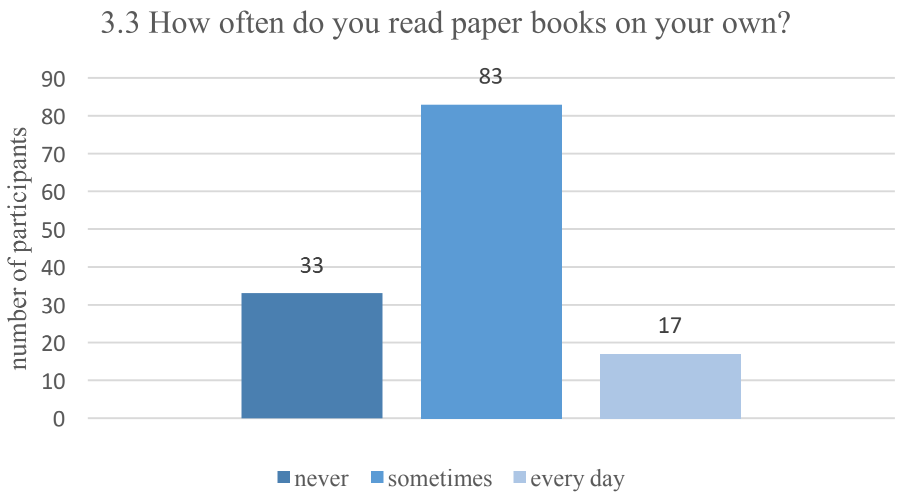
	More than once a day	Once a day	3-4 times a week	Once a week	Less than once a week	Never
6.1 Playing games for fun						
6.2 Playing educational apps (letters or numbers)						
6.3 Watching programmes or clips						
6.4 Watching/ listening to music						
6.5 Communicating with people (eg. facetime)						
6.6 Using children's websites						
6.7 Reading stories						
6.8 Finding things out						

Appendix E: Descriptive statistics and further analysis of student interview questions 3 & 6

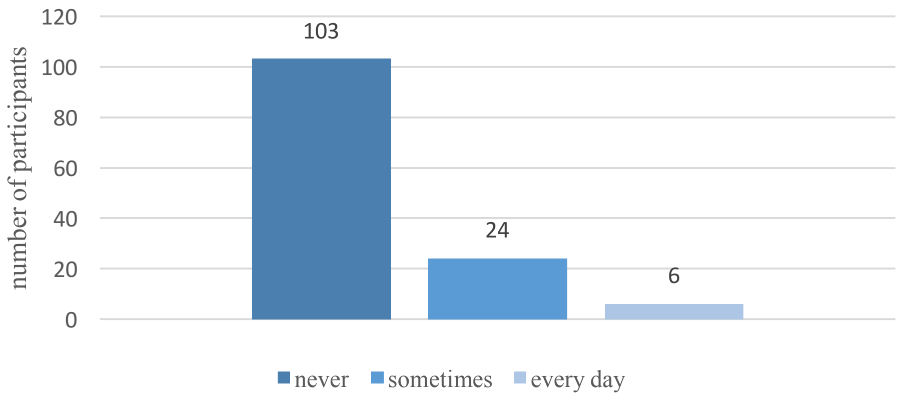
Descriptive statistics: Frequency of reading on paper and on digital devices

Question 3: Reading on paper and on digital devices

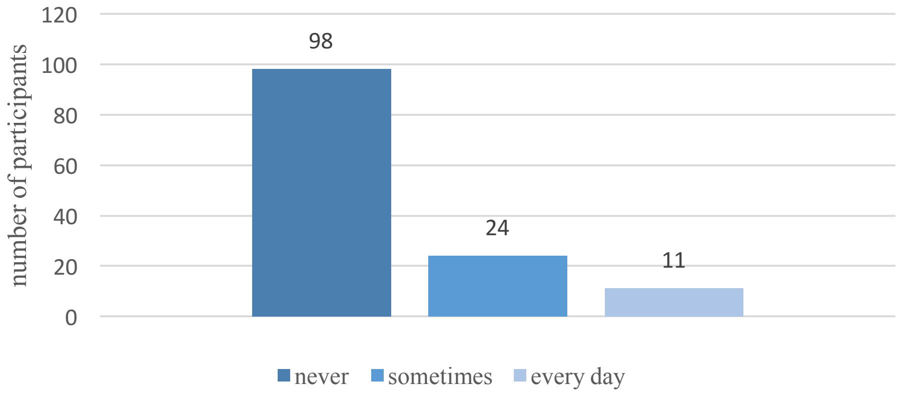




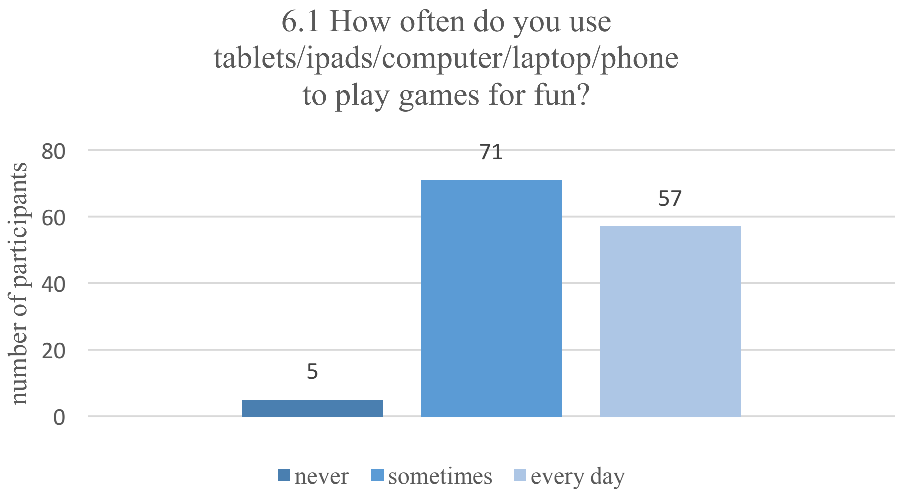
3.2 How often do you read stories on the tablet/ipad/etc. together with grown-ups?

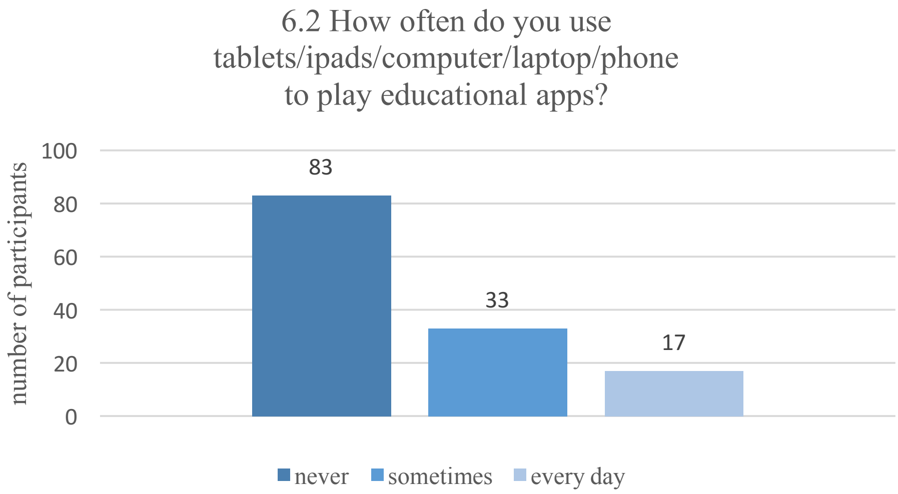


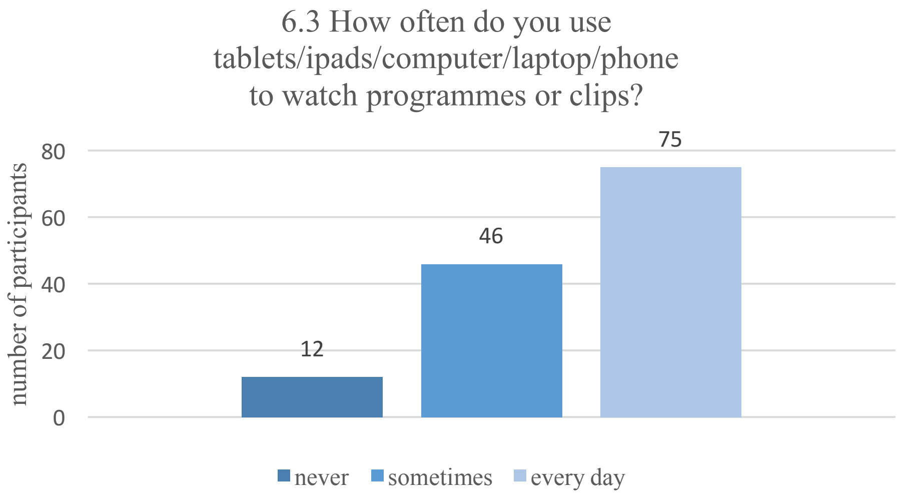
3.4 How often do you read stories on the tablet/ipad/etc. on your own?

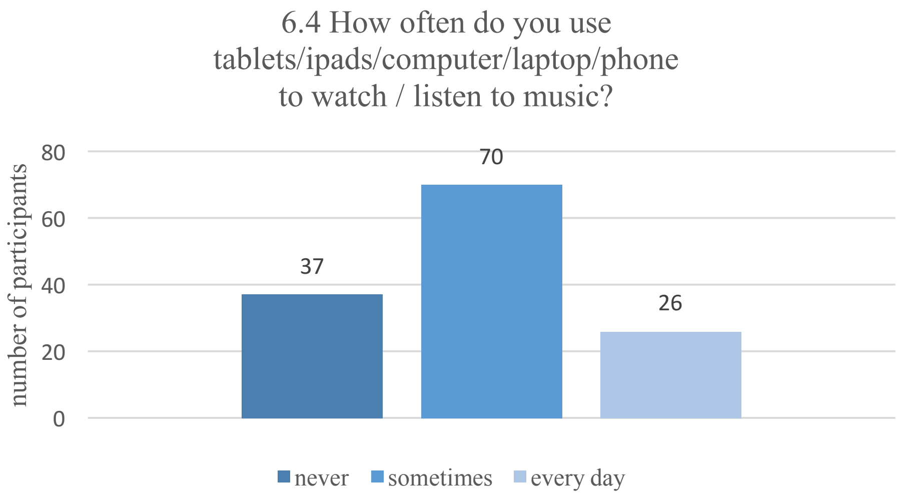


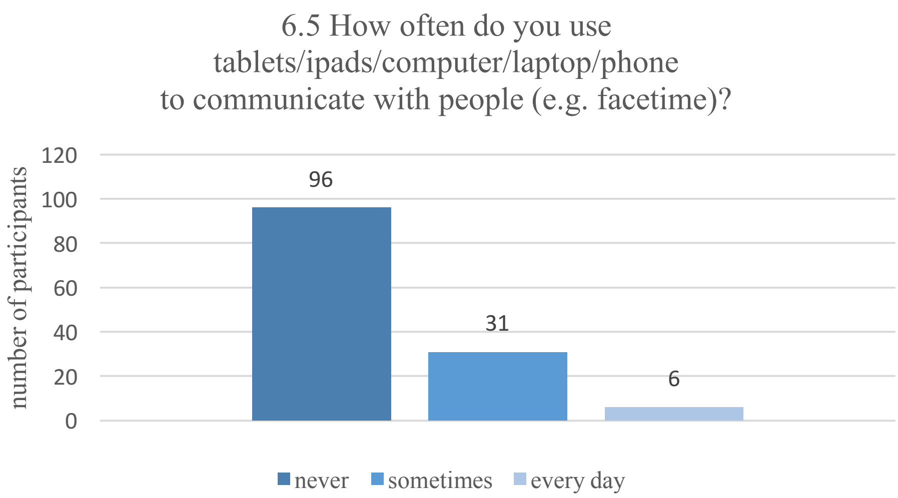
Question 6: Digital device use frequency

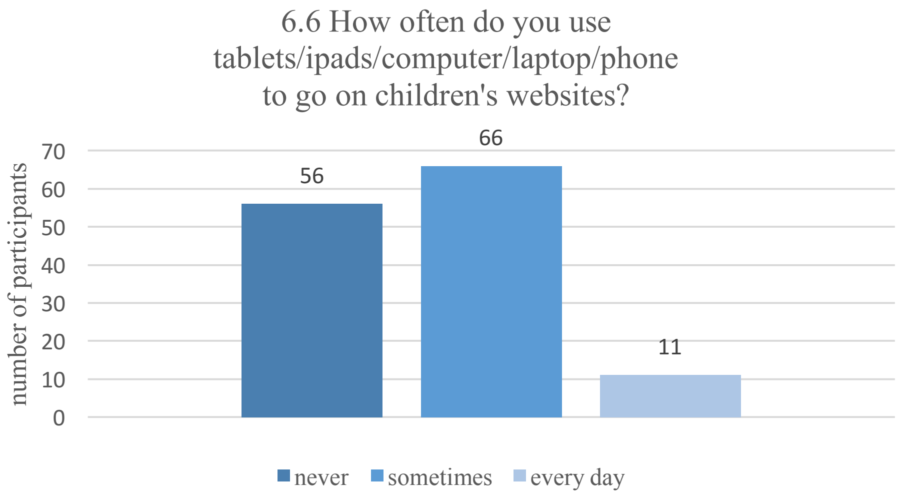


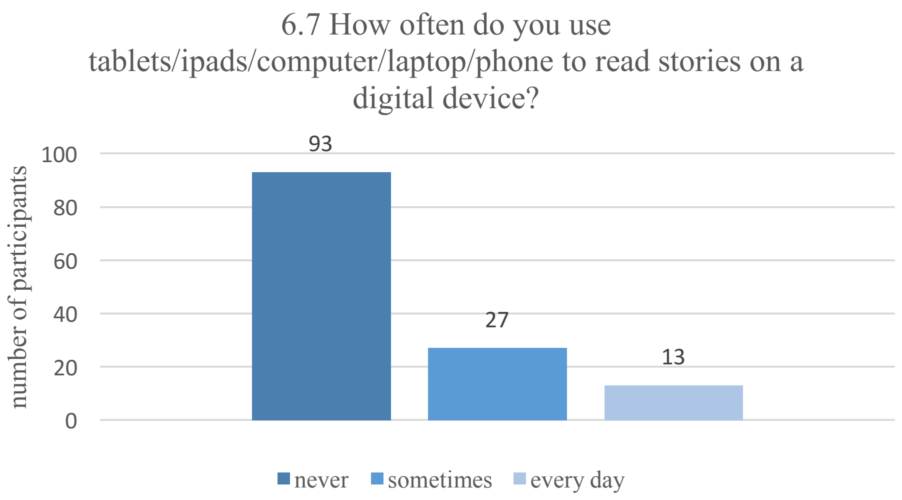


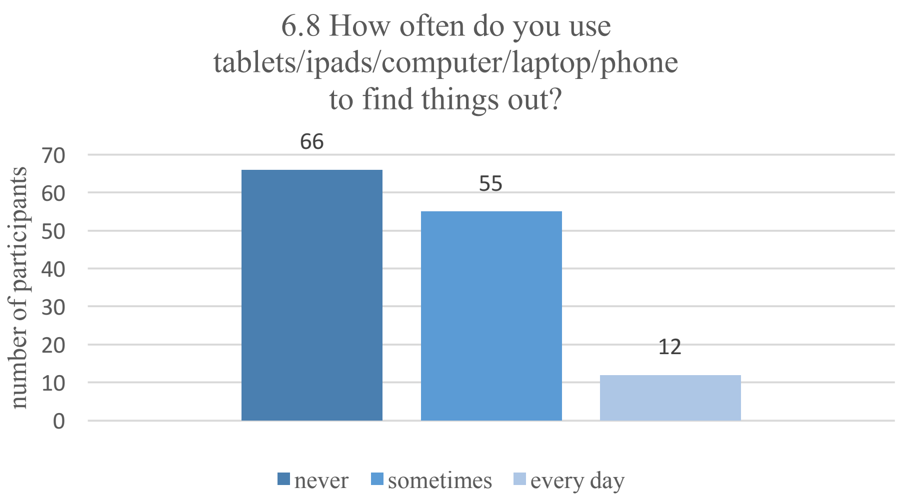

6.3 How often do you use
tablets/ipads/computer/laptop/phone
to watch programmes or clips?
number of participants
0
20
40
60
80
12
46
75
never
sometimes
every day


6.4 How often do you use
tablets/ipads/computer/laptop/phone
to watch / listen to music?
number of participants
0
20
40
60
80
37
70
26
never
sometimes
every day


6.5 How often do you use
tablets/ipads/computer/laptop/phone
to communicate with people (e.g. facetime)?
number of participants
0
20
40
60
80
100
120
96
31
6
never
sometimes
every day


6.6 How often do you use tablets/ipads/computer/laptop/phone to go on children's websites?
number of participants
0
10
20
30
40
50
60
70
56
66
11
never
sometimes
every day


6.7 How often do you use tablets/ipads/computer/laptop/phone to read stories on a digital device?
number of participants
0
20
40
60
80
100
93
27
13
never
sometimes
every day


6.8 How often do you use tablets/ipads/computer/laptop/phone to find things out?
number of participants
0
10
20
30
40
50
60
70
66
55
12
never
sometimes
every day

Further analyses on relationships between answers to questions 3 & 6

Relationships between answers on questions 3.2 and 3.4 – reading on digital devices with grown-ups and on one's own – and questions 6.7 – reading stories on digital devices – were significant and very strong, suggesting that children provided the same answer when asked about their reading habits on digital devices in two – slightly differently worded questions.

Table 1

Pearson's correlations between answers on Question 3.2, Question 3.4, and Question 6.7 of the student interviews at t2

	Question 6.7
Question 3.2	.83***
Question 3.4	.79***

Note. Statistical significance is indicated with asterisks: *** p < .001.

In addition, moderate correlations were found between digital device use frequency score (Q 6) and the two sub-questions targeting children's digital device use when reading with grown-ups (Q. 3.2), and on their own (Q. 3.4). These findings suggested that children, who read on digital devices also tended to use digital devices for other activities.

Table 2

Pearson's correlations between answers on Question 3.2, Question 3.4, and all sub-questions of question 6 of the student interviews at t2

	Question 6
Question 3.2	.44***
Question 3.4	.40***

Note. Statistical significance is indicated with asterisks: *** p < .001.

Appendix F: Additional regression analyses

Summary of concurrent individual hierarchical regression analyses for whole report in relation to receptive vocabulary, short-term memory, and phonological awareness predicting Year 1 single word reading

Step and predictor variable	**Year 1**				
	B	SE B	β	Adj. R^2	Adj. Δ R^2
Step 1:				.239***	
t2 Receptive vocabulary	.755	.116	.495		
Step 2:				.263***	.024*
t2 Receptive vocabulary	.660	.121	.432		
t2 Whole report	6.307	2.735	.183		
Step 1:				.186***	
t2 Short-term memory	3.530	.633	.438		
Step 2:				.240***	.054**
t2 Short-term memory	3.114	.625	.386		
t2 Whole report	8.621	2.669	.250		
Step 1:				.549***	
t2 Phonological awareness	.674	.053	.743		
Step 2:				.558***	.009
t2 Phonological awareness	.642	.055	.708		
t2 Whole report	4.017	2.090	.117		

Note. Statistical significance is indicated with asterisks: * $p < .05$; ** $p < .01$; *** $p < .001$.

Results from the first step of the hierarchical multiple regression analyses predicting single word reading at t2 from predictor skills at t1 excluding phonological awareness

	R²	***Adj. R²***
Overall prediction model	.44***	.42***
Predictors	Step 1	
	R²	***Adj. R²***
t1 Receptive vocabulary	.01	.01
t1 Short-term memory	.07	.07
t1 Letter-sound knowledge	.11	.11
t1 NVIQ	.01	.01
t1 Whole report	.02	.02

Note. Statistical significance is indicated with asterisks: *** $p < .001$. NVIQ = non-verbal intelligence quotient.